Liquid lithium Target in IFMIF (International Fusion Materials Irradiation Facility)

Hiroo Nakamura
Japan Atomic Energy Research Institute

WS on High-power Targetry for Future Accelerators
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What is IFMIF

International Fusion Materials Irraddiation Facility

2000 - 2002	KEP (Key Element Technology)
2003 - 2004	Transition Phase
2005 - 2009	EVEDA (Engineering Validation and Engineering Design Activitiy)
2010 - 2016	Construction
2017 -	Operation

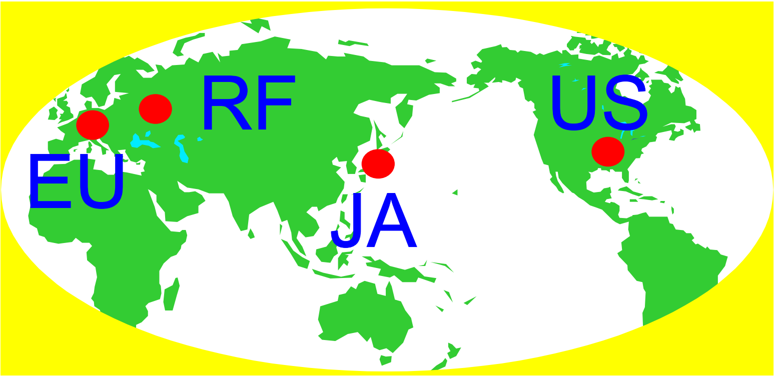
IFMIF Organization

IEA-Fusion Material Irradiation Research

Users Group

IFMIF sub-Exco 

IFMIFI team 

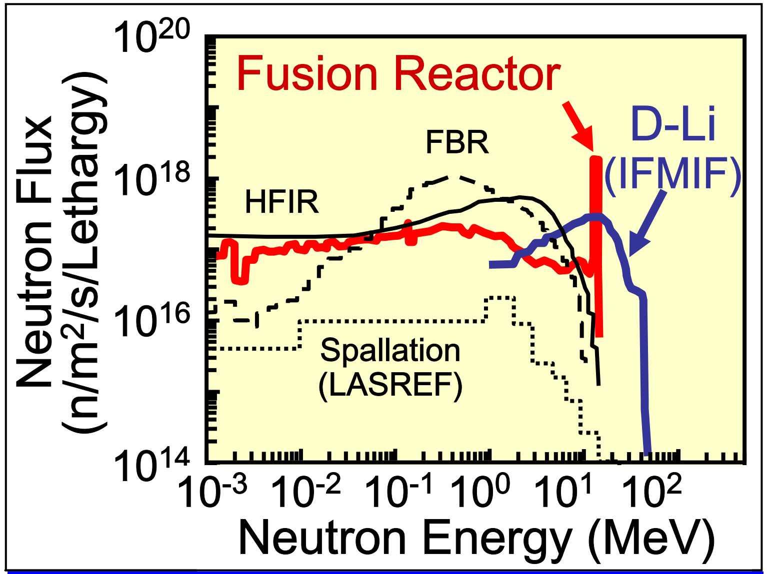


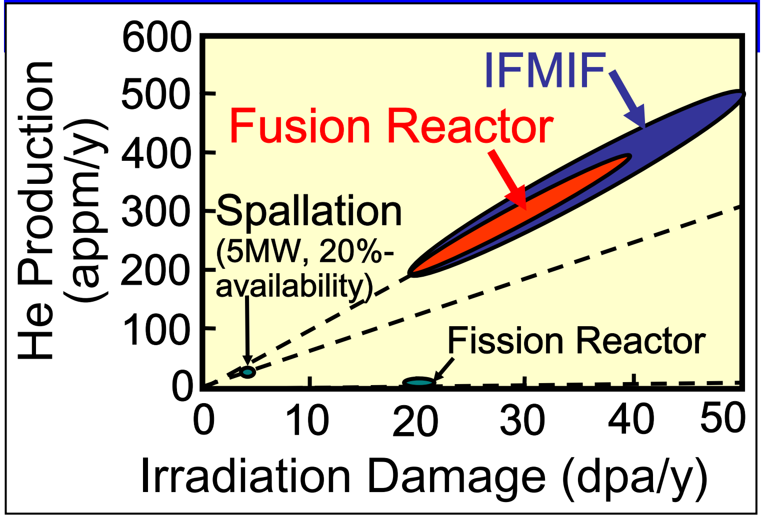
- Acceleratior Gr
- Target Gr
- Test Facility Gr
- Design Integration Gr

Requirements of Neutron Source for Development of Fusion Materials

D-Li neutron source has been selected.

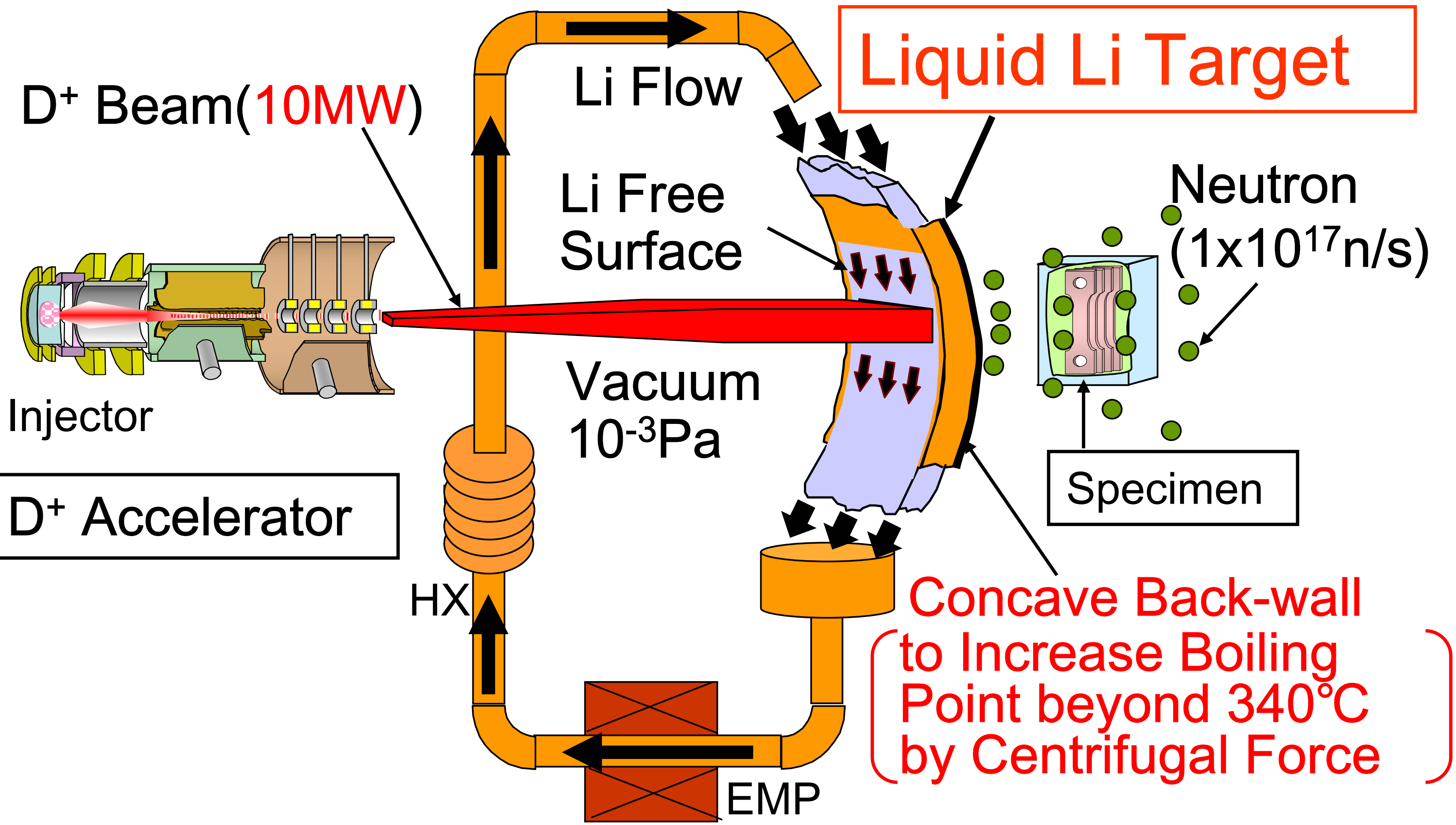
- 14MeV neutron
- Neutron intensity
  100-200dpa
  (20dpa/year, $2MW/m^2$)
- He production/damage
  ~10appm/dpa
- Irradiation volume
  500cc
  (LAF steel, V-alloy, SiC/SiC)



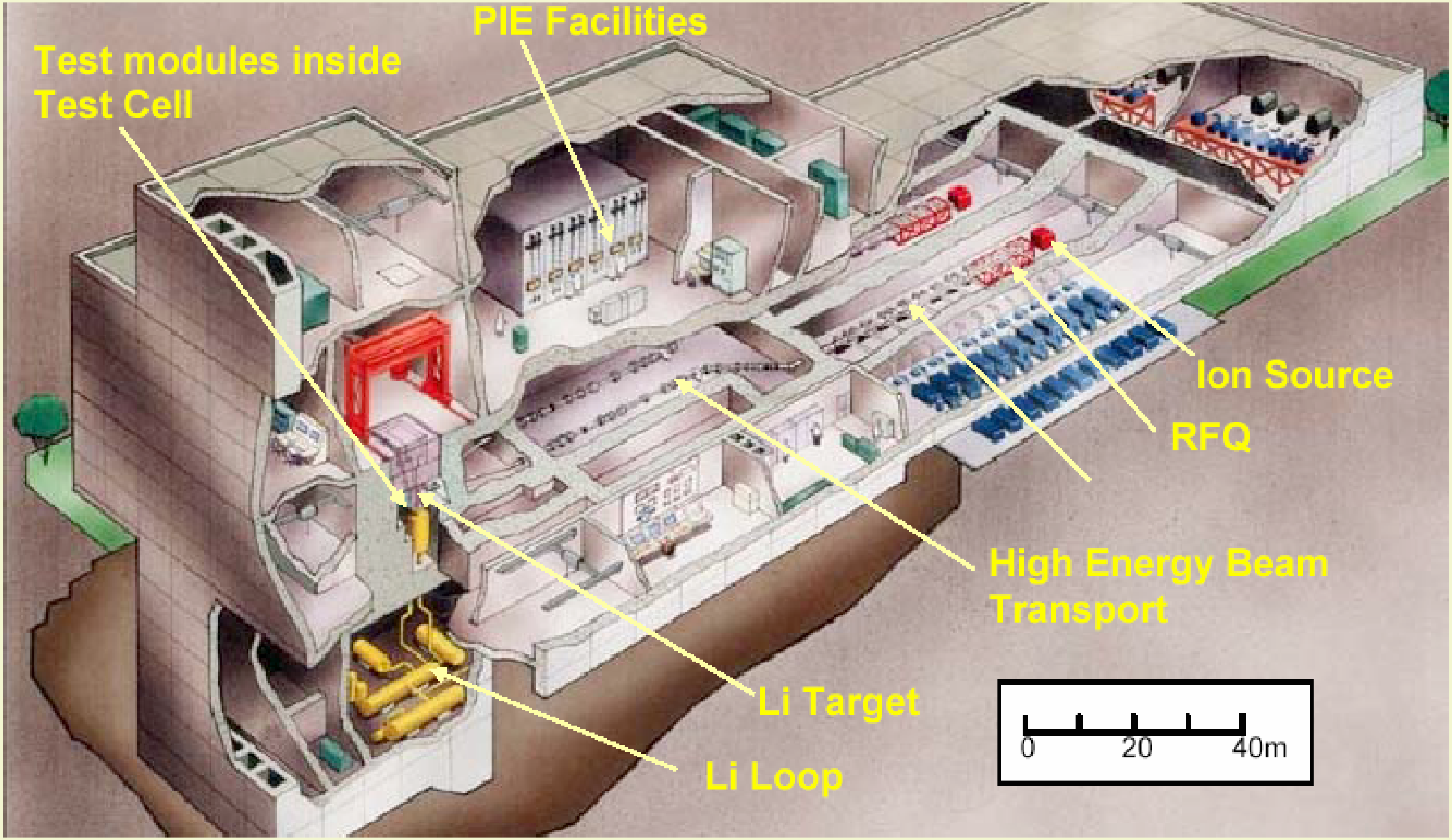


Concept of D-Li Neutron Source

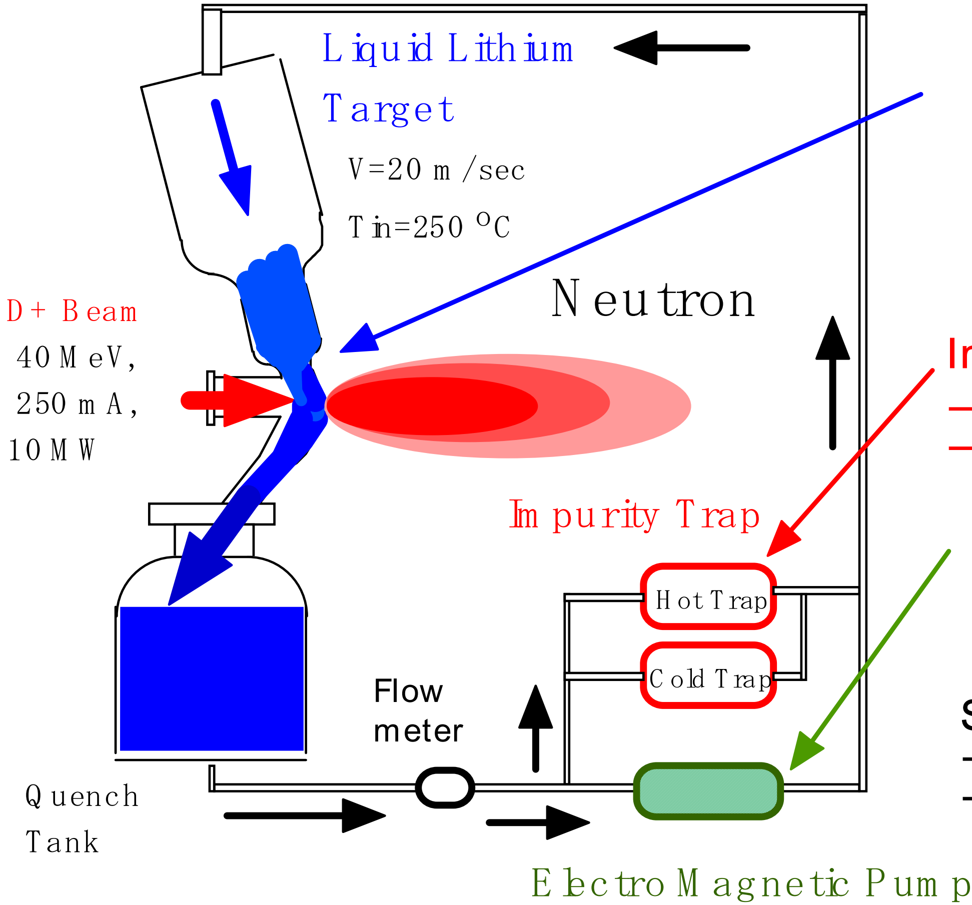
High-speed liquid Li flow along concave back-wall is selected as Li target to handle high heat load (1GW/m^2) of 10MW D$^+$ beams.



IFMIF - Reduced Cost Design (1999)



Major Issues of Target System



Liquid Lithium Target :
(10 MW into 20 cm wide x 5cm)
－> Stable and High Speed Flow
－> Good Compatibility of nozzle material with Li flow
－> Easy Remote Maintenance

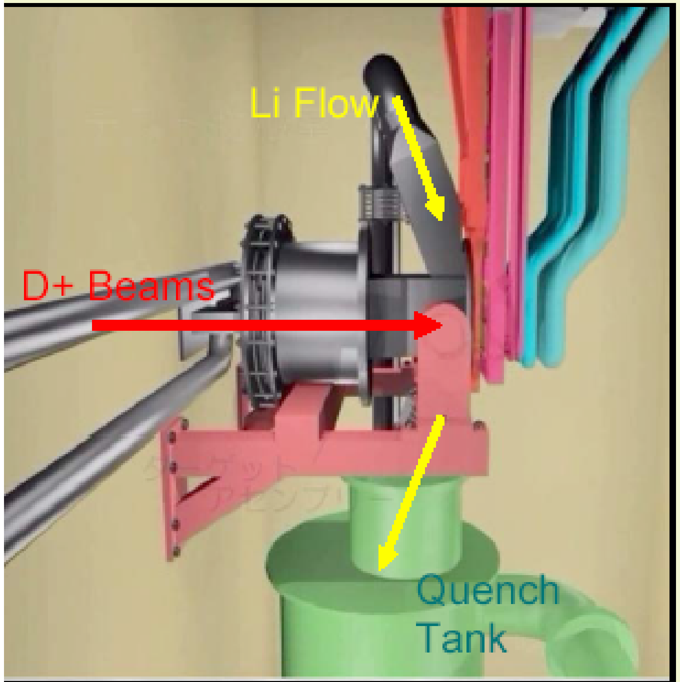
Impurity Trap :
－> Removal of products (T、^{7}Be)
－> Reduction of impurities (N_2, O_2, etc)

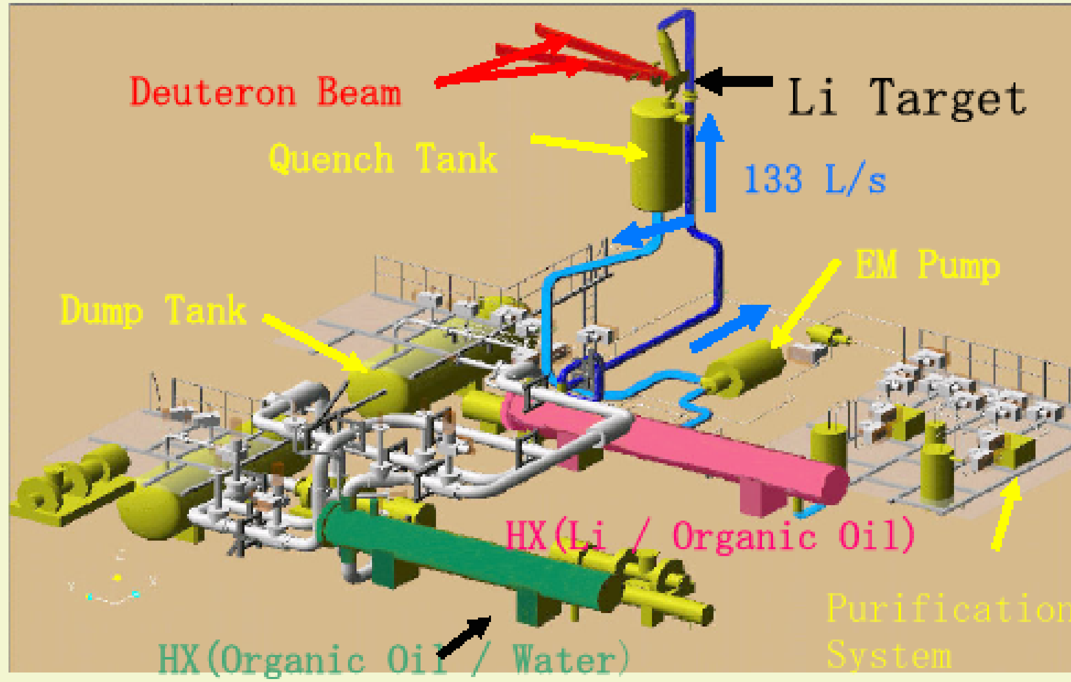
Electro Magnetic Pump :
－> Stable and Cavitation less operation

Safety :
－> Conefinement of radioactive product
－> Prevention of Li fire

Proof of principal in FMIT → Need data in IFMIF conditions

IFMIF Target System Design





Function:
Obtain stable and high speed
Li flow under 10 WM D+ beam

Major Specifications:

- Heat flux by beam: 10MW/100 cm^2
- Li-flow: 15 (range 10-20) m/s
- Width/Thickness of Li: 26cm/ 2.5 cm
- Inlet, Outlet, Peak Li Temp: 250, 300, 450 °C
- Tritium Generation rate: 7 gr/yr
- Impurity contents: 10 wppm (C, N, O, each)

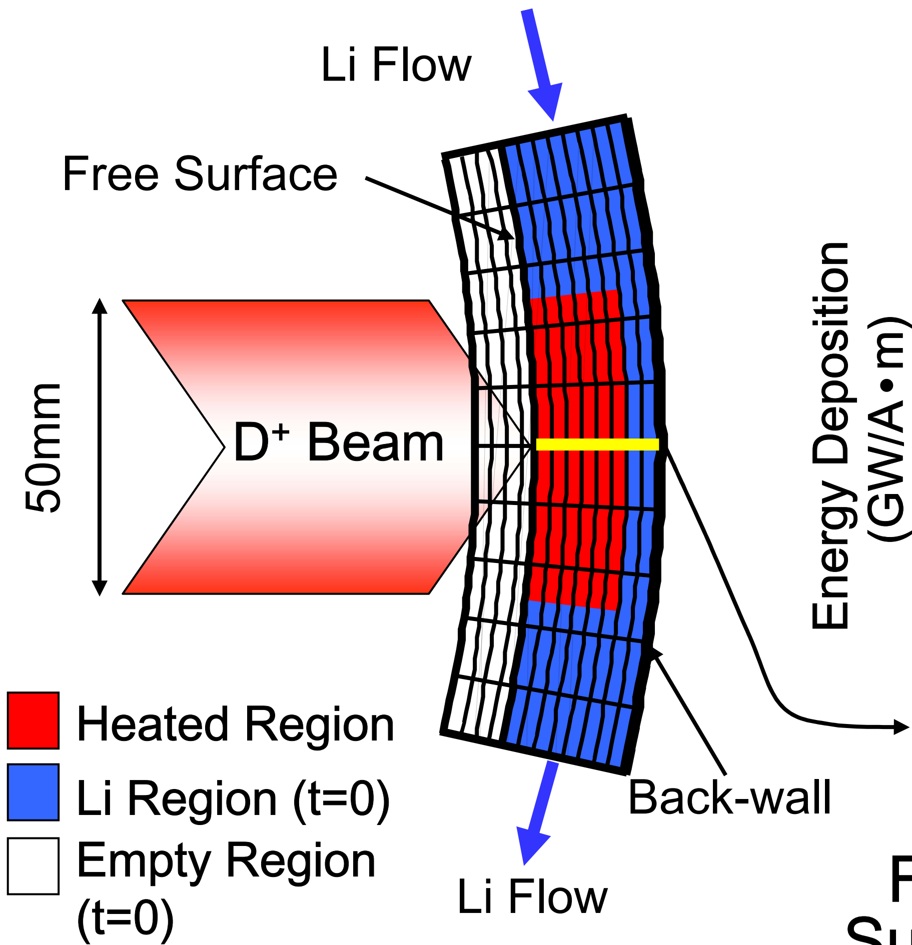
Key Element Technology Phase (2000-2002)

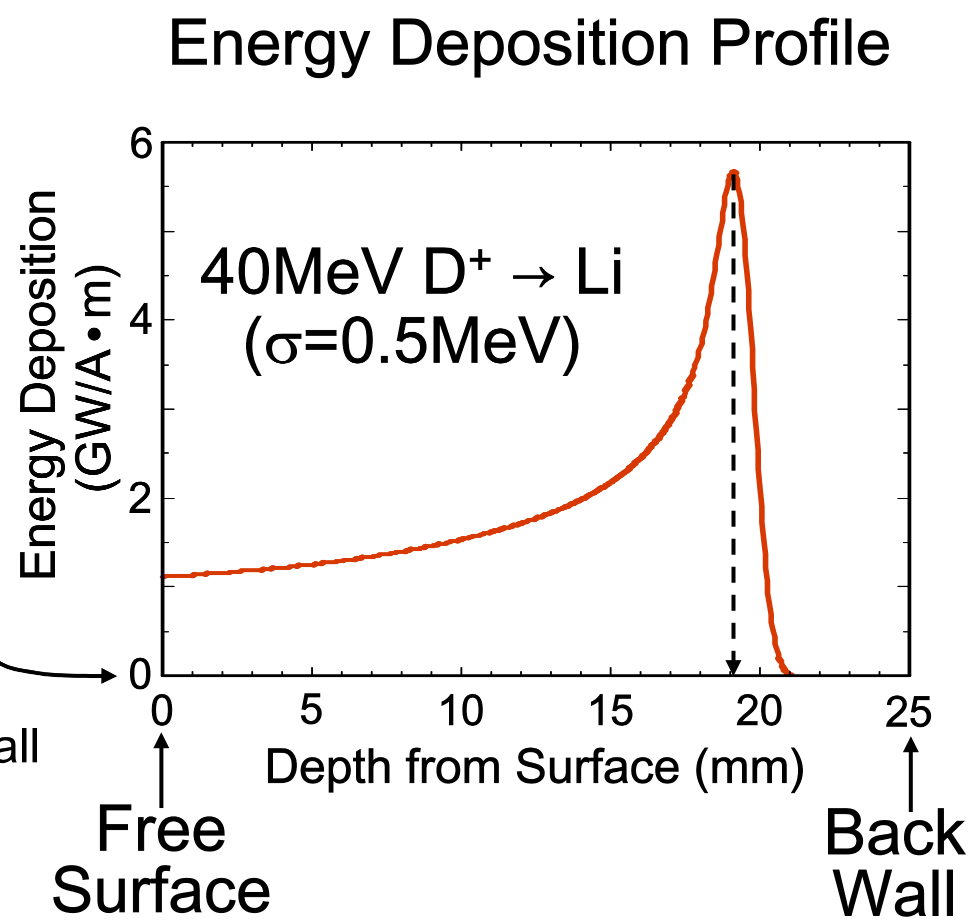
Thermal-hydraulic Analysis

Calculation code : FLOW-3D
Viscosity estimation : k-ε turbulent model
Mesh size : 0.2mm x 1mm
Average velocity (U_0) : 10, 20m/s
Back-wall radius (R_W) : 100, 250, 1000mm
Jet thickness : 25mm
Inlet temperature : 250℃

Calculation Model

Temperature was calculated using input data of beam deposition.

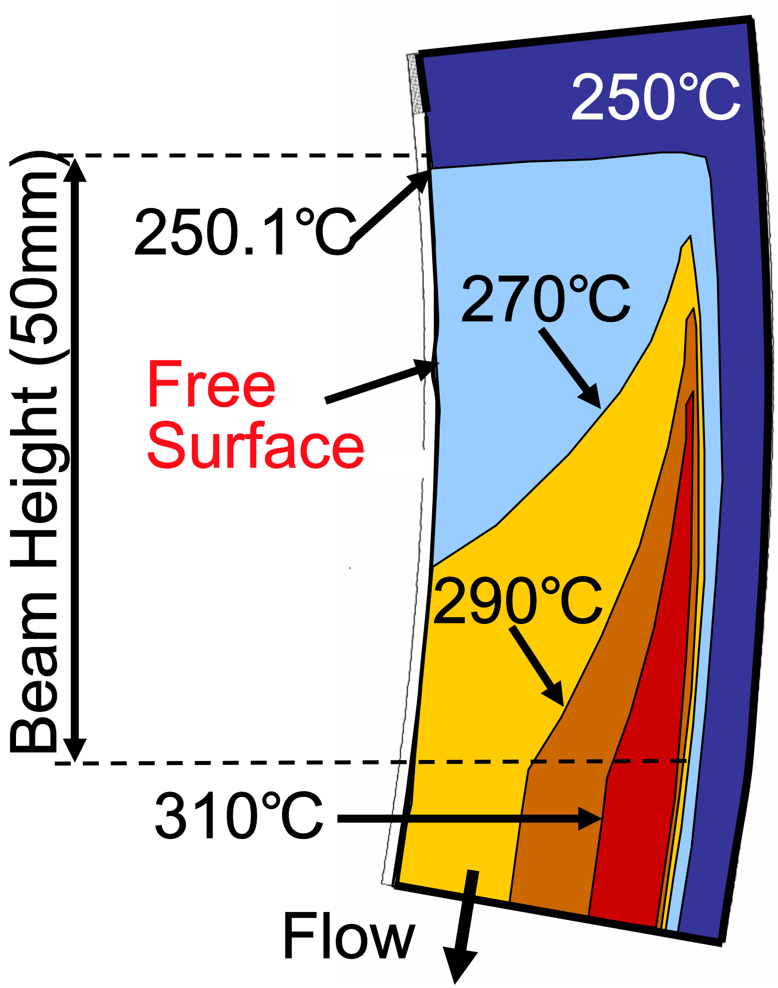


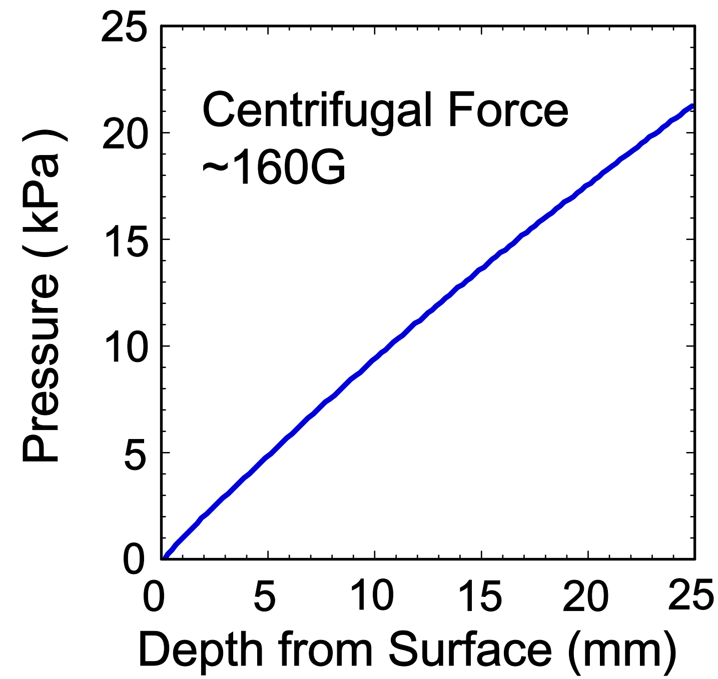


Calculated Temperature & Pressure

(Case : U_0=20m/s, R_W=250mm)

Max. temperature is given at lower edge of beam.
Pressure increases with depth by centrifugal force.



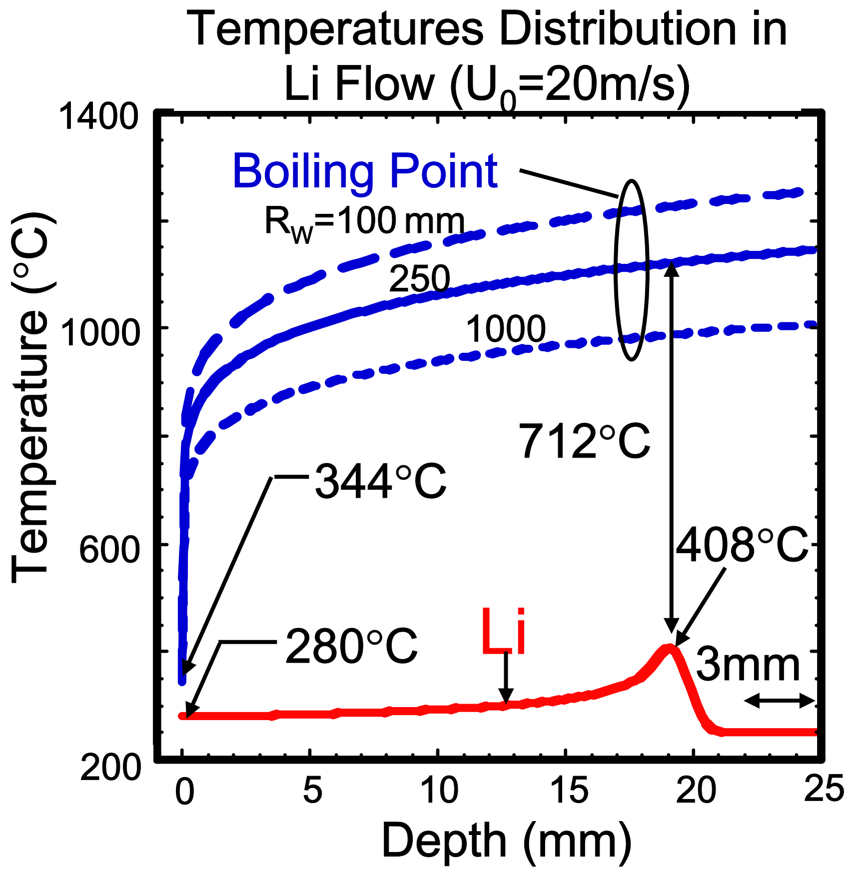


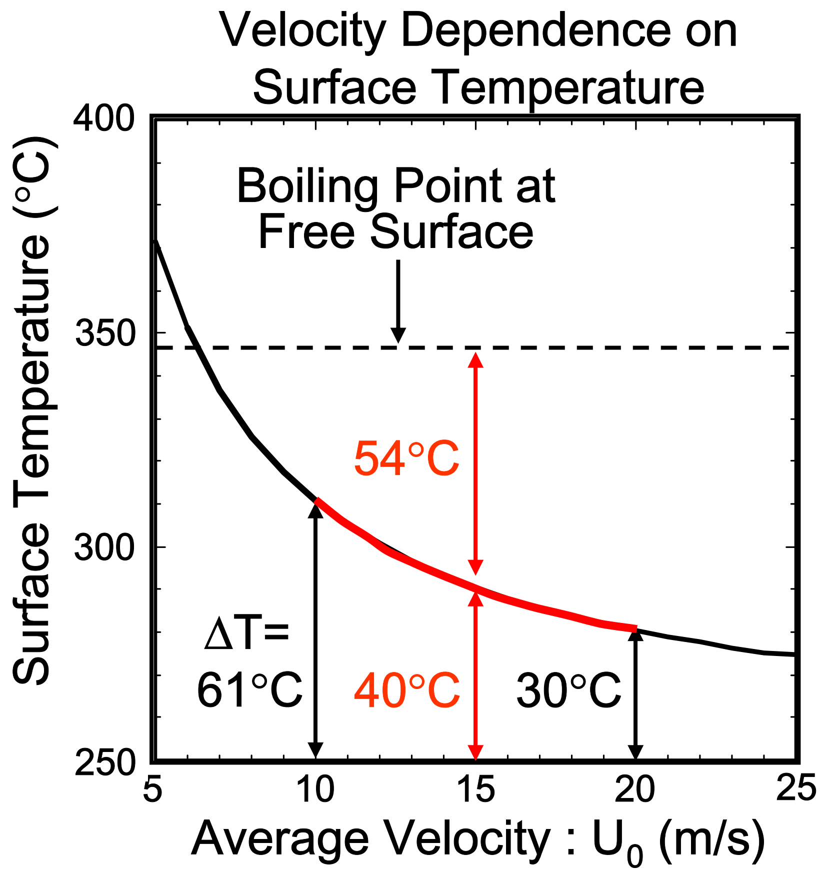
$$\text{Boiling Point} = \frac{17900}{22.7 - \log P(\text{Pa})} - 262$$

(230-1230°C, JSME, Engineering data of heat transfer, Edit.4)

Distribution of Li Temperature, Boiling Point and Boiling Margin

Velocity of 20m/s gives enough margin.
Spatial margin > 3mm on back-wall side.





Simulating Experiments by Water

Objectives :

- To verify stable flow generation by double reducer nozzle
- To clarify effect of nozzle wall roughness on surface waves

Advantages of Water Experiment :

- Well simulation of Li flow with fitting Reynolds number
- Convenience at velocity measurement

Effectiveness of Simulation by Water

Water experiments can simulate Li flows with same kinematic viscosity and Reynolds number.

Flow Parameters at Velocity of 20m/s

	Li flow (250℃)	Water flow (20℃)
Kinematic viscosity (m^2/s)	0.98×10^{-6}	1.01×10^{-6}
Reynolds number (L=25mm)	510,000	495,000
Density (kg/m^3)	510	998
Viscosity (Pa•s)	5.01×10^{-4}	1.00×10^{-3}
Surface tension (N/m)	0.386	0.0728

Effect of Test Section Arrangement

Water experiments with horizontal, straight wall are expected to well simulate surface of Li flow with vertical, concave wall.

Effect of Forces on Surface Wave Stability

Wave amplitude

$\propto (g+U_0^2/R_W+\sigma K^2/\rho)^{-0.5}$

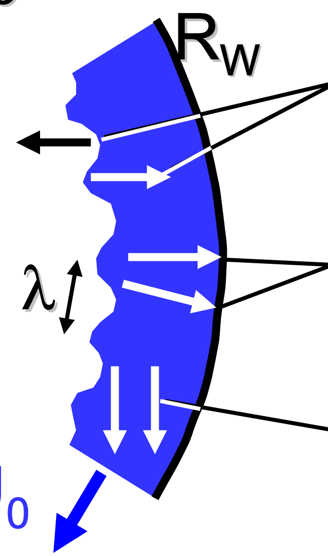
$\sim (\sigma K^2/\rho)^{-0.5}$

σ : Surface tension

ρ : Density

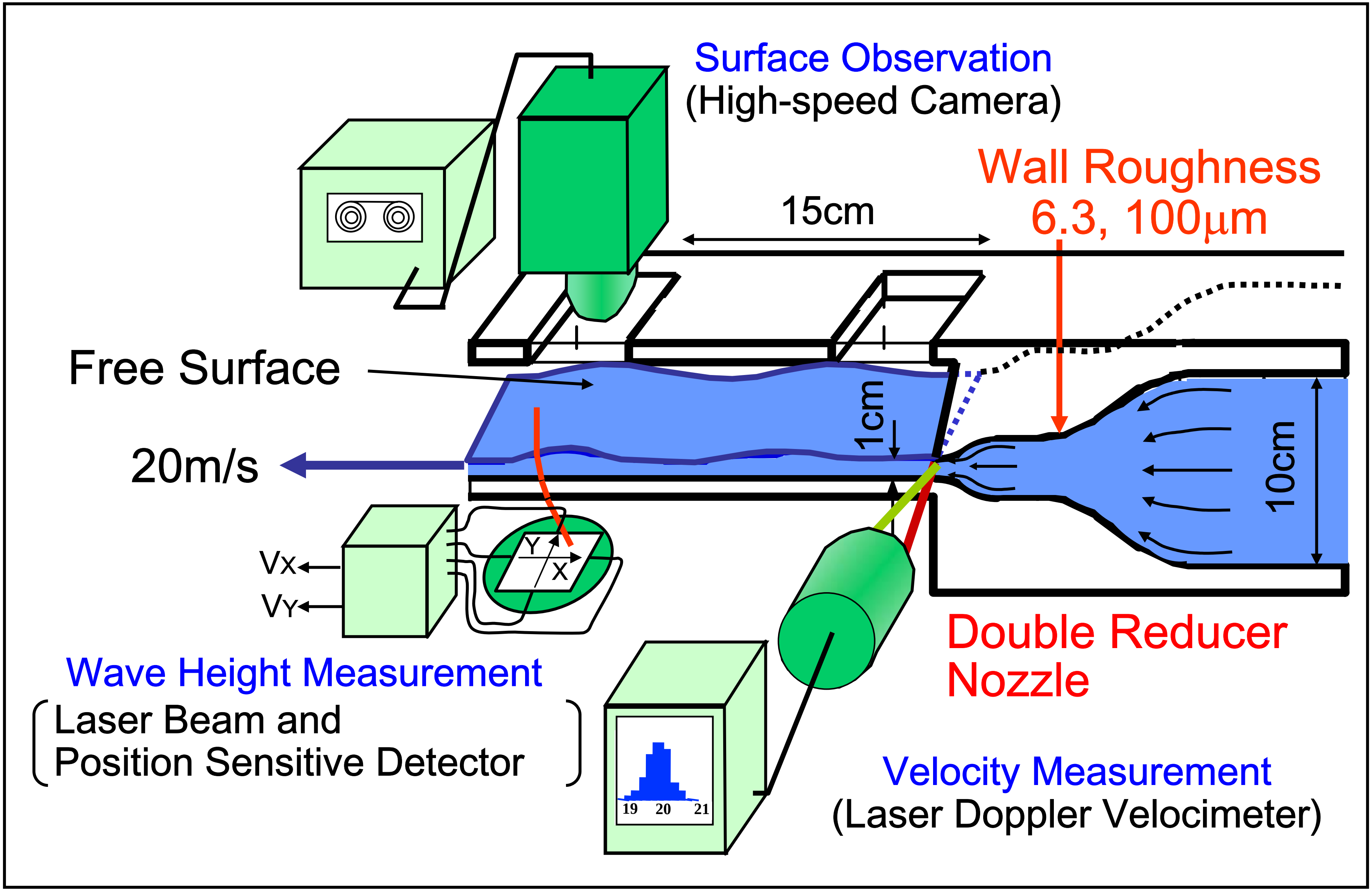
K : Wave number

(2π/ λ ~2π/1mm)

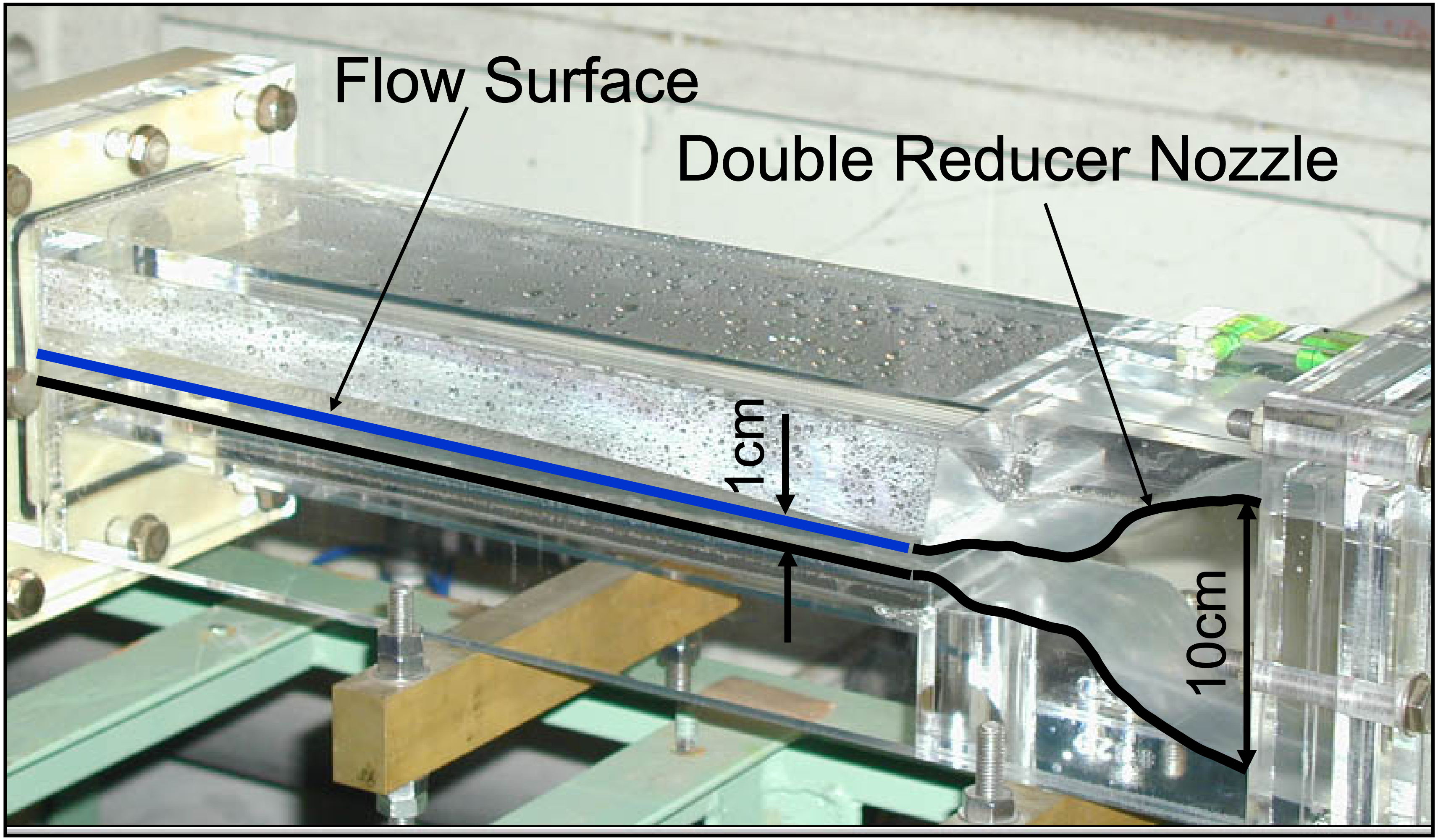


Force	Effect (m/s^2)
Surface tension ($\sigma K^2 \rho$)	30,000
Centrifugal force (U_0^2/R_W)	1,600
Gravity (g)	9.8

Experimental Setup

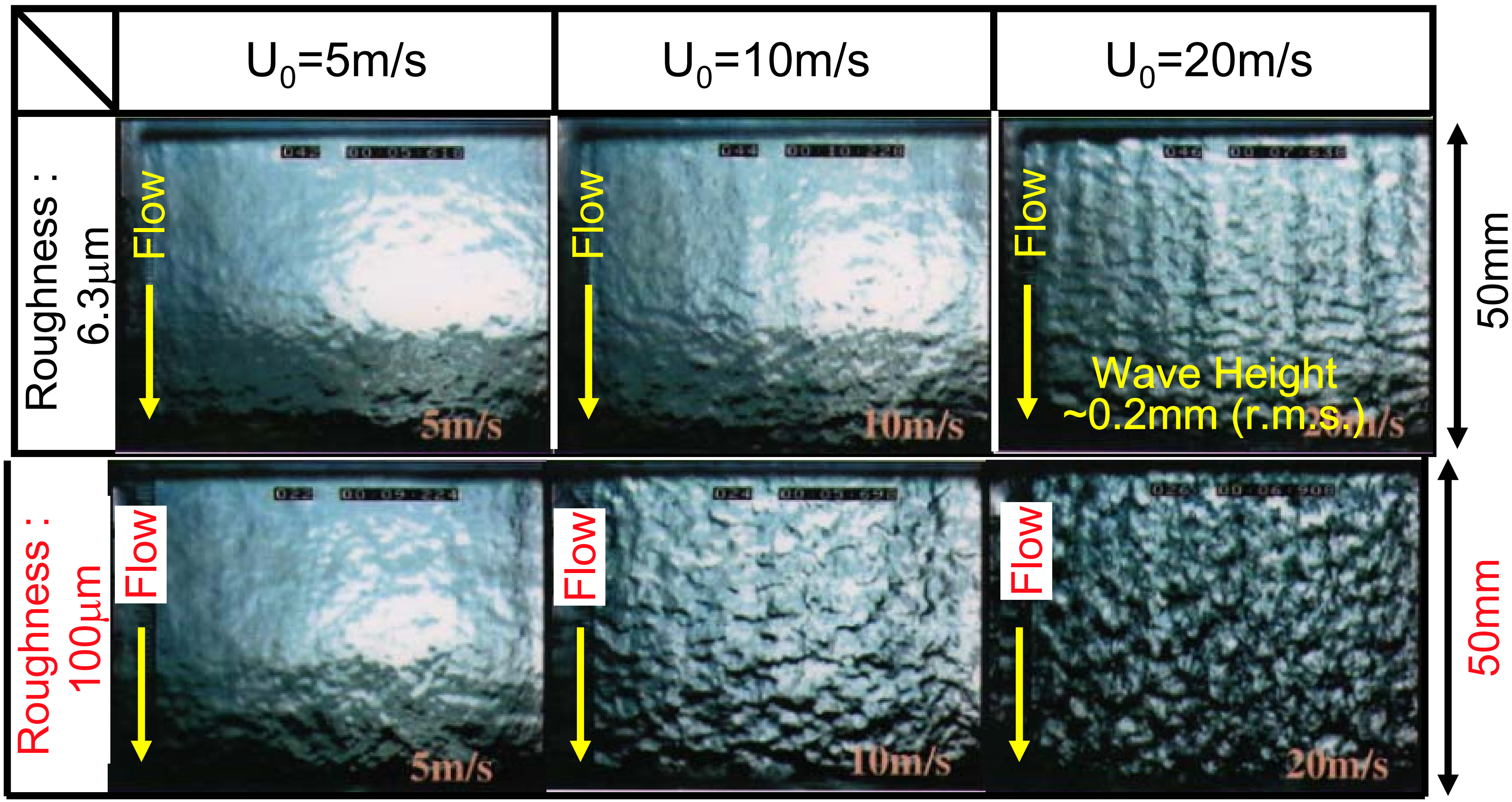


3D View of Test Section
(Test Operation without Measuring Devise)



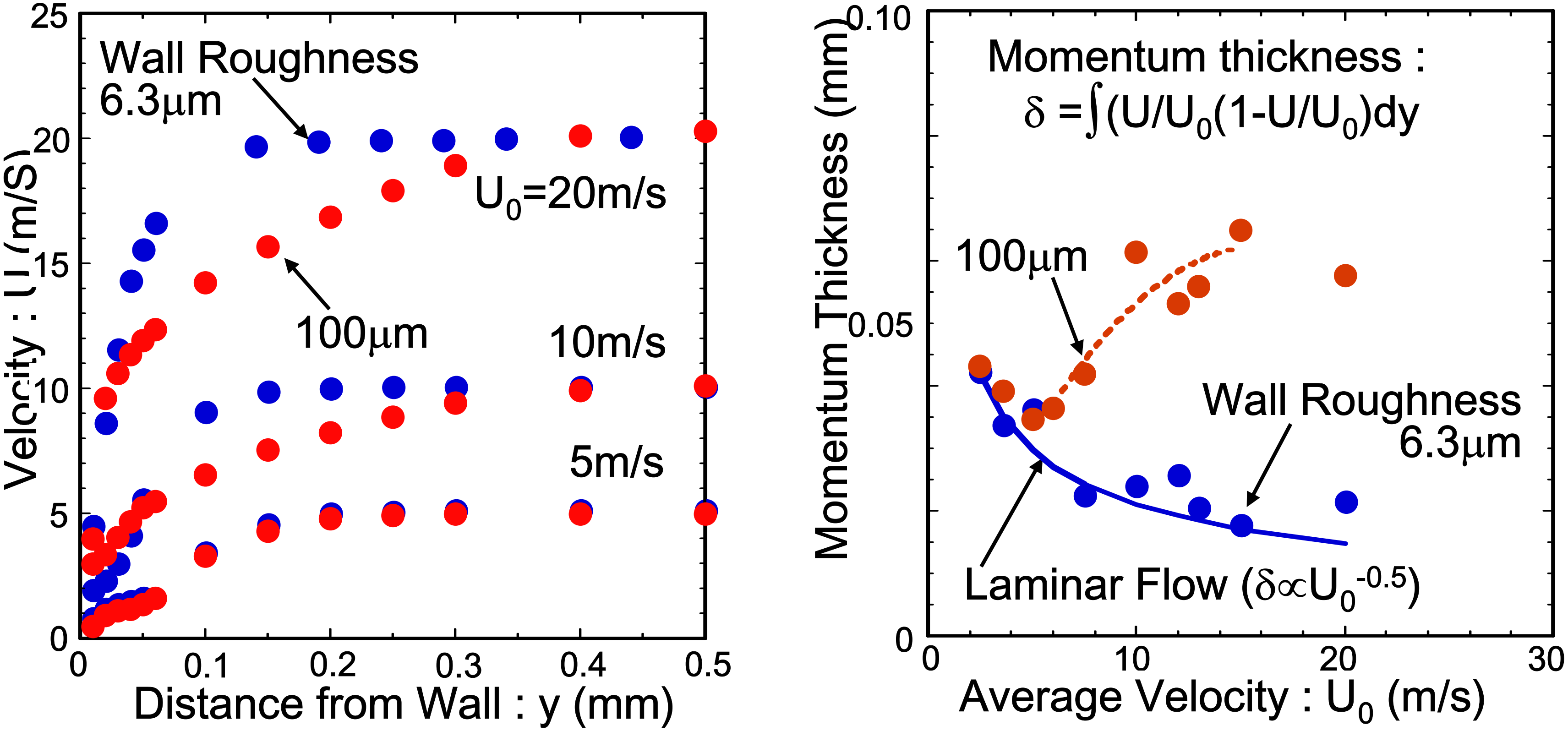
Flow velocity & Roughness

- Double reducer nozzle generates stable flows with surface deviation < 1mm.
- Rough (100μm) wall nozzle generated waves in IFMIF velocity range of 10-20m/s



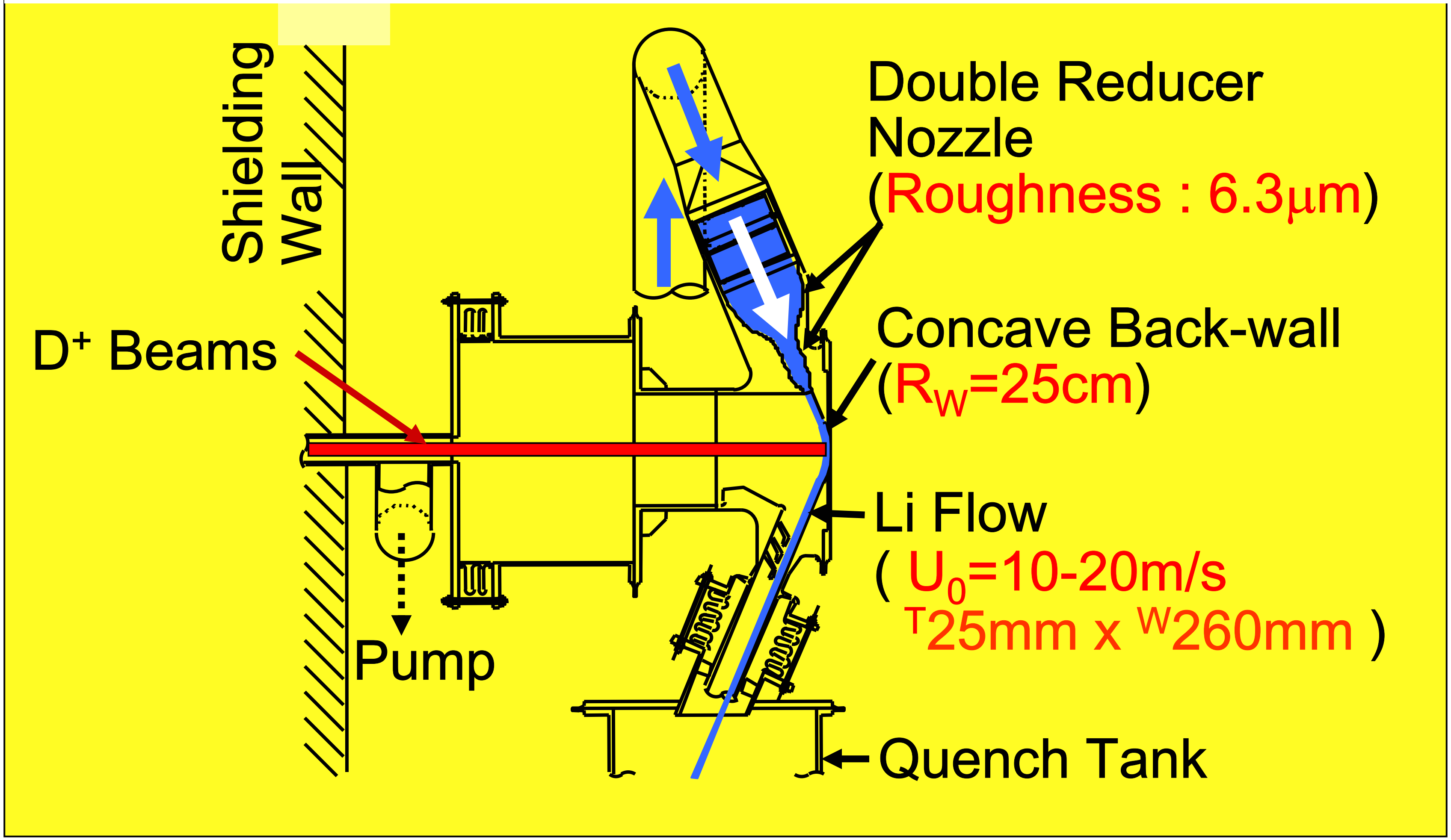
Characteristic Change of Boundary Layer at Nozzle Exit

Change of boundary layer from laminar to turbulent occurred at U_0>5m/s in case of rough (100μm) wall nozzle.



Selection of Target Parameters

IFMIF Li target has been designed utilizing results of analyses and experiments.



Transition Phase
(2003-2004)

The IFMIF Transition Phase 2003 - end 2004

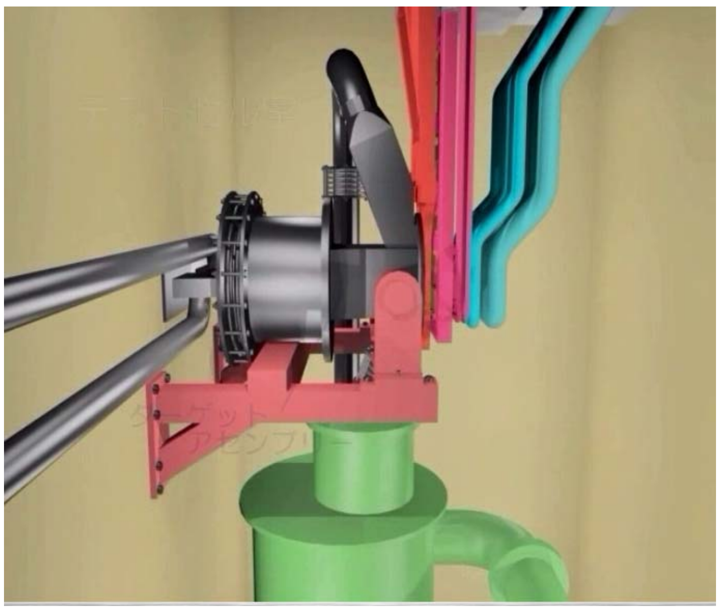
To prepare for EVEDA, the Parties of the IEA Implementing Agreement on FM (Annex II) will:

- produce a comprehensive report that integrates the results of the Conceptual design activities (CDA), the Conceptual Design Evaluation Phase (CDE) and KEP together with an updated estimation of the cost and time schedule for EVEDA, and IFMIF construction, operation and decommissioning phases;
- update the reference design with input from KEP tasks;
- continue to develop and optimise system components;
- prepare an outline work programme covering the whole EVEDA period.

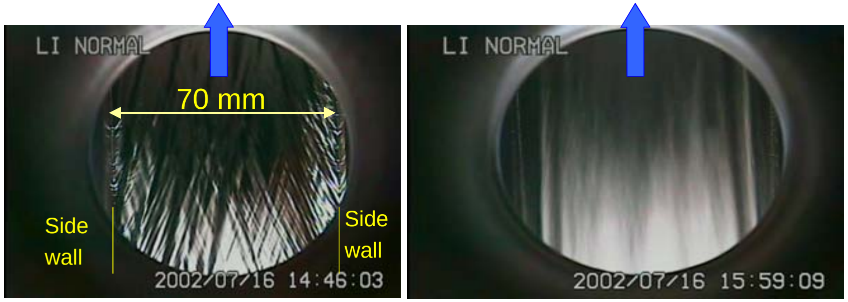
Transition phase in Japan

JAERI / JNC

System design of Li target



Osaka Li loop



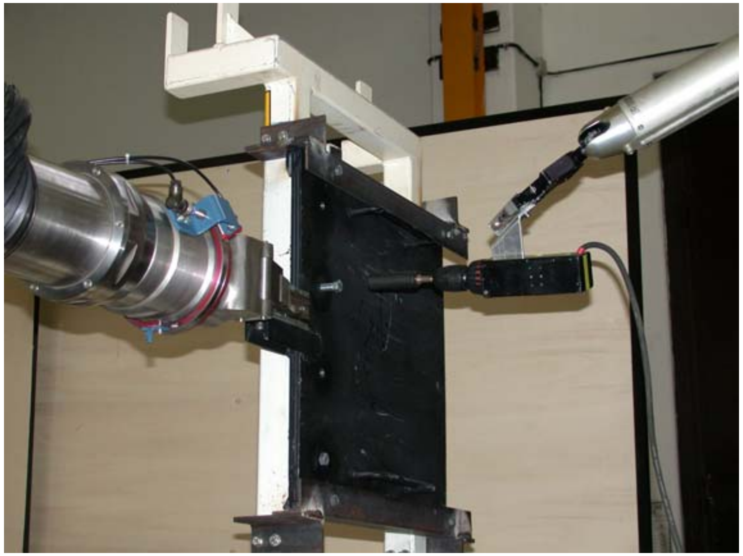
2.2 m/s

13 m/s

Transition phase in ENEA-EU

Water Experiment

Remote Handling

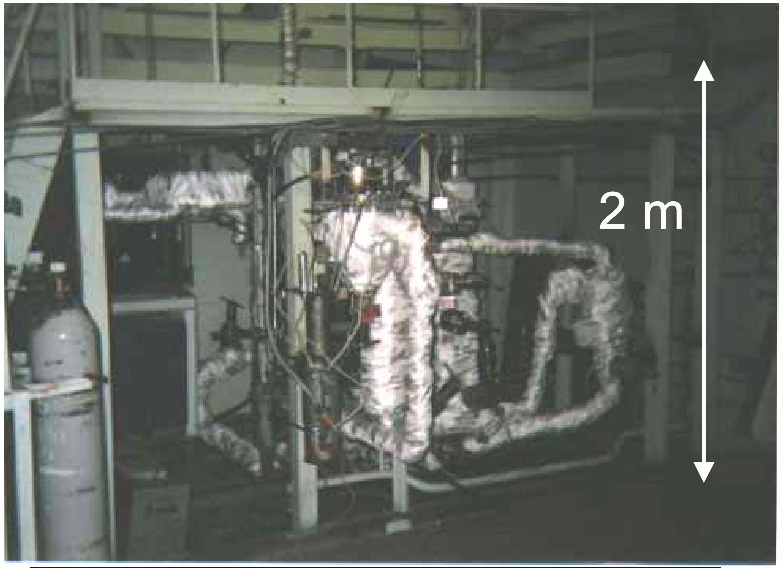


Schedule in 2003
-Joint gap:0, -0.05,- 0.1, +0.05,+ 0.1 mm
-Curvature : 25 cm,45 cm

Schedule in 2003
-RH Experiment : March - June
-Report : July

Transition phase in IPPE-RF

3 year Li target program (June 2002-June 2005) is on going under ISTC project.



Li Loop for Impurity Monitor and Li Purification System

Rotating Target for Corrosion Test (15 cm φ for 20 m/s)

EVEDA
(Engineering Validation and Engineering Design Activities)
2005-2009

IFMIF EVEDA Main activities

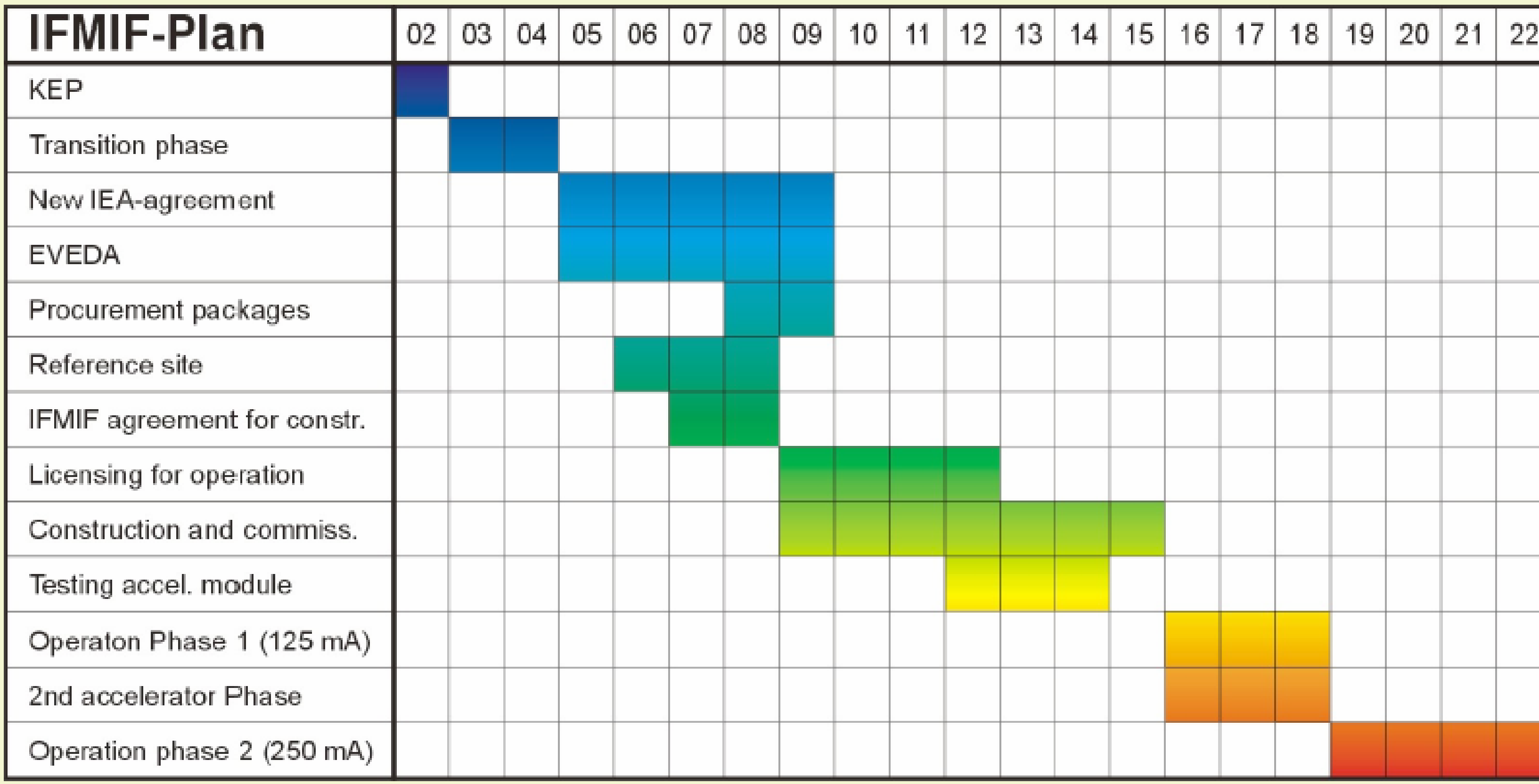
- Establish the **engineering design** of IFMIF (detailed engineering design & specifications, schedule, human & financial resources for construction
- Establish the **site requirements** for IFMIF and perform the necessary safety and environmental analysis
- Establish the programme and cost for the operation, exploitation and decommissioning of IFMIF
- Carry out validating R&D work required for performing the activities described above, including:
  - manufacturing and **testing of scalable models and/or prototypes** to ensure engineering feasibility;
  - development and testing of components for **engineering validation (mainly endurance tests** and remote handling tests)
- Develop proposals of joint implementation for decisions by the participants on construction, operation, exploitation and commissioning

IFMIF EVEDA Tasks Li-Target

- SUB-SYSTEM TESTS, ENGINEERING VALIDATION
  - Construction and operation of an IFMIF-relevant Li test loop (long term operation)
  - Verification of operating parameters, system integrity, maintenance, reliability, and safety systems
  - Development of Li-jet monitoring systems
  - Development and verification of remote handling systems of the back wall and the target assembly
  - Verify Li-jet dynamics under various conditions
  - Verification of on-line and off-line diagnostics for all relevant impurities

- ENGINEERING DESIGN
  - Detailed final design of Li-Target components and remote handling system
  - Design activities related to activation, safety, auxiliary systems and interface issues

IFMIF Road Map



M. Gasparotto; Status 11-2002

IFMIF Summary

1. The availability of a dedicated neutron source is indispensable for the qualification of materials for design and safe operation of fusion power reactors.

2. **Suitability:** IFMIF meets all relevant user requirements

   Feasibility:
   – IFMIF is well developed, and ready to proceed to prototyping and engineering design
   – The reference design is conceived for long-term operation with an annual availability of at least 70%

3. **Future plans:**

   The IFMIF design is at a level of maturity that would readily justify, a positive decision towards an engineering phase "EVEDA"

   – Under the IEA preparations are being made to start EVEDA in 2004
   – In this case, IFMIF operation could start in 2016