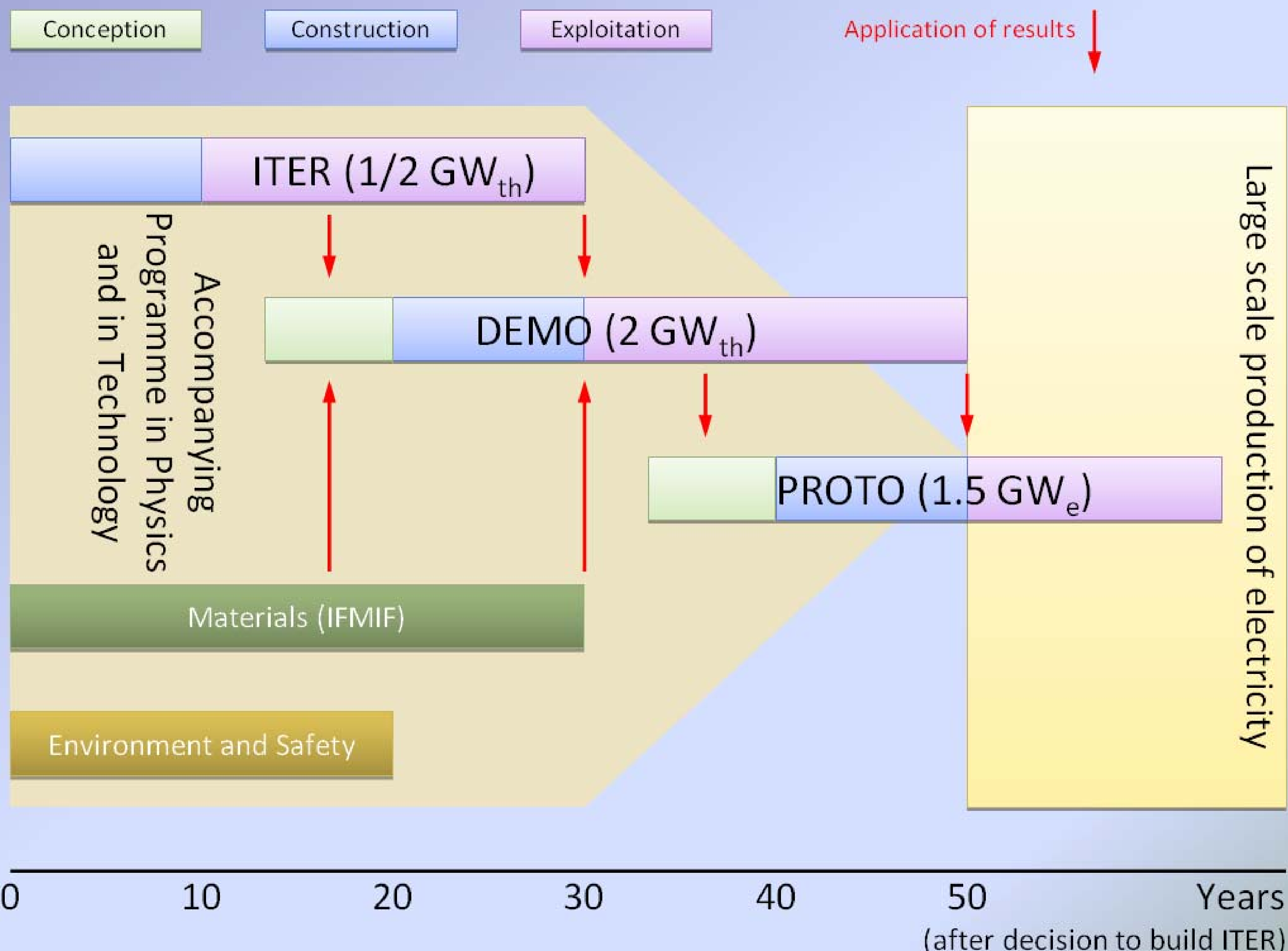
IFMIF, Status and Developments

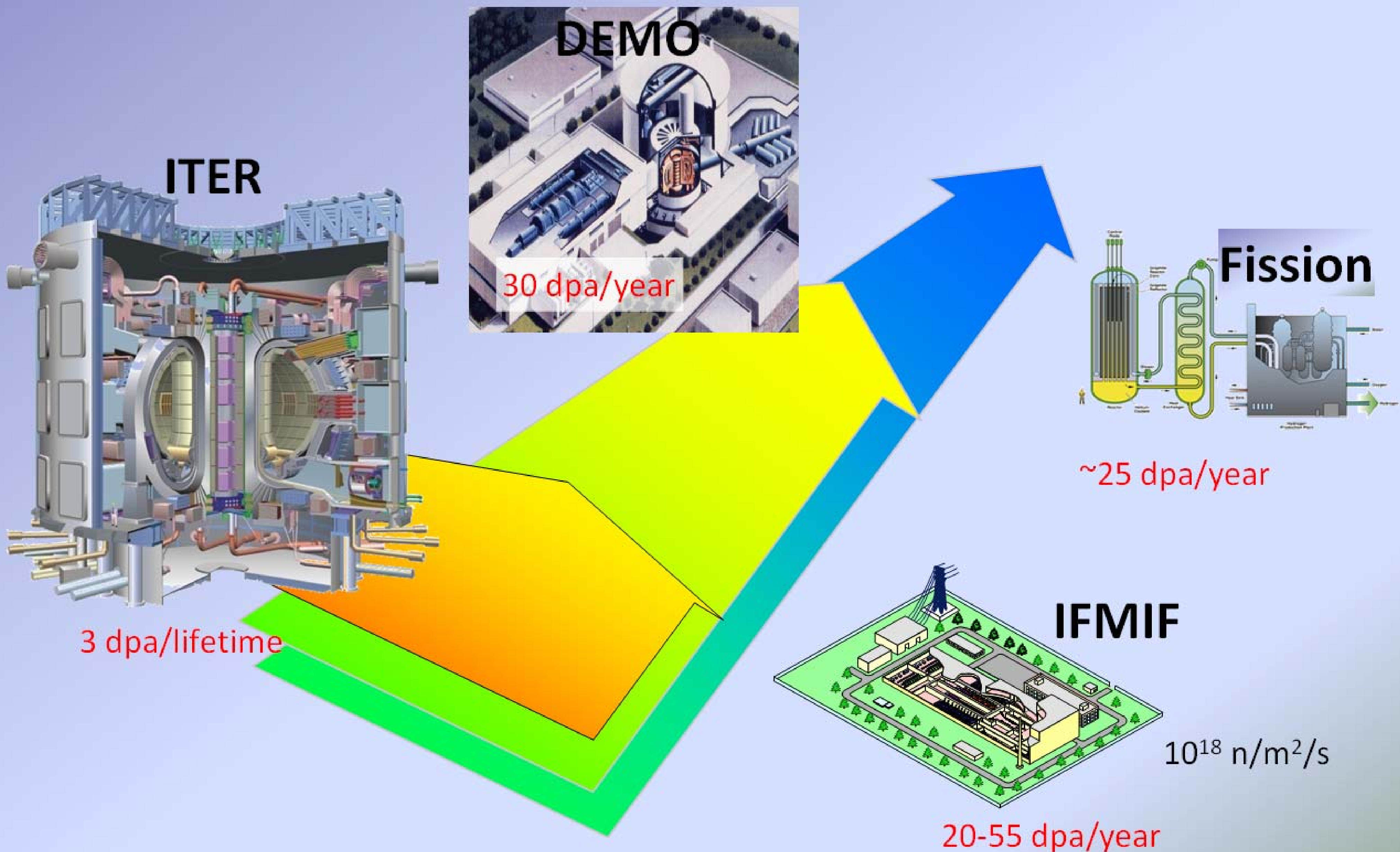
Pascal Garin, CEA (Rokkasho, Japan)
on behalf of the Project Team and Institutes

EPAC 2008, Genoa – 24 June 2008

Perspectives for fusion



International Strategy Scenarios



Versatility of the Test Cells

High Flux volume

Materials

Reduced activation First wall and blanket structural materials

• Ferritic-Martensitic (ODS) steels	250-650 °C	150 dpa
• Vanadium alloys	350-650 °C	150 dpa
• SiC/SiC composites	600-1100 °C	150 dpa
• Refractory metals (e.g. W-alloys)	650-1100 °C	80 dpa
• Brazing materials & joints	650-1100 °C	80 dpa

Type of experiments

- Mainly instrumented irradiation capsules for PIE in hot cells
- In a later stage a sub-sized test blanket module

Medium & Low Flux volumes

Materials

• Ceramic insulators	20-500 °C	0.1-10 dpa
• RF windows	20-400 °C	0.001-1 dpa
• Ceramic Breeder materials	300-700 °C	1-60 dpa
• Neutron multipliers (Be-alloys)	300-900 °C	1-60 dpa
• Superconducting materials	80-100 K	<0.1 dpa

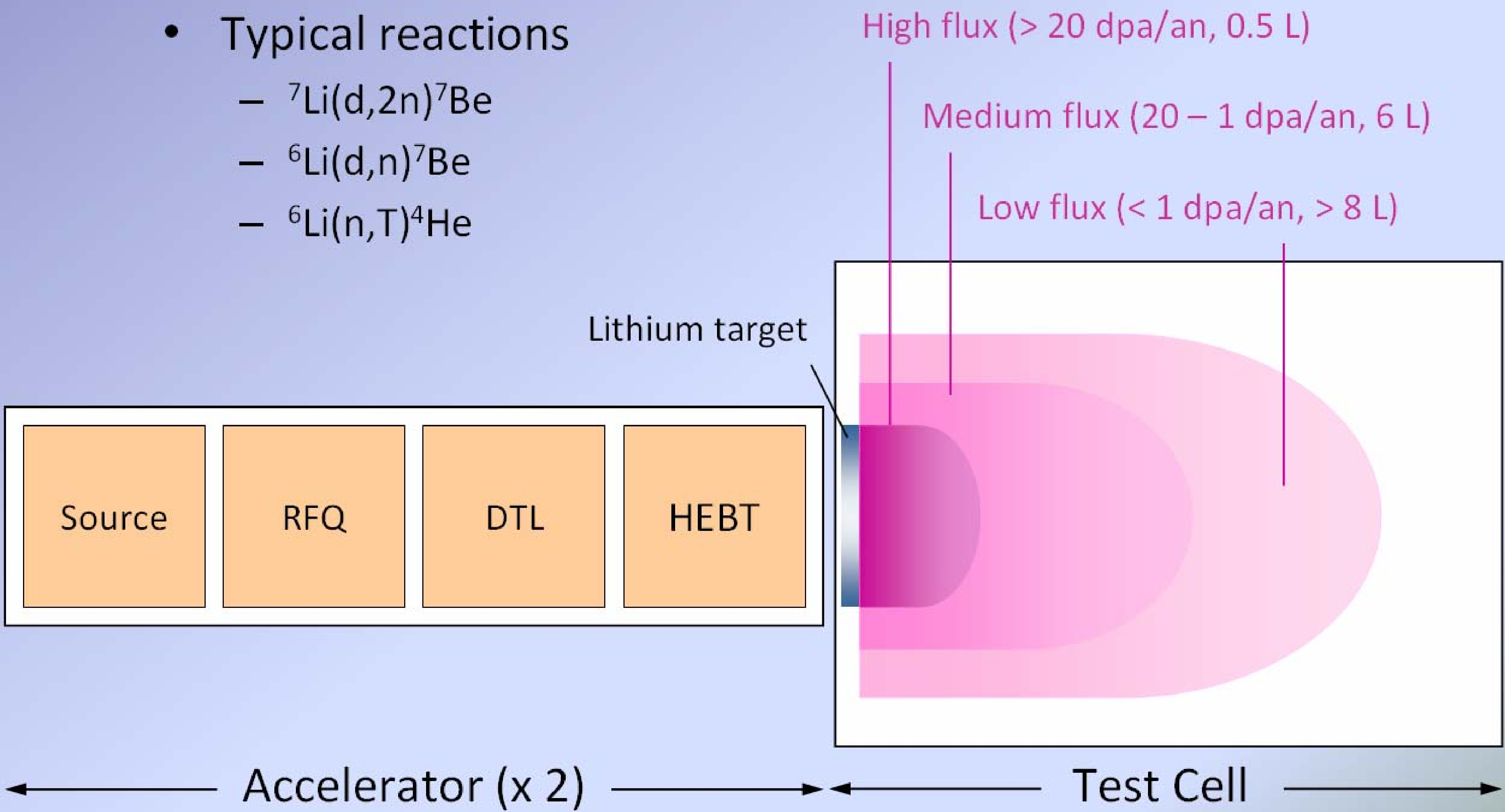
Type of experiments

Fully instrumented in situ tests under irradiation, such as

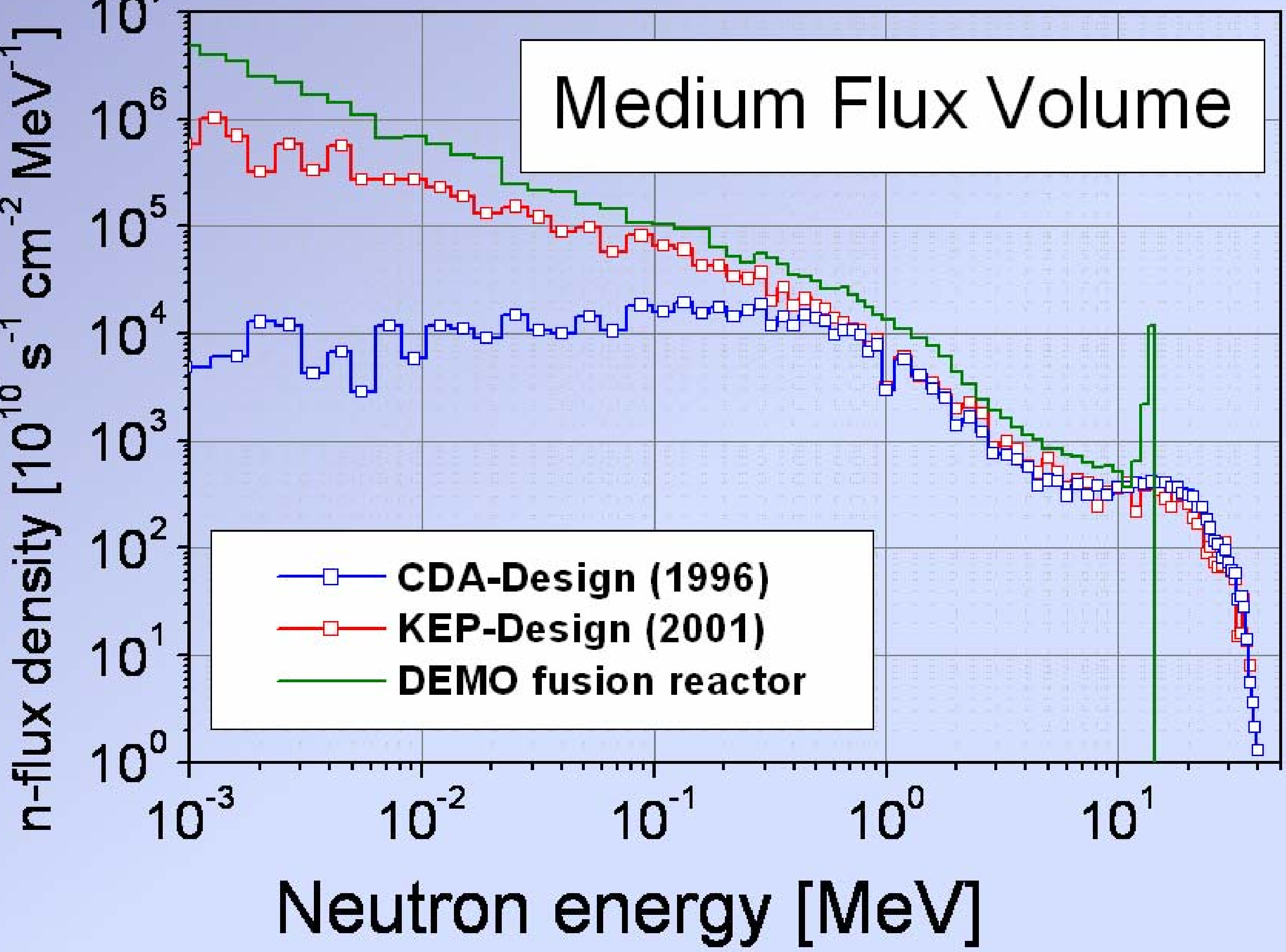
- Creep-fatigue and crack growth tests
- Stress corrosion tests (IASCC)
- Radiation induced conductivity and electrical degradation
- Tritium diffusion & release experiments (ceramic breeders, Be-alloys)

IFMIF Principles

- Typical reactions
  - $^{7}Li(d,2n)^{7}Be$
  - $^{6}Li(d,n)^{7}Be$
  - $^{6}Li(n,T)^{4}He$

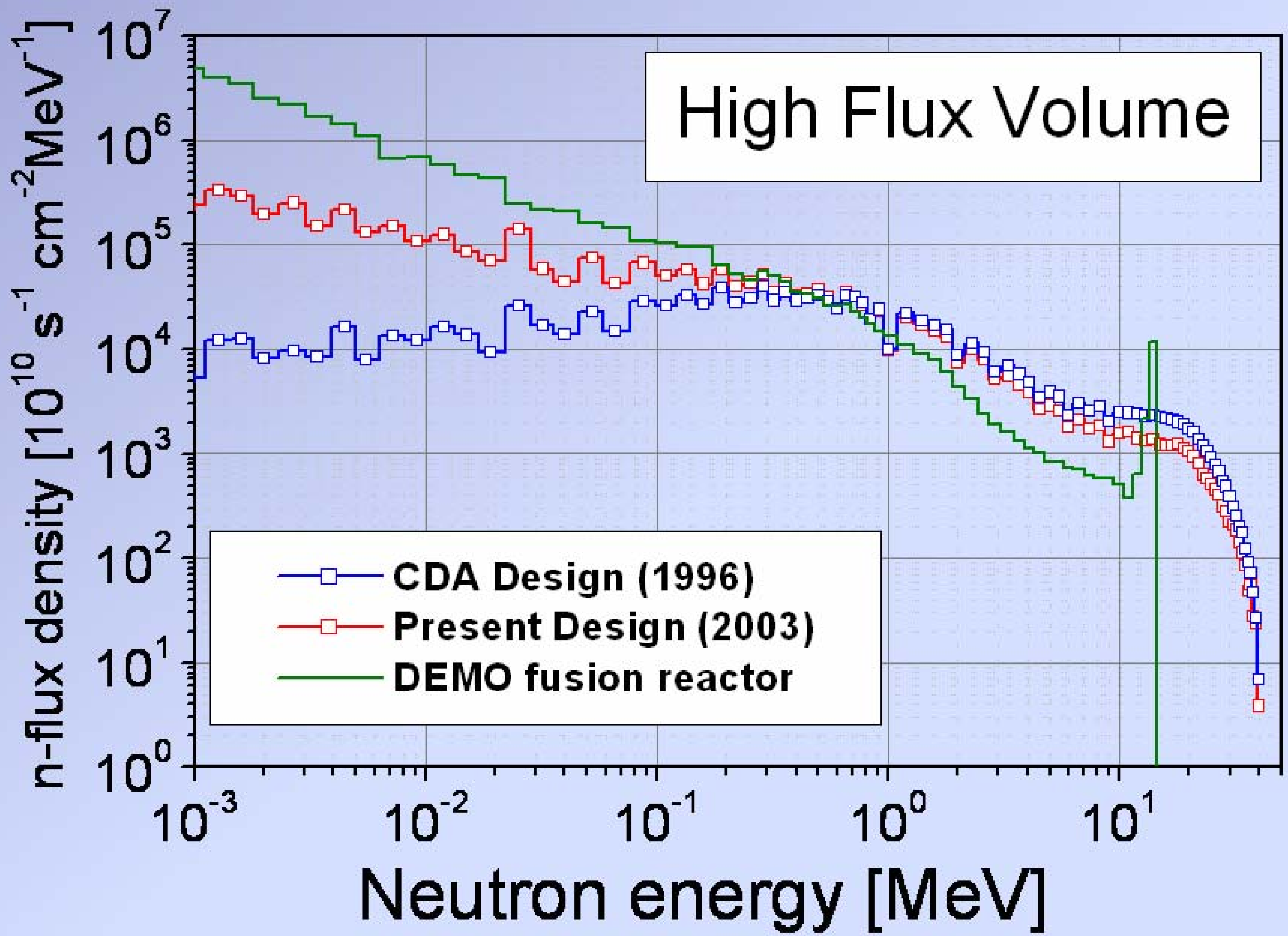


IFMIF neutron spectra



- Neutron moderators and regulators enabled
  - To drastically improve the neutron spectrum
  - To increase the irradiated volume

IFMIF neutron spectra



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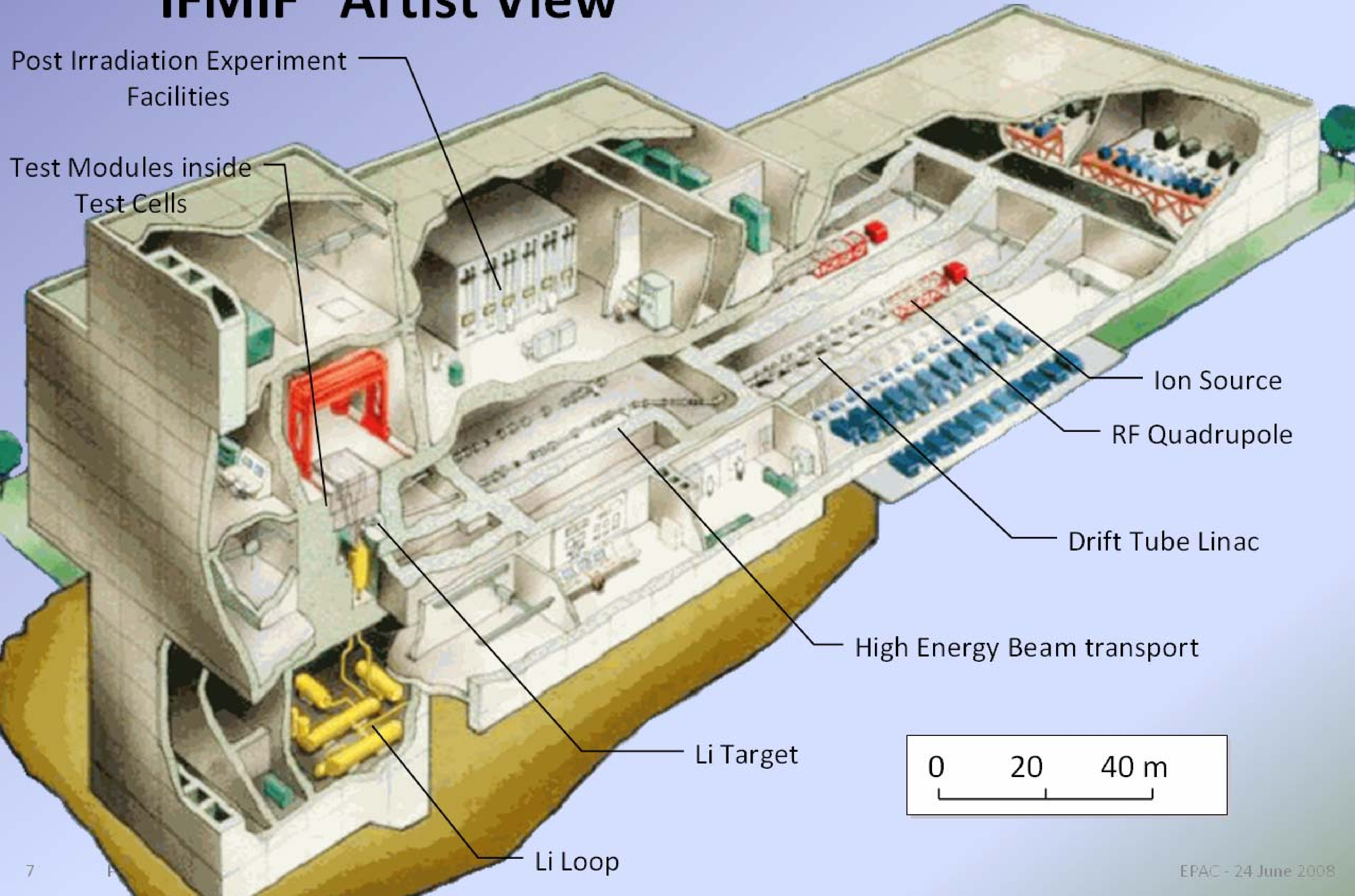
IFMIF “Artist View”



Scope of EVEDA phase: Design
(Engineering Validation and Engineering Design Activities)

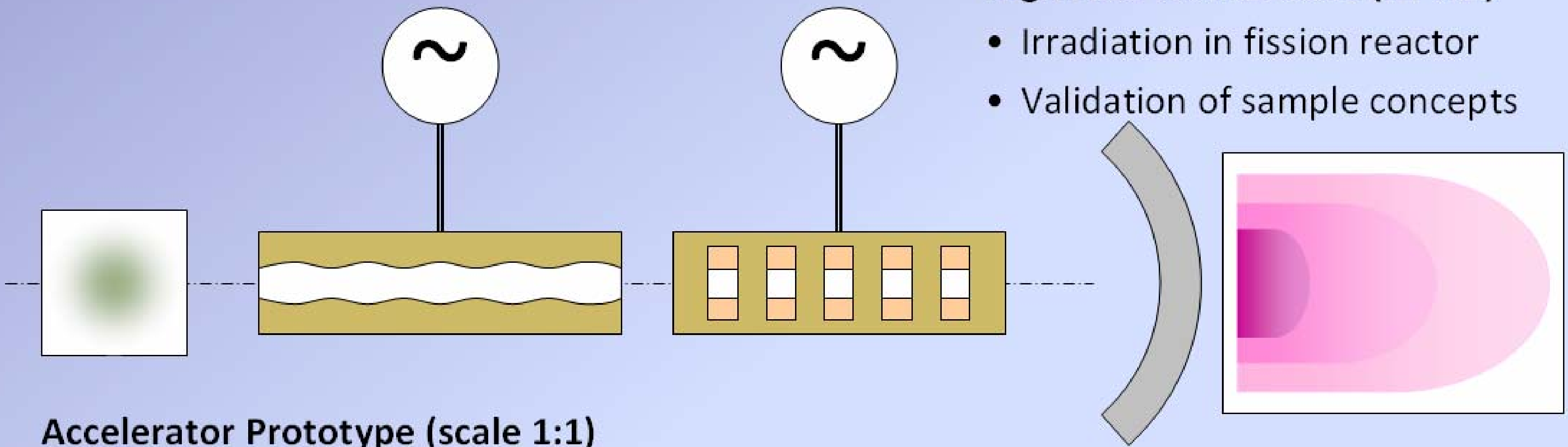
- Integration of elements provided by Working Groups
  - Accelerator
  - Lithium target
  - Test Facilities
- Costing
  - Of IFMIF (construction, operation and dismantling)
  - Of construction planning
- Generic Site Safety Report
- Site Requirements and Site Design Assumptions
- Specifications of elements on the critical path

Scope of EVEDA phase: Validation

(Engineering Validation and Engineering Design Activities)

High Flux Test Module (HFTM)

- Irradiation in fission reactor
- Validation of sample concepts



Accelerator Prototype (scale 1:1)

- Ion Source
- RadioFrequency Quadrupole
- First section Drift Tube Linac
- Building (at Rokkasho)
  for the test of the accelerator

Lithium Loop (scale 1/3)

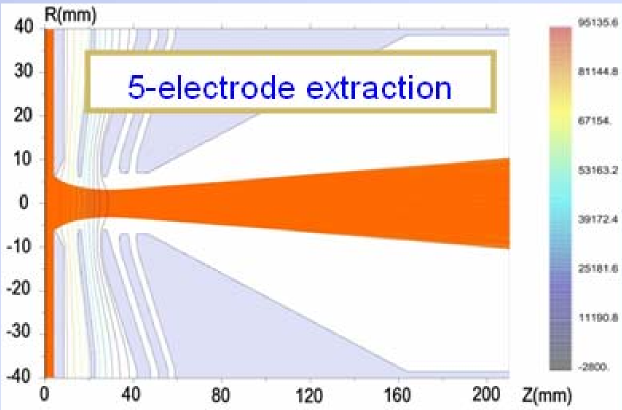
- Diagnostics
- Erosion/Corrosion
- Purification system
- Remote Handling

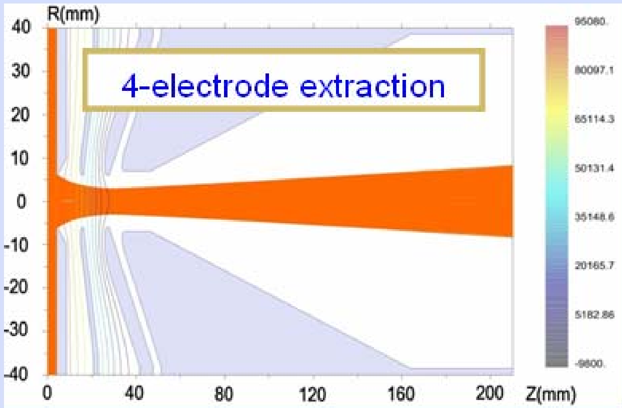
Some technological challenges of IFMIF

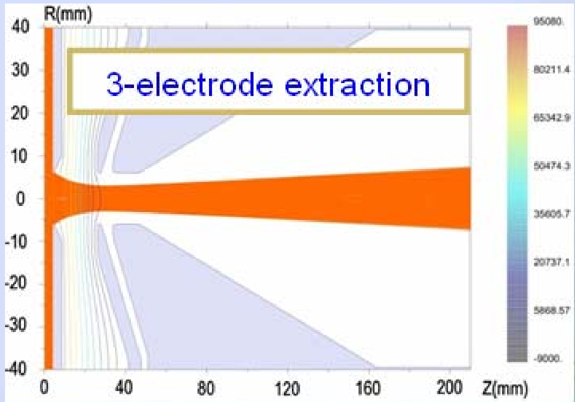
- Accelerator: D^+ – 125 mA – CW – 40 MeV
  - Space Charge, Beam Instabilities, CW operation
  - Beam interception (activation)
  - Shape of the Beam Footprint at the Target

Injector and LEBT

- D⁺ beam: 140 mA – 100 keV
  - Limitation of the emittance growth
  - Better matching to the RFQ
- Improvement of the Extraction Design
  - Comparison between 3, 4 and 5 electrodes
  - Reduction of the Accelerator Gap Length
  - Enlargement of the plasma Electrode Diameter
  - Beam Neutralization close to the plasma efficiency increase
  - Compromise between performances / tunability

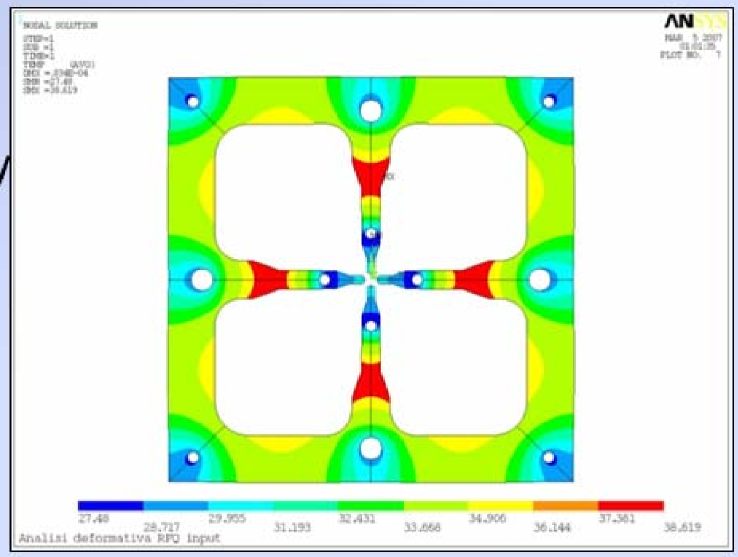


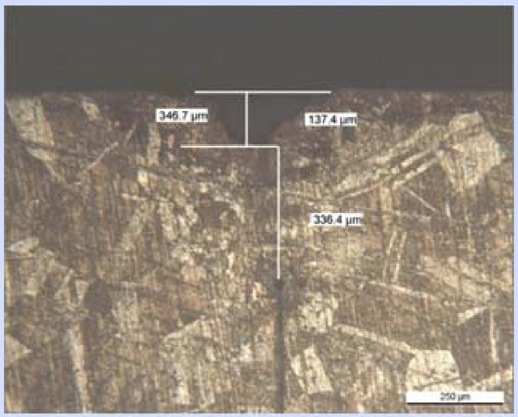


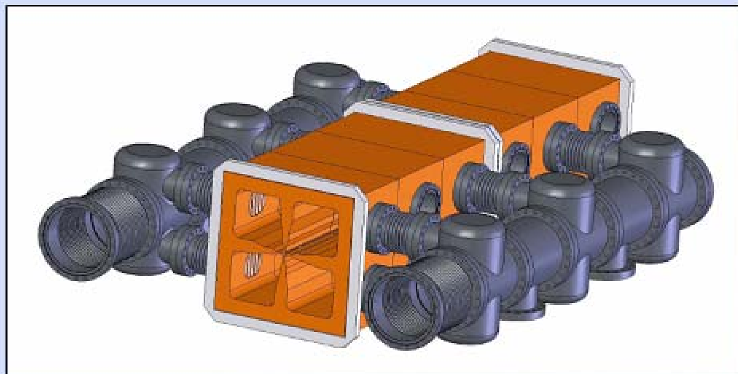


RadioFrequency Quadrupole

- Characteristics
  - Length: 9.8 m – Output energy: 5 MeV
  - RF Power: 2 MW – 175 MHz
- Mechanical Design (Preliminary)
  - Thermal and Structural Analysis
  - Evaluation of the Deformation
- Manufacturing and Assembly Tests
  - Different construction options: brazing chosen in March 2008
  - Cooling optimization ongoing



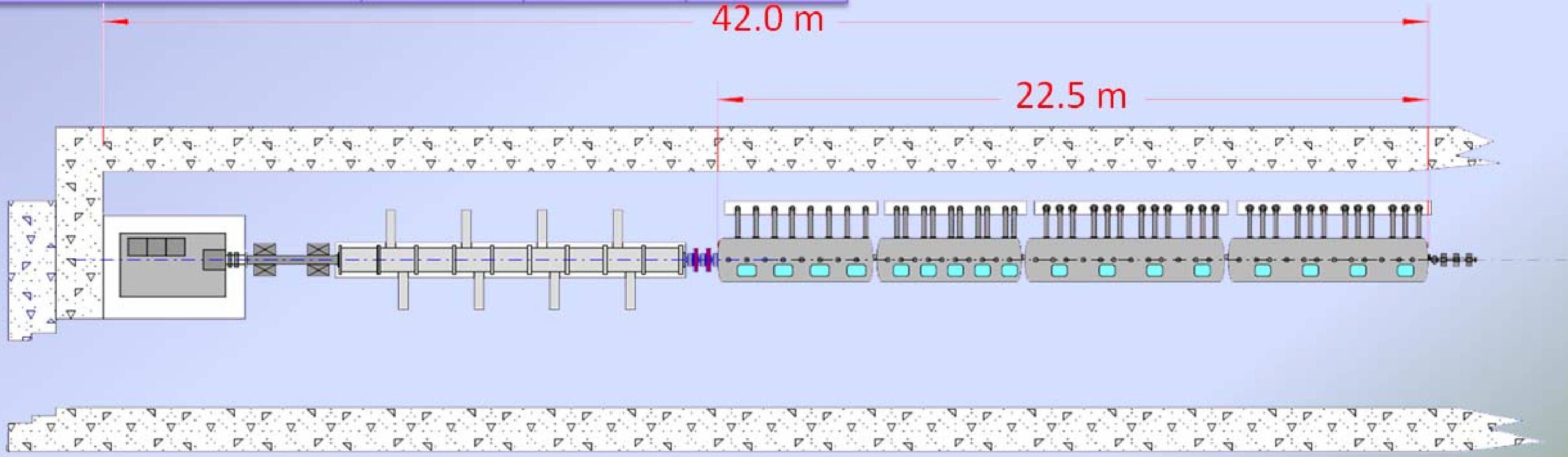




Half Wave Resonant Cavities Drift Tube Linac

Cryomodules	1	2	3 & 4
Cavity β	0.094	0.094	0.166
Cavity length (mm)	180	180	280
Beam aperture (mm)	40	40	48
Number of cavities / period	1	2	3
Number of cavities / cryostat	1 x 8	2 x 5	3 x 4
Number of solenoids			
Cryostat length (mm)	4.64	4.30	6.03
Output energy (MeV)	9	14.5	26 / 40

Reduction of the length by 10 m



Proposal of Test for EVEDA

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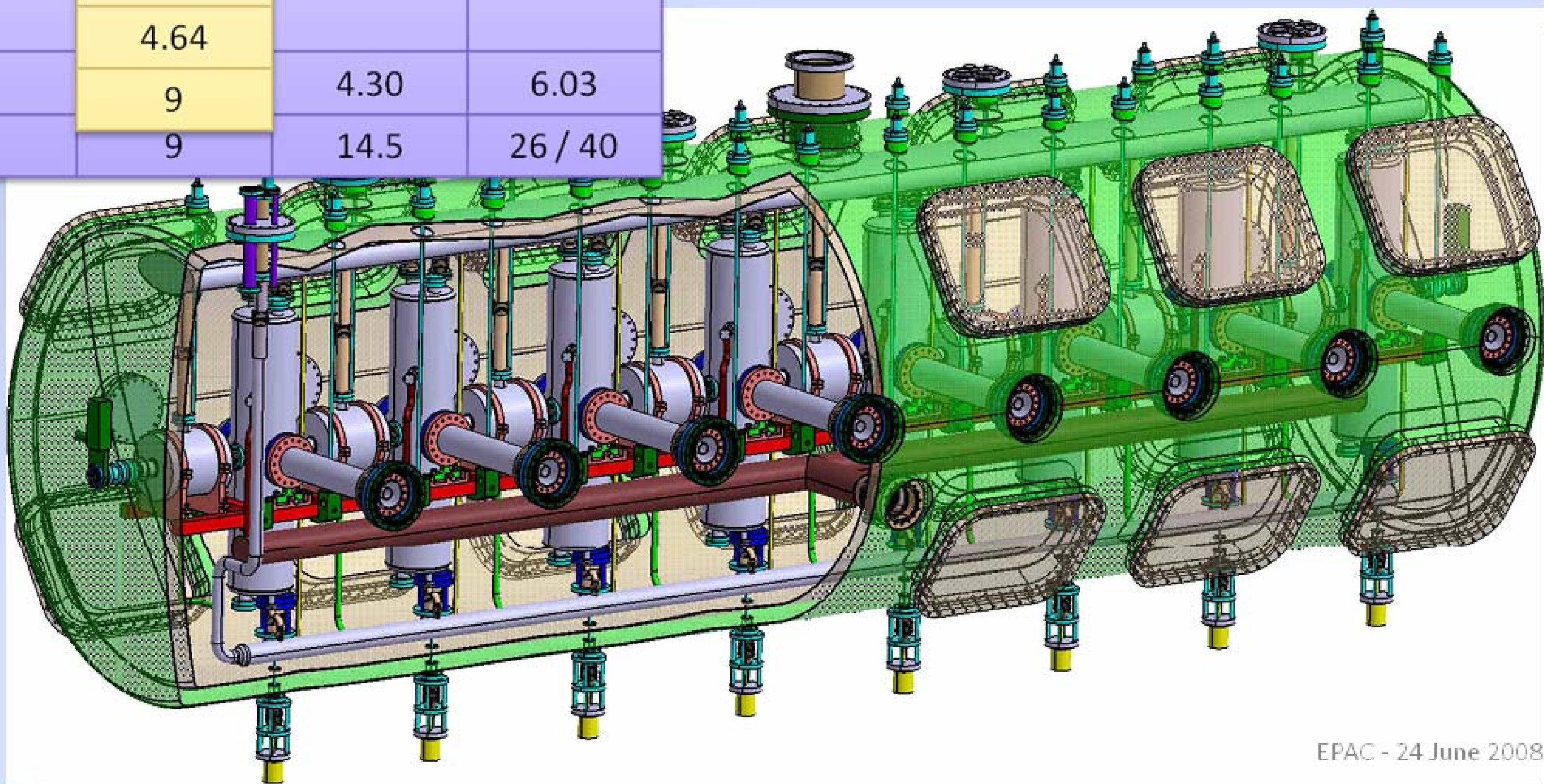
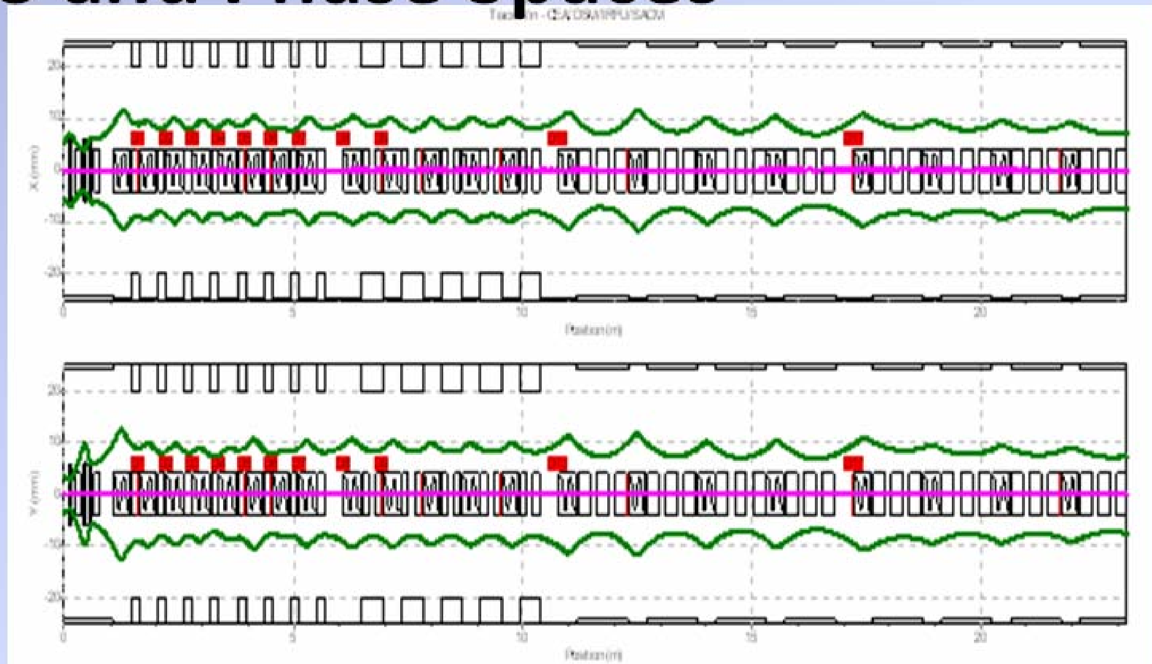


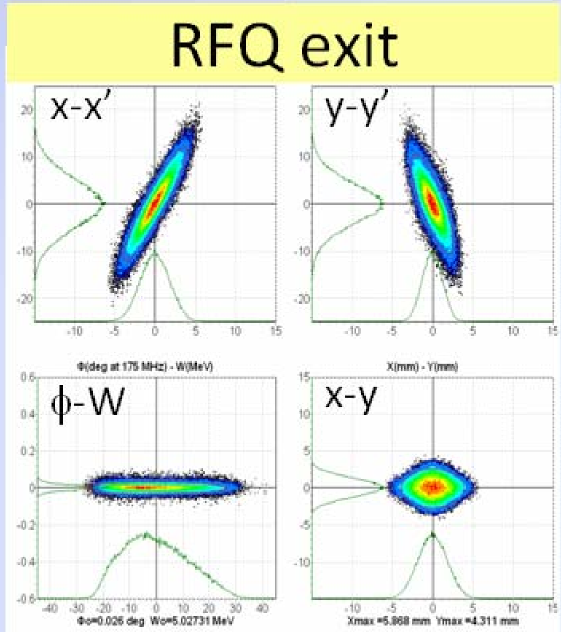
Beam ENVELOPES and Phase Spaces

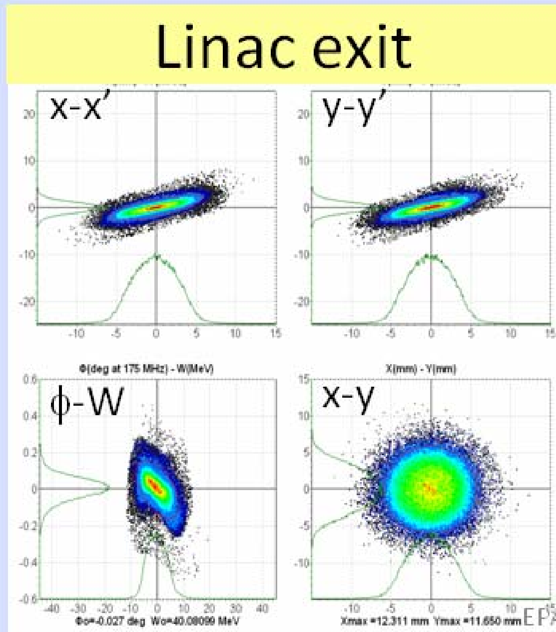
Beam envelopes 3 x rms values
Beam matched in the 3 planes
100 % transmission (10^6 particles)

$\Rightarrow$ comfortable safety margin
with respect to beam pipe

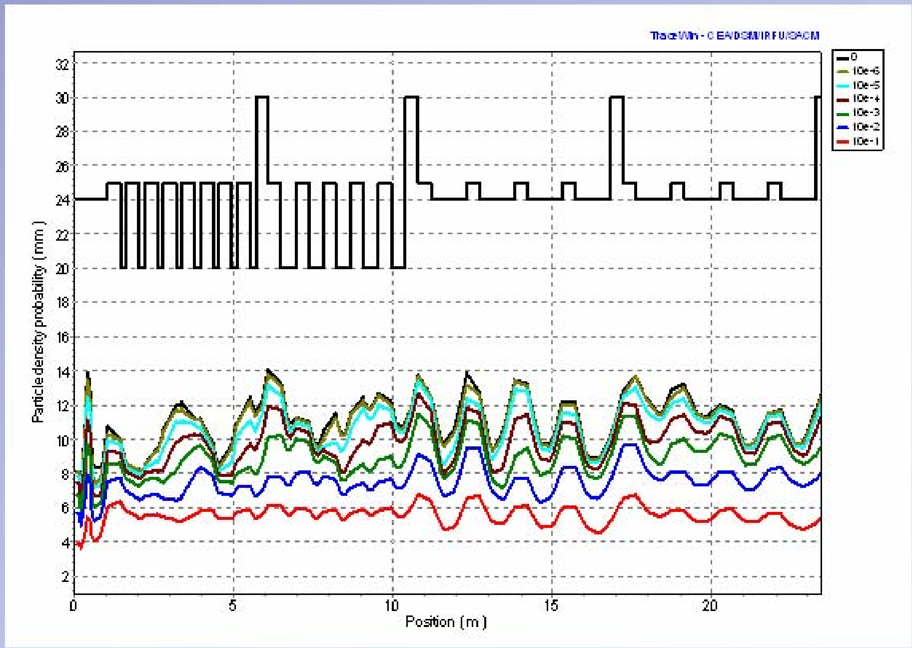


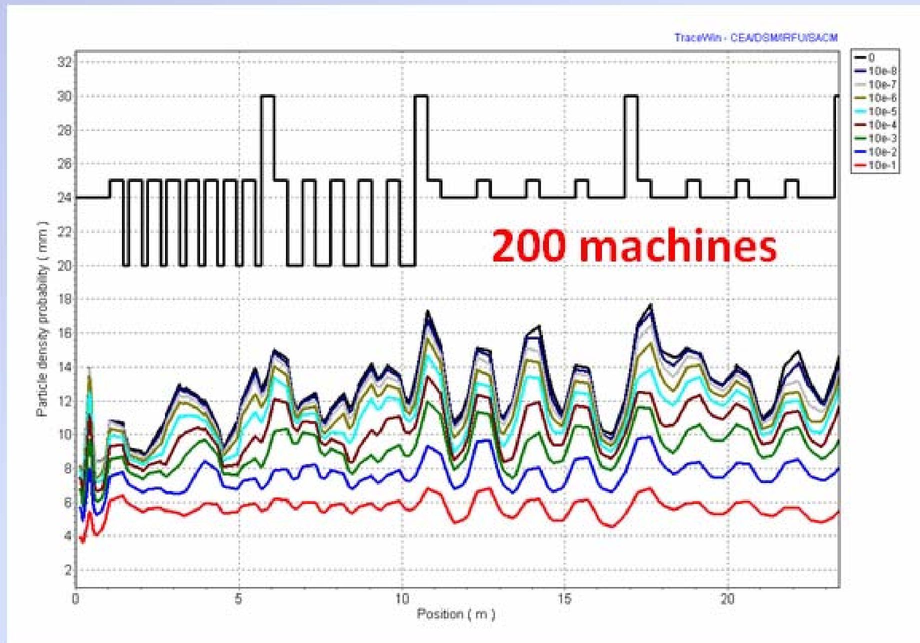
Phase spaces
Gaussian input beam distribution





Beam Transmission





Contour lines encircling 90 to 100 % of particles (10^6)

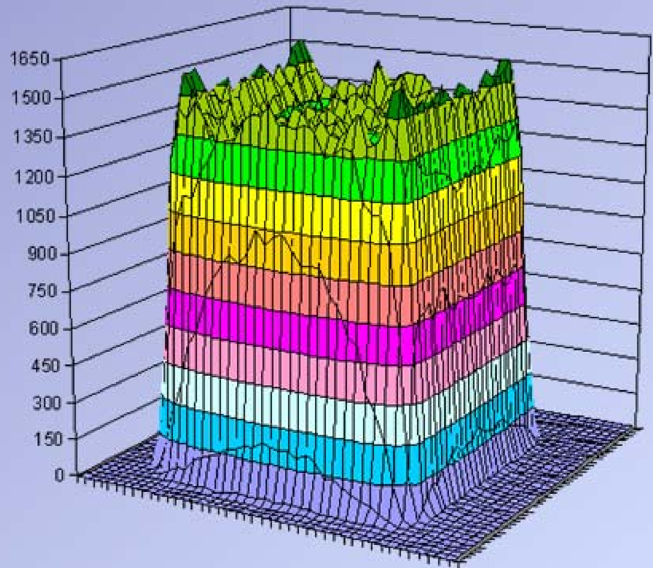
Without errors

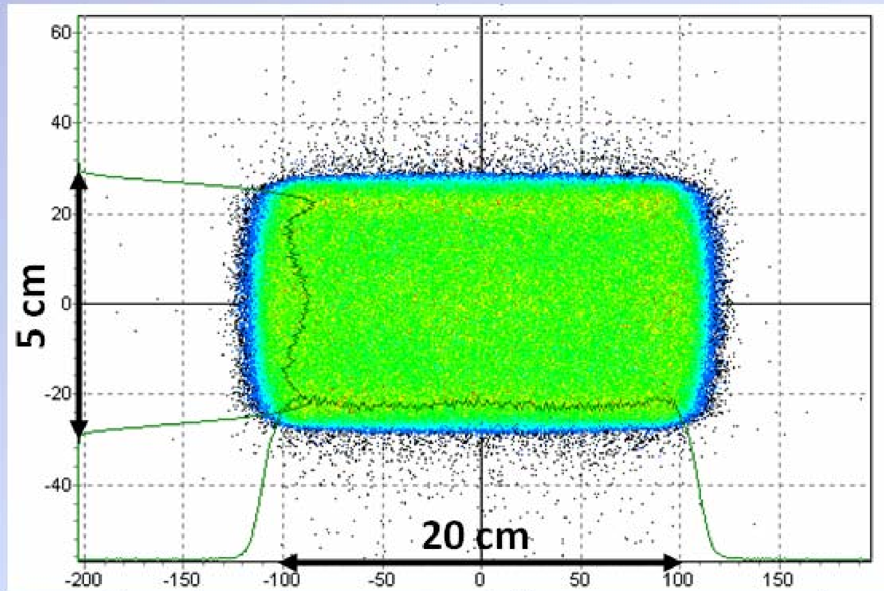
- Beam occupancy: 60 – 70 %
- Distance Beam – Wall: 6-10 mm

With errors (1 mm, 10 mrad)

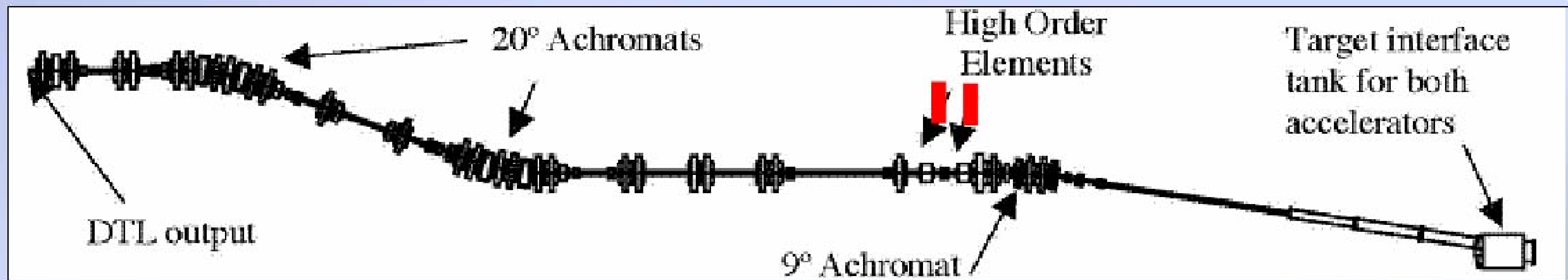
- Beam occupancy: 75 %
- Distance Beam – Wall: 5-6 mm

HEBT Design



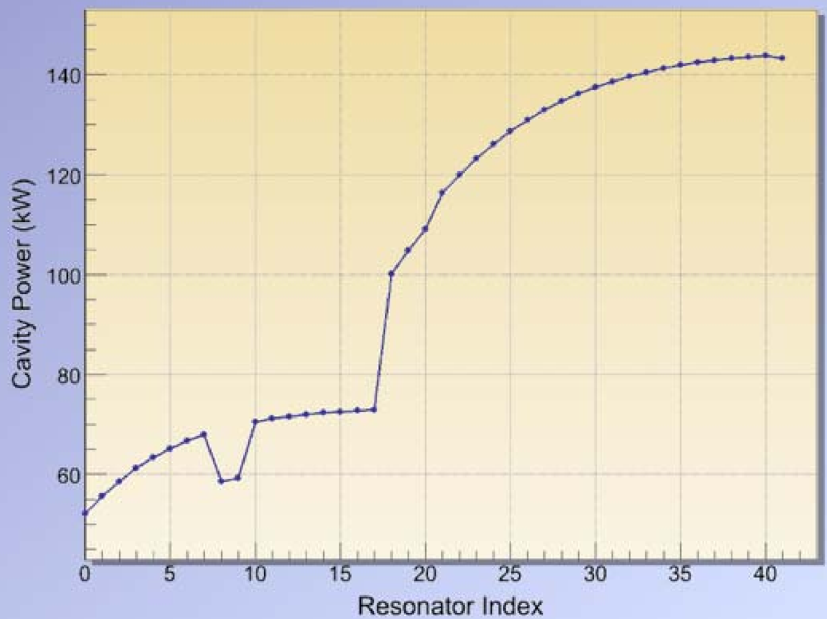


- The beam density distribution has to be tailored to the required flat top rectangular shape (20 cm x 5 cm) ⇒ **non-linear multipole lenses**
- The beam has to intercept the target with an angle (9°) to avoid neutron back-streaming into the active beamline components ⇒ 2 bending magnets



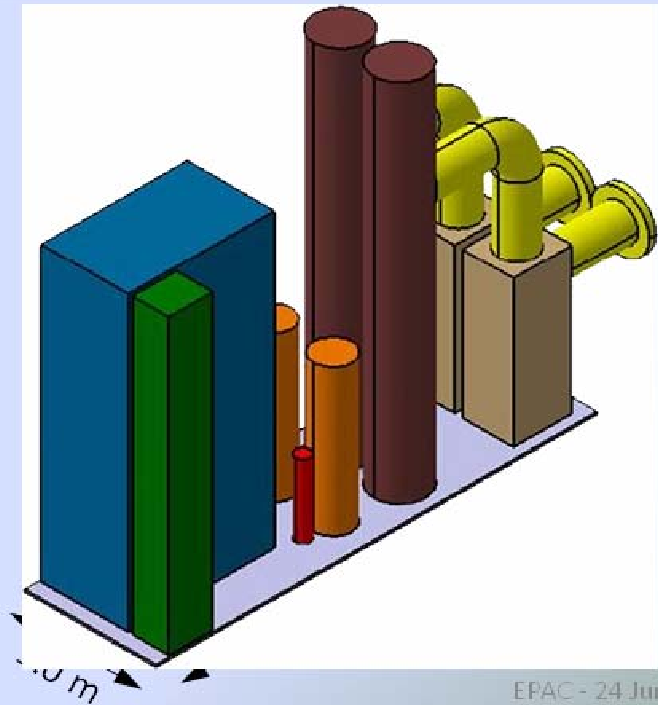
Alternative: **raster-scanning**, but scanning speed > 1 km/s to avoid boiling the lithium target
⇒ feasibility of the magnet and power supply (E. Surrey, UKAEA)

New RF Power System proposal (175 MHz)

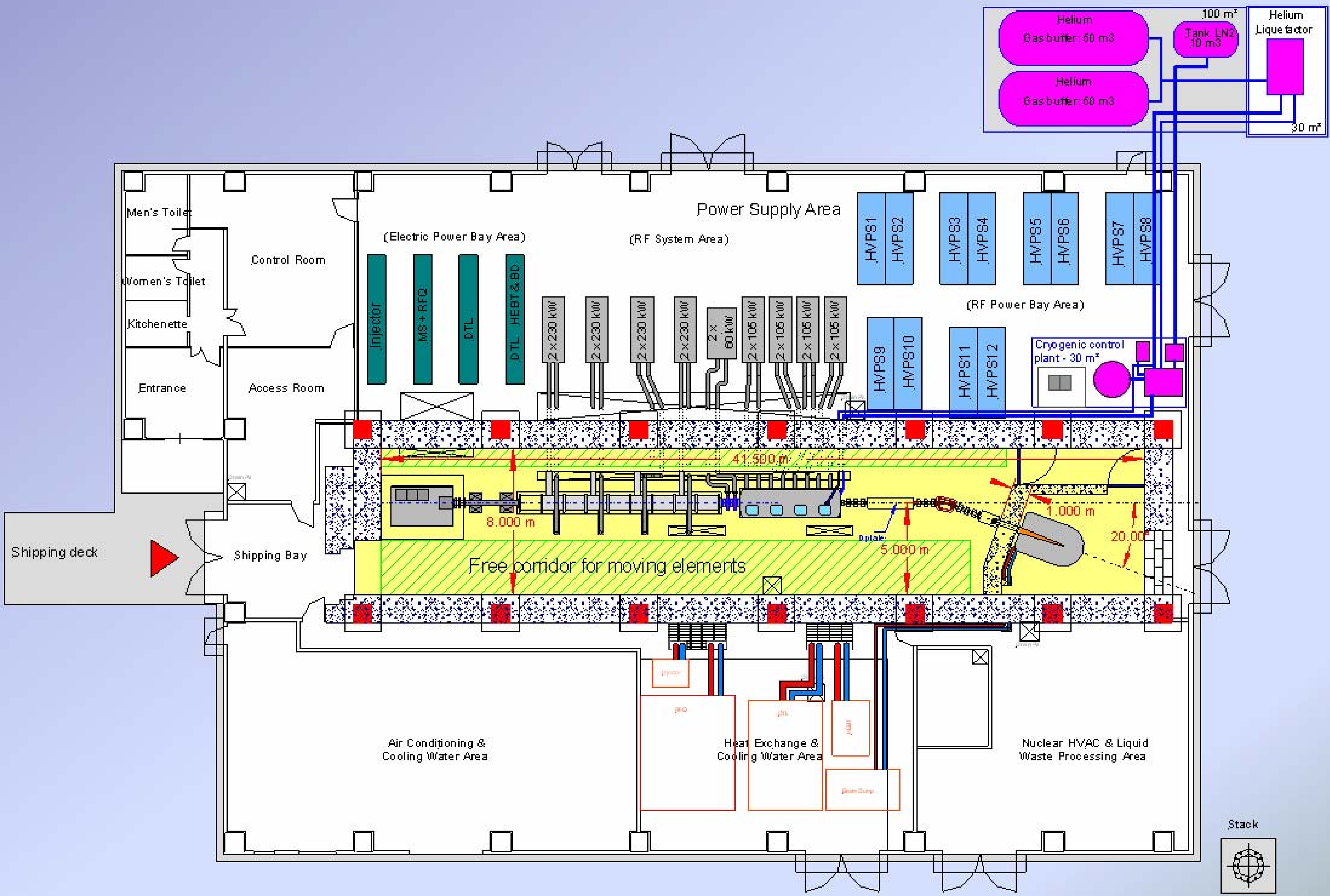


Power amplifiers	60 kW	105 kW	230 kW
SC resonators	–	18	24
RFQ cavity	–	–	8
Buncher cavity	2	–	–
Total for 1 linac	2	18	32
Total for 2 linacs	**4**	**36**	**64**

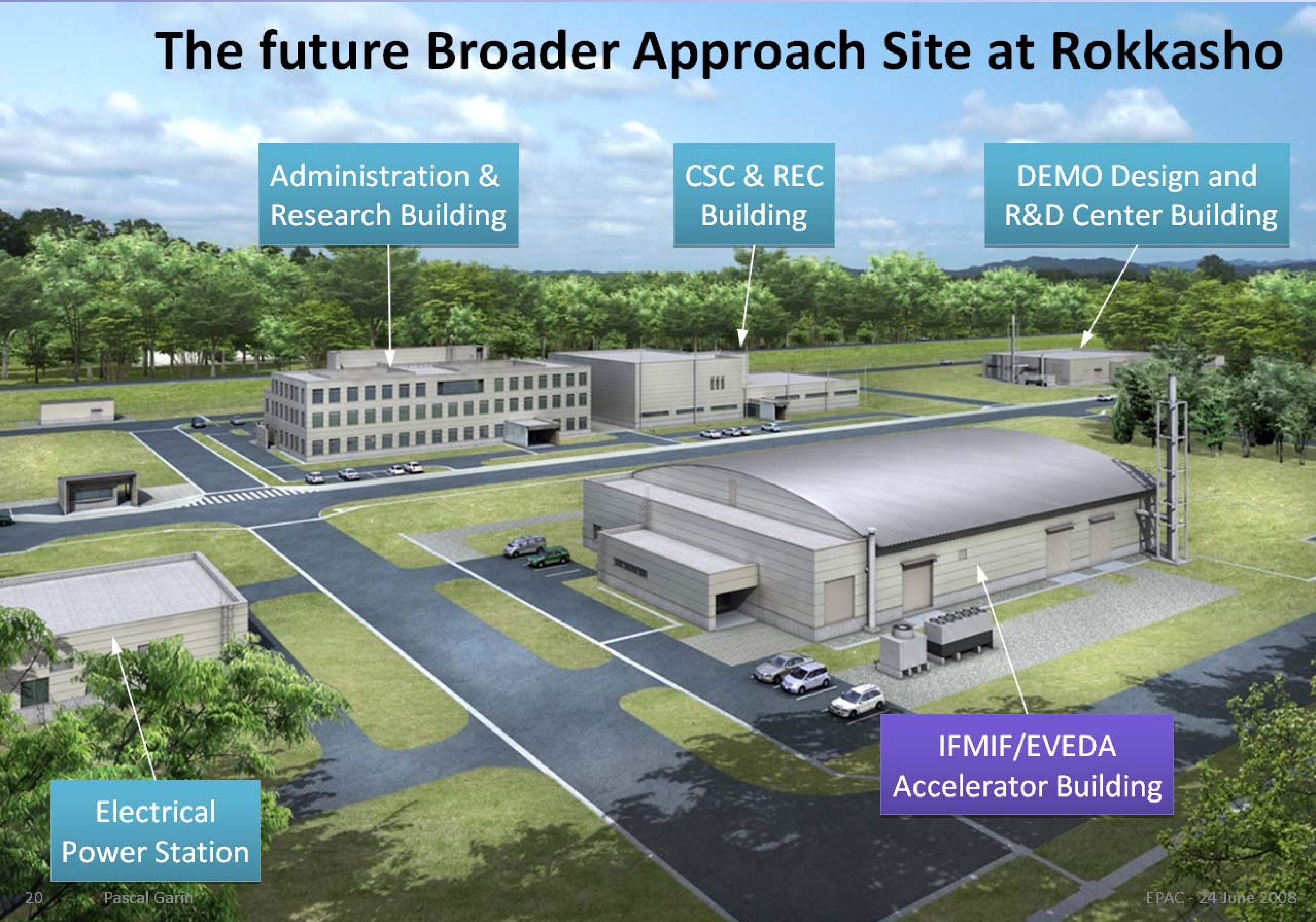
- Simplification of RF sources
  - Two chains required
    - 60 kW Units
    - 105-230 kW Units
  - Standardization
- Improvement of reliability



Accelerator Prototype Building Layout



The future Broader Approach Site at Rokkasho



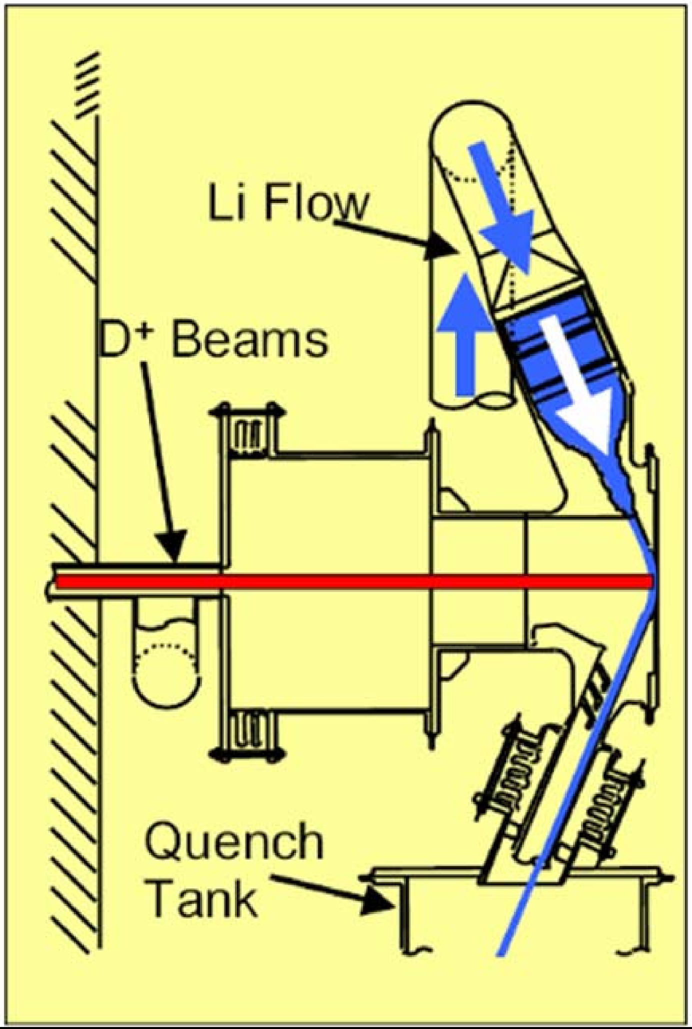
Some technological challenges of IFMIF

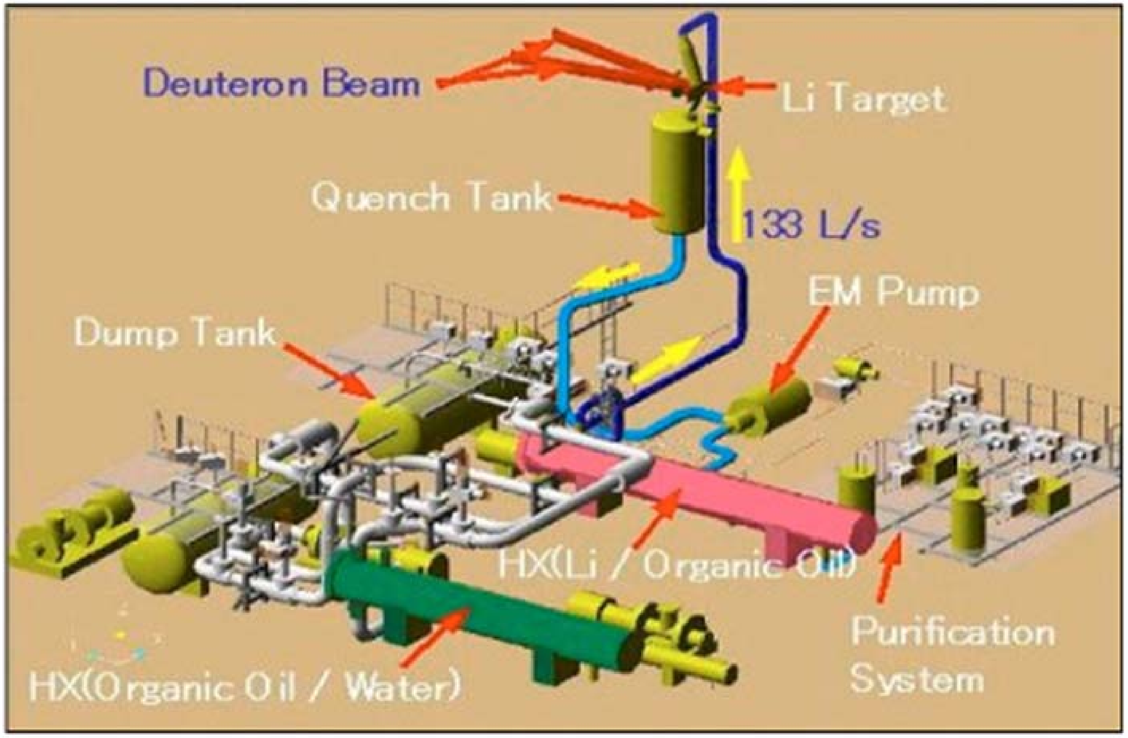
- Accelerator
  - Space Charge, Beam Instabilities
  - Beam Interception (activation)
  - Shape of the Beam Footprint at the Target
- Lithium Target
  - Stability of the Lithium Flow (thermo hydraulic, MHD?)
  - Control of the Purity of the Lithium (erosion, corrosion)
  - Backplate (> 50 dpa/year)

Lithium Target: principle of the loop

Function;

- Obtain stable and high speed liquid Li flow under 10MW Deuterium beam.

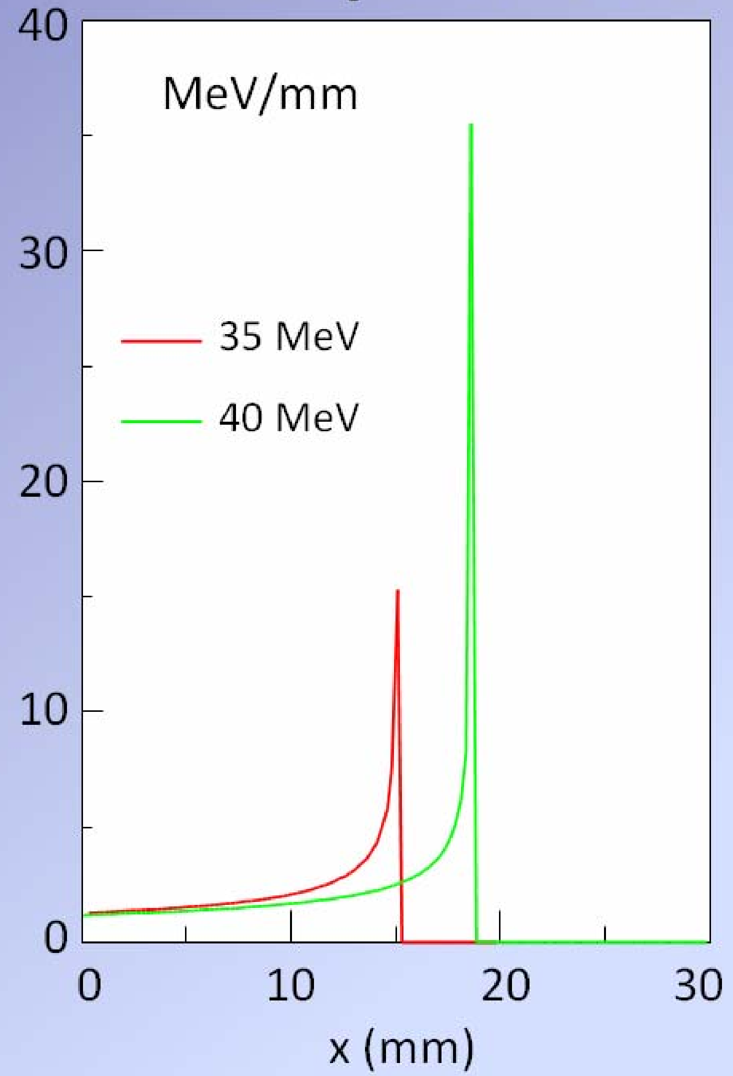




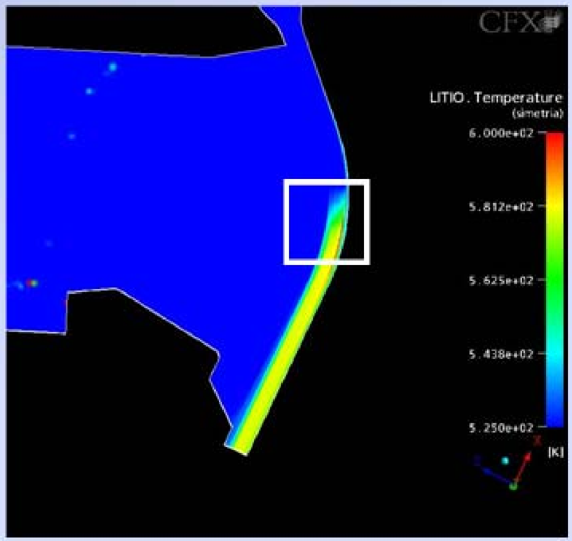
Major Specifications;

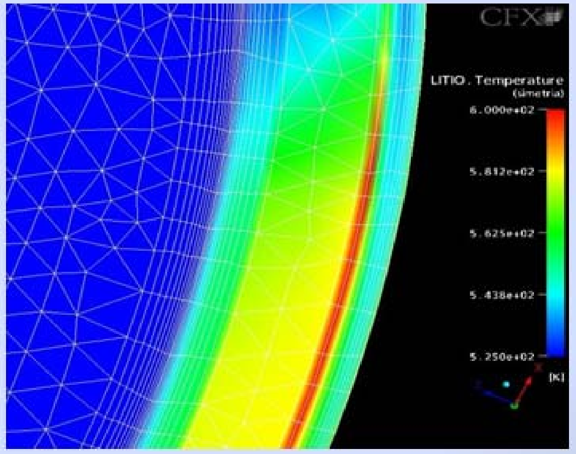
- Heat flux by beam : 1 GW/m^2
- Li flow : 15(range10 - 20) m/s
- Width/Thickness of Li : 26/2.5 cm
- Inlet, Outlet, Peak Li temp. : 250, 300, 450 ℃
- Tritium generation rate : 7g/year
- Impurity contents :10 wppm (C, N, O: each)

Absorption of Deuterons by the Lithium flow



Power deposition (Bragg curve) in the jet along the beam direction at different deuteron energies



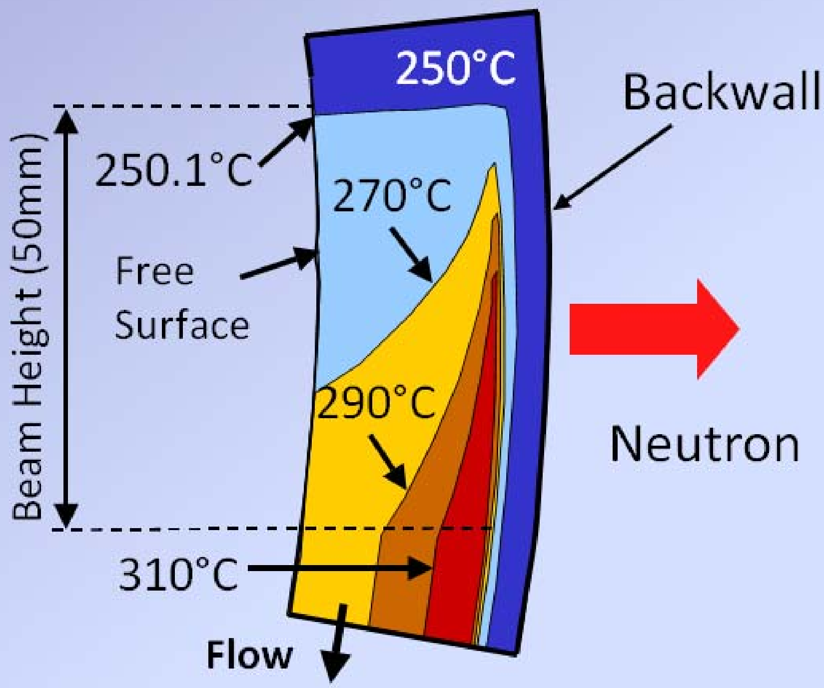


Maximum temperature in the liquid Lithium: 368 °C at 22 cm downstream the nozzle exit

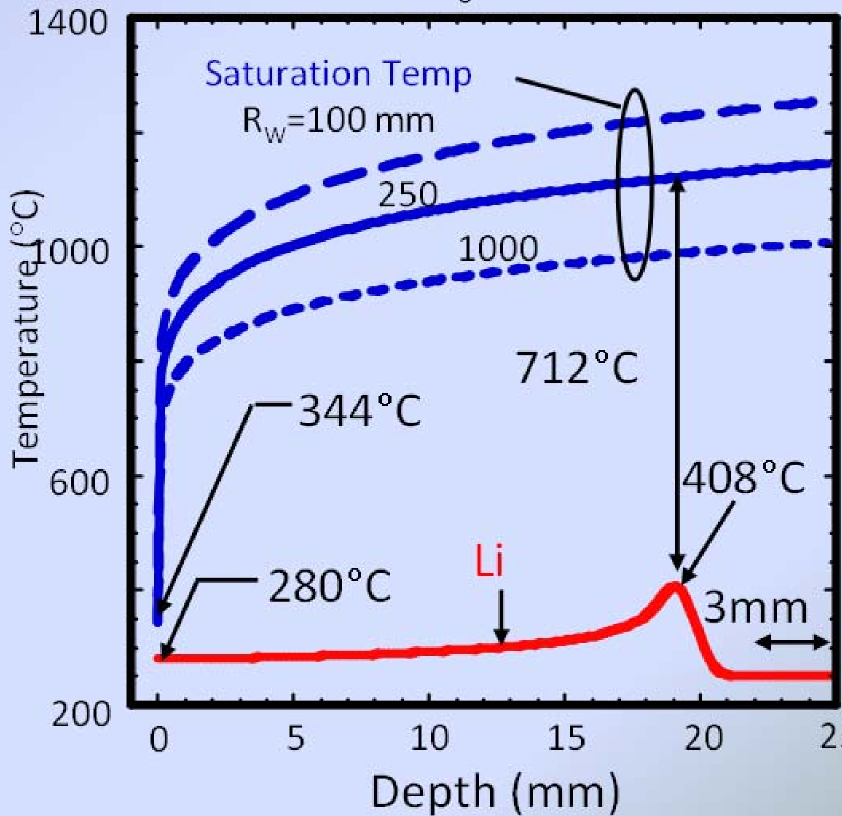
Thermo-Fluid Analysis of Li Flow

Centrifugal force by concave backplate increases saturation temperature around 1000 °C in Li flow

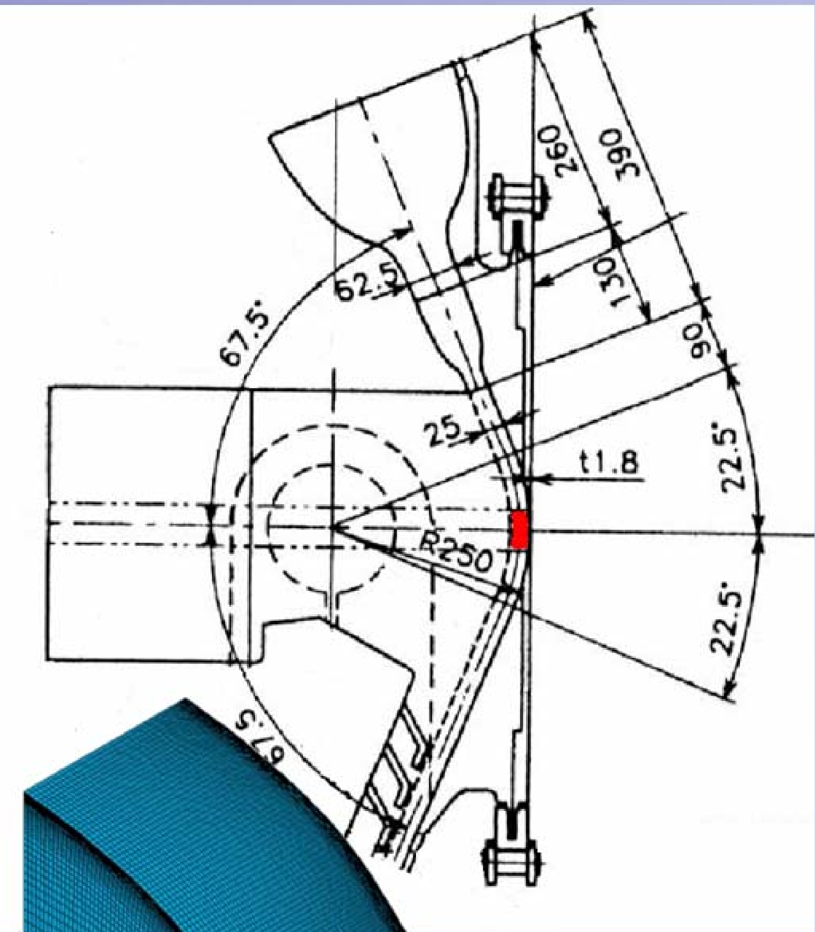
Contour of Li temperature in beam heated region (T_{in} = 250°C)

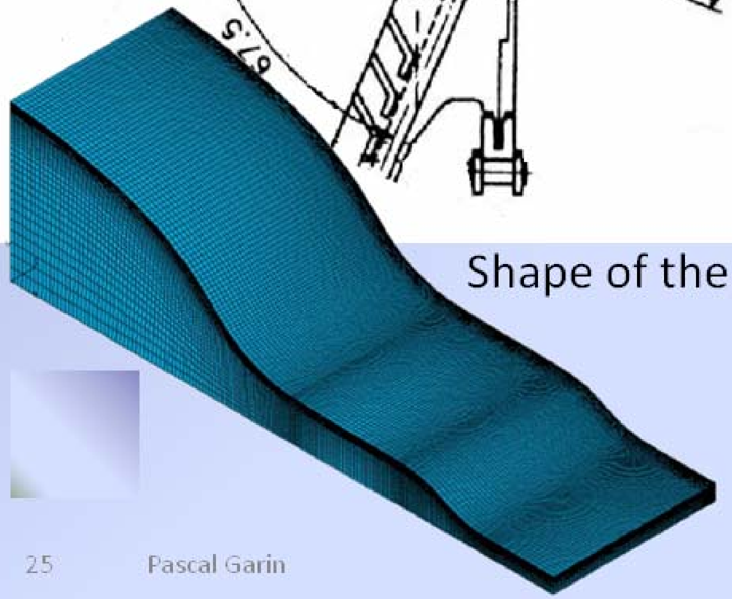


Temperatures Distribution in Li Flow (U_0 = 20 m/s)

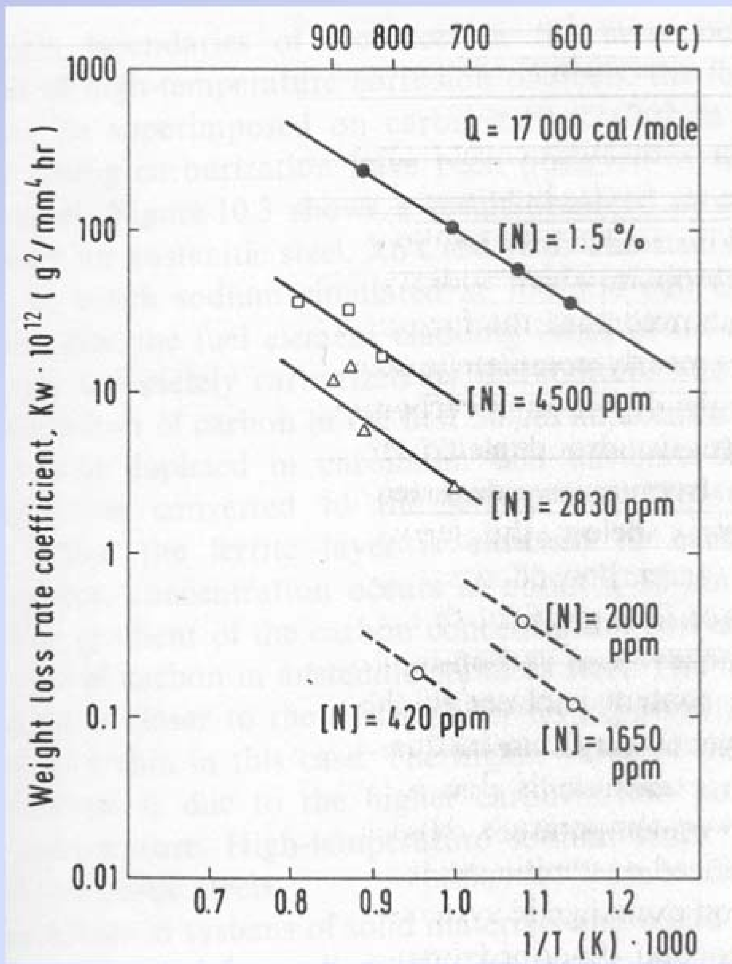


Optimisation of the Lithium Flow





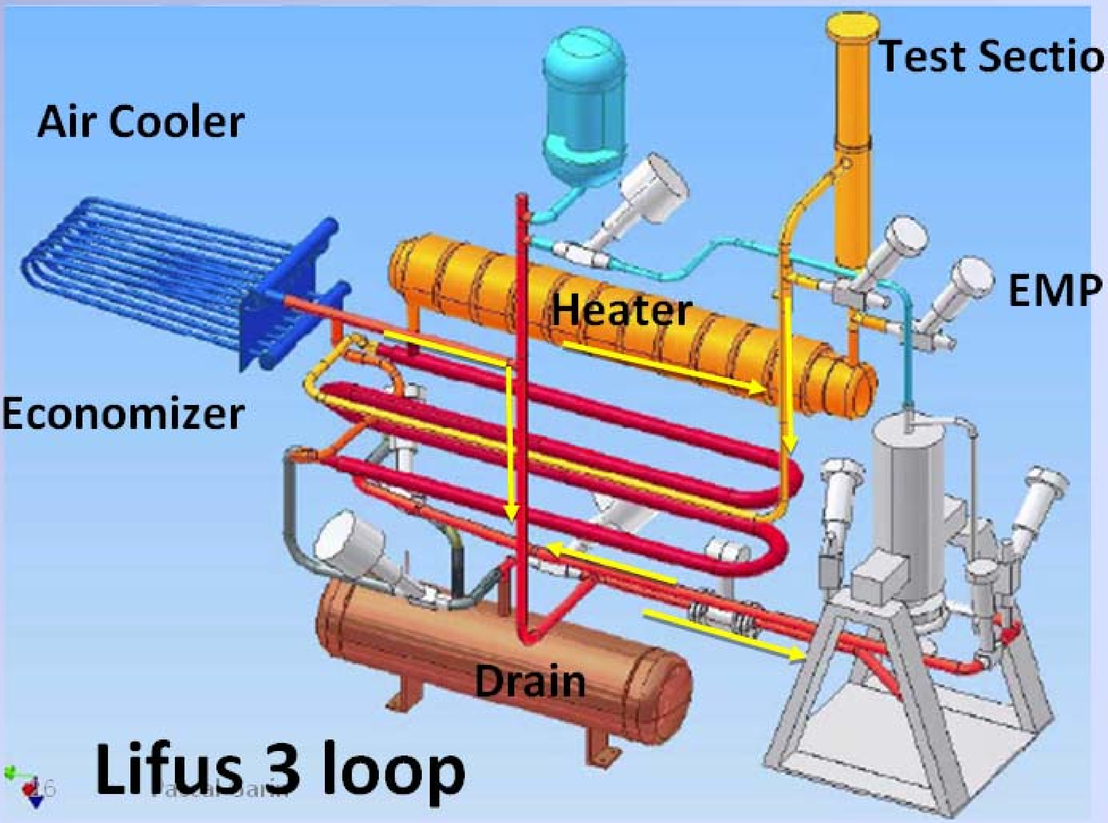
Shape of the nozzle



Influence of nitrogen content in lithium on the corrosion rate of stainless steels [Borgstedt]

Erosion/Corrosion

- Lifus 3 loop commissioned
- First test of 1,000 hrs with 316L and Eurofer done
- Three traps (cold, Ti –hot, Y-hot) manufactured



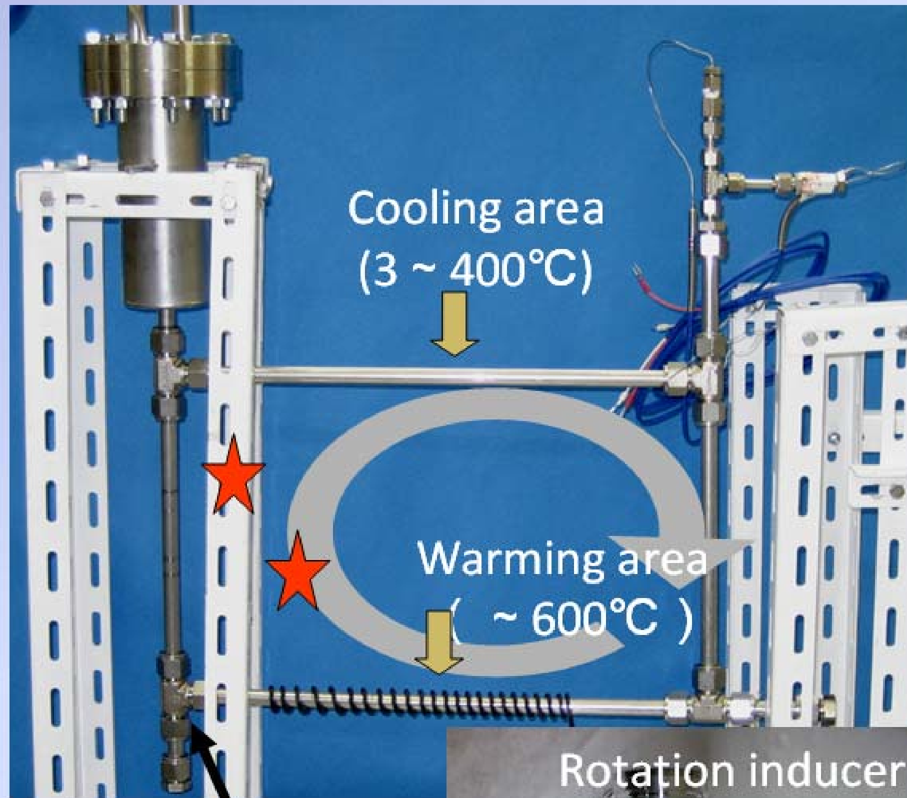
Lifus 3 loop

- Lithium velocity: 16 m/s max.
- Temperature: 450 °C max.
- Temperature difference: 30°C min.
- Lithium content: 42 liters

Nitrogen Gettering

- Fe-7.5%Ti Alloy Plates
- Temperature: ~600°C
- Oxygen getter
- Flow rate: ~4 cm/s

- After 1000 h immersion in the loop, a small weight loss is observed (0.013 $g/m^2.h$)



Er powder as O getter

Fe-Ti alloy is compatible even in flowing lithium with thermal gradient.

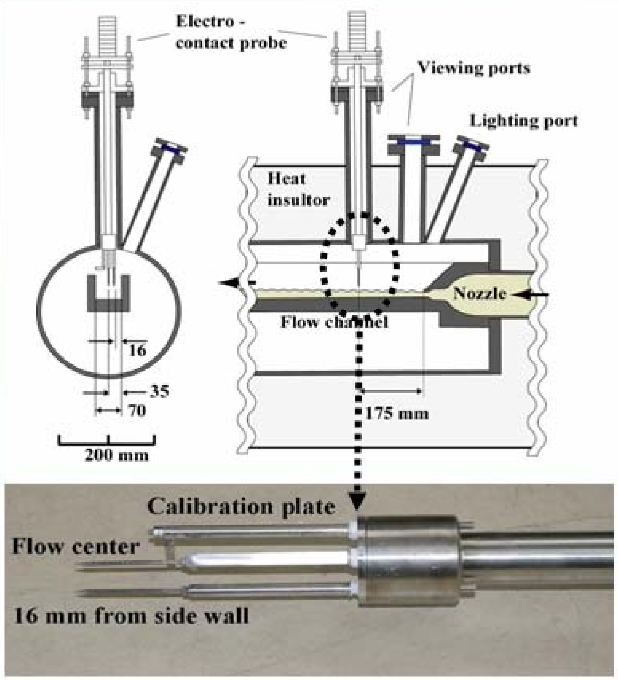
Diagnostics for the Lithium Loop

Li flow experiments

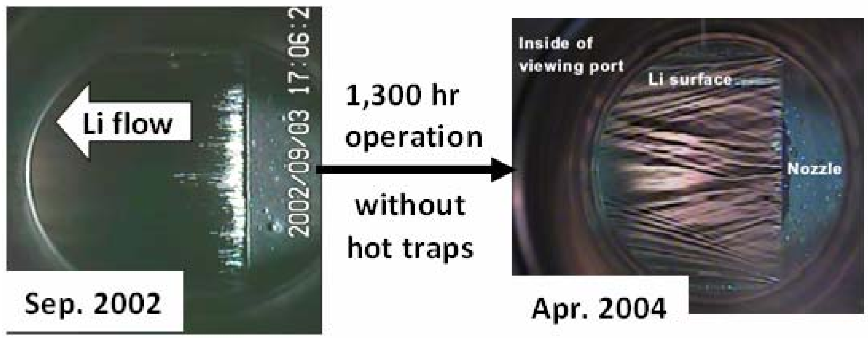
- Contact probe (wave height)
- High-speed video (velocity)
- Quartz crystal (vaporization)
- Hydraulic analysis (wake)

Improvement of Test section

- Replaceable nozzle piece to validate diagnostics on Li flow without erosion/corrosion effects simulating EVEDA/IFMIF
- Extension of viewing ports to cover larger ranges of measurement area and laser reflection angle

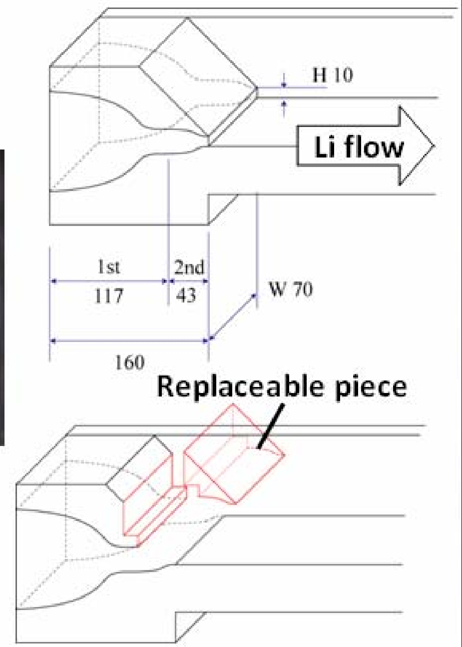


Contact probe



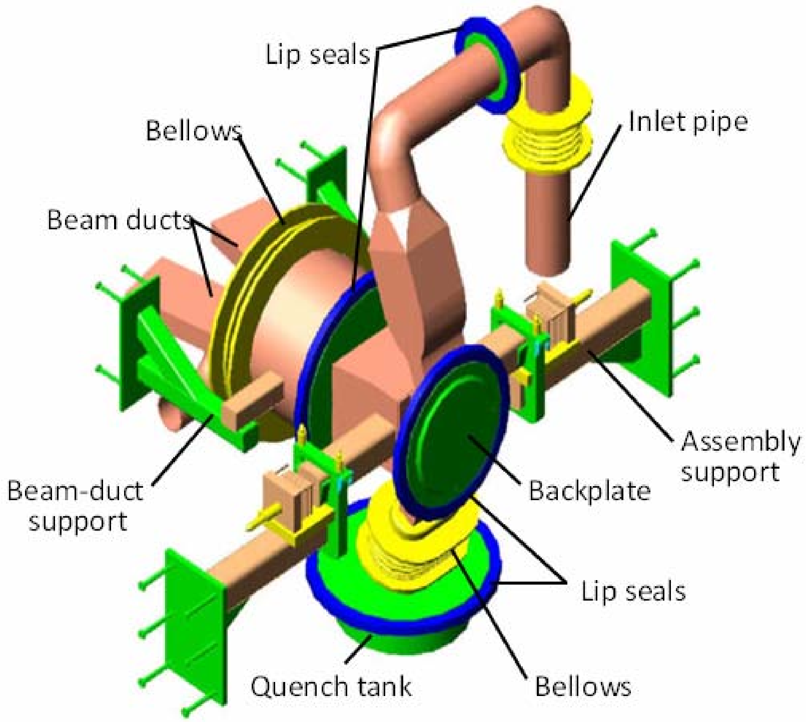
Li free-surfaces at nozzle exit

7 m/s – Use of F82H?

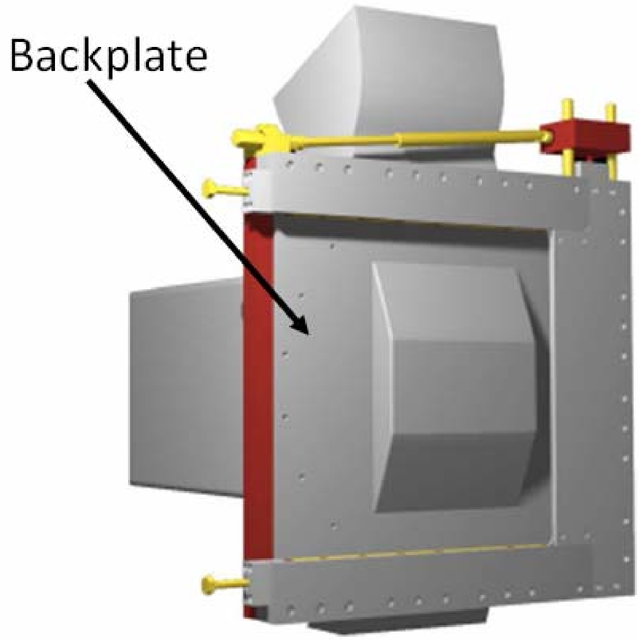


The two options for the Backplate

Cutting/Rewelding JAEA option



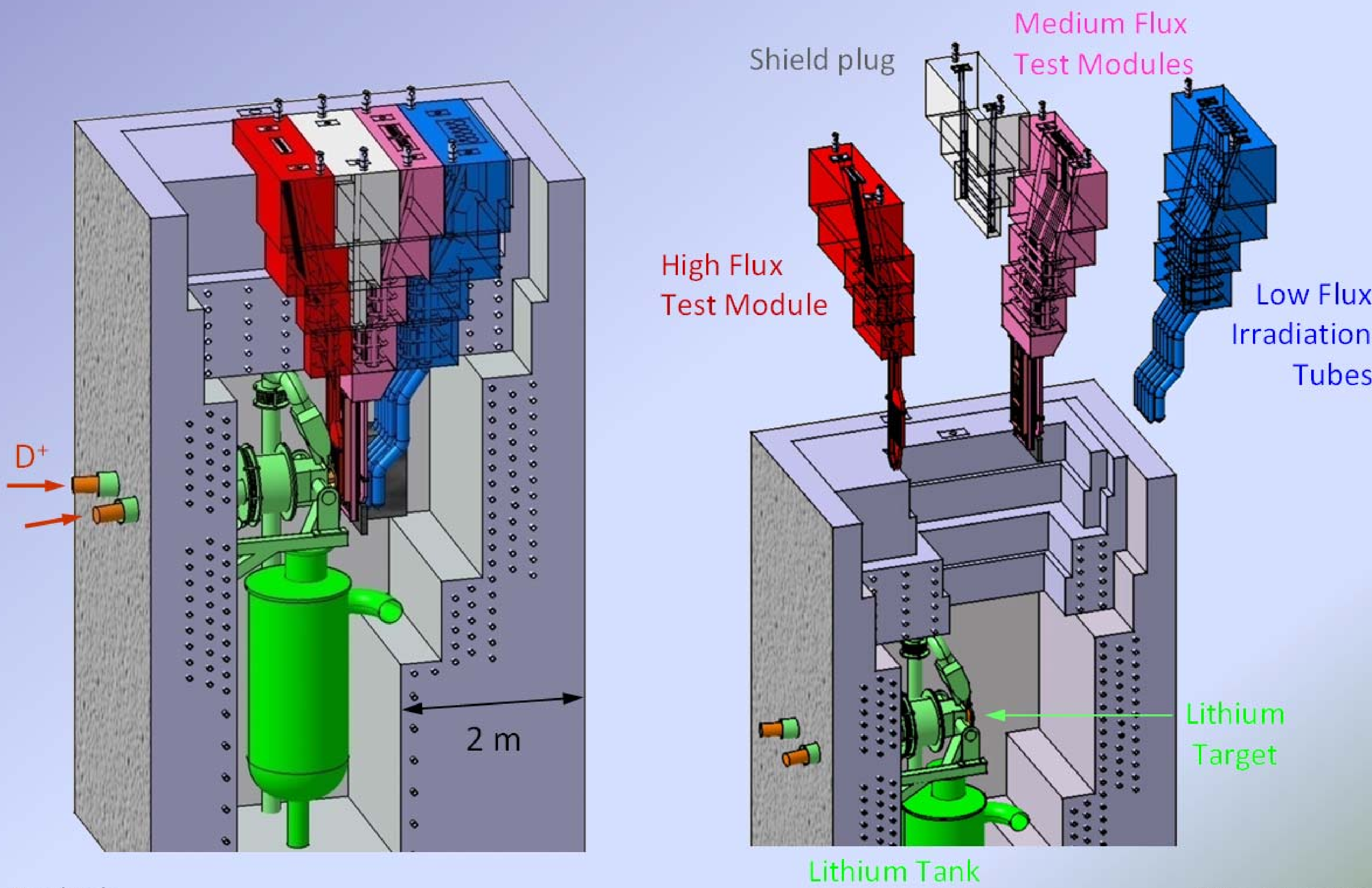
“Bayonet” type, mechanically replaceable option (ENEA)



Some technological challenges of IFMIF

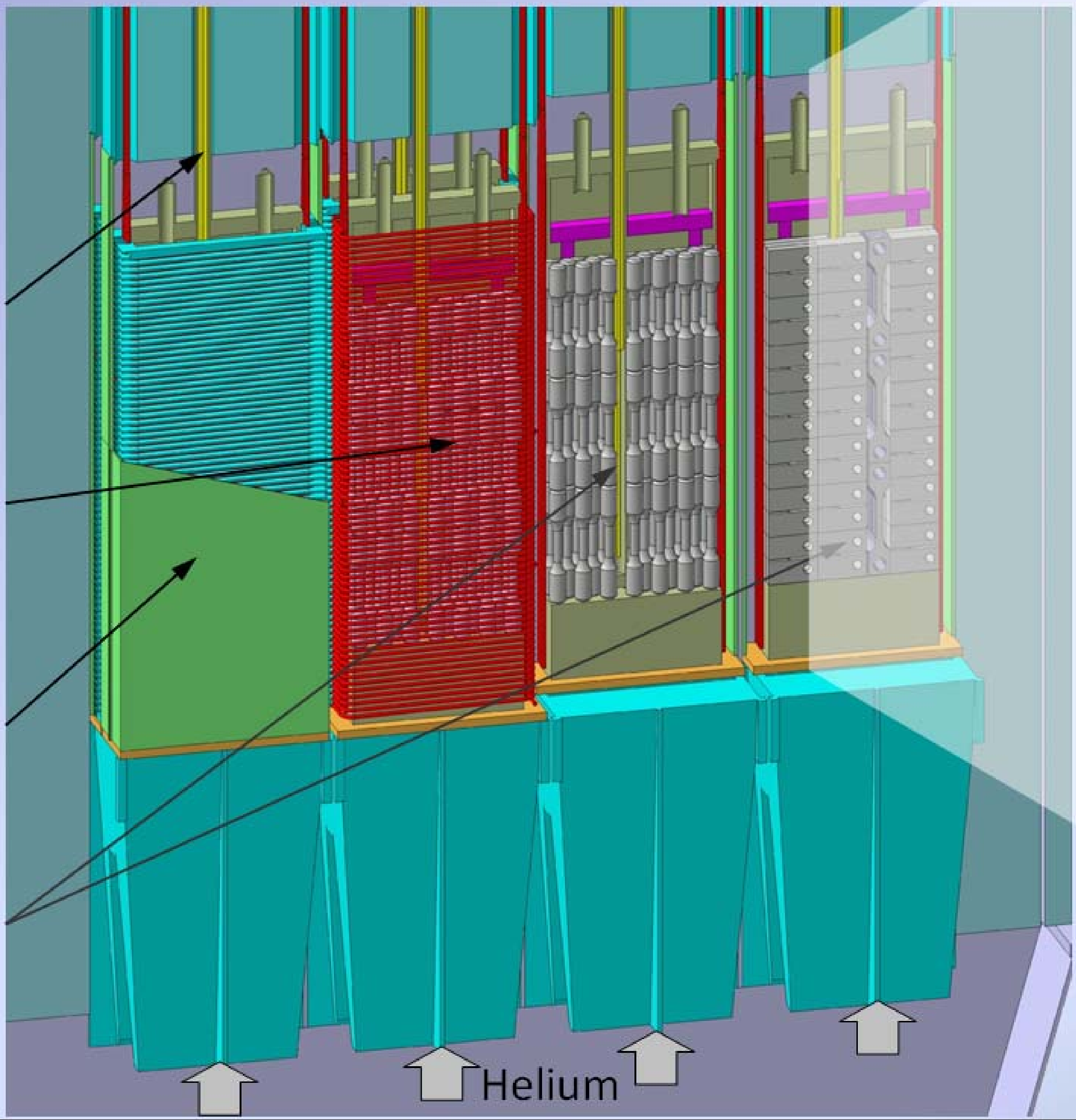
- Accelerator
  - Space Charge, Beam Instabilities
  - Beam Interception (activation)
  - Shape of the Beam Footprint at the Target
- Lithium Target
  - Stability of the Lithium Flow
  - Control of the Purity of the Lithium (erosion, corrosion)
  - Backplate (> 50 dpa/year)
- Test Facilities
  - Knowledge of operating conditions (temperature, neutron flux)
  - Integration and Interfaces

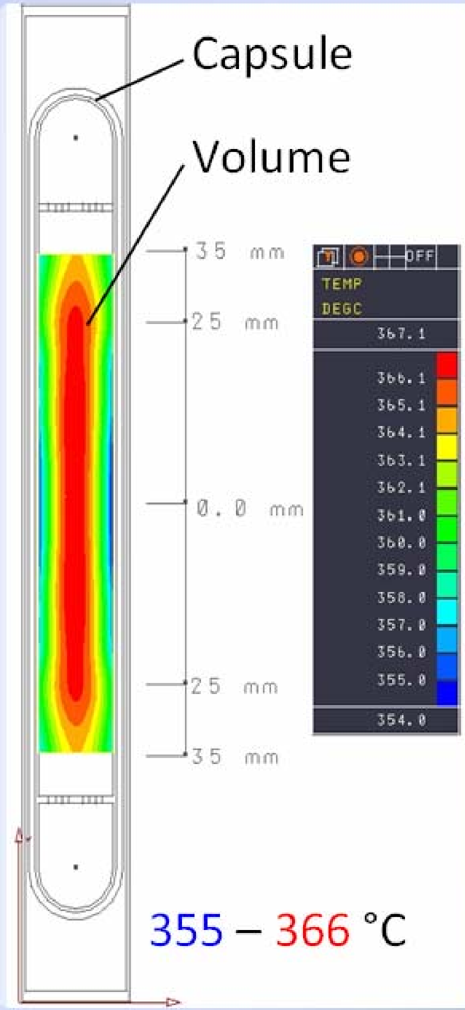
Principle of Test Modules



IFMIF High Flux Test Module

(20 to 50 dpa/full power year)





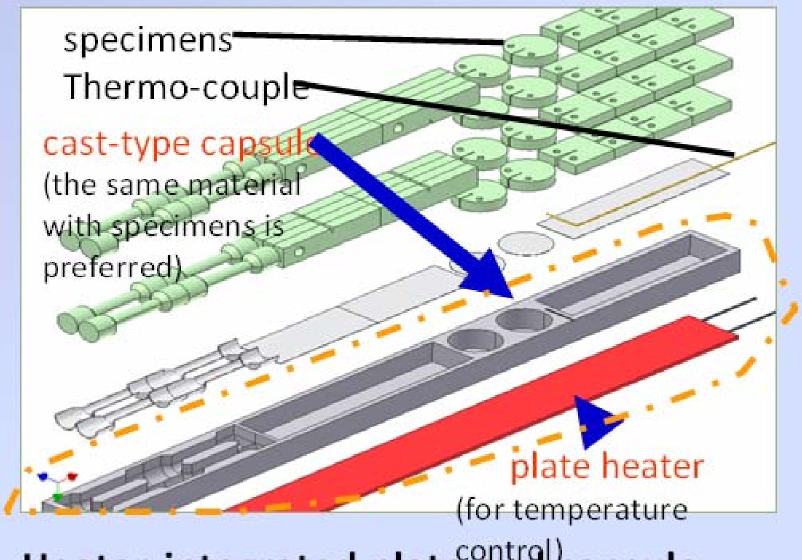
Horizontal Set-up (Japan)

Kyushu University, JAEA (Japan)

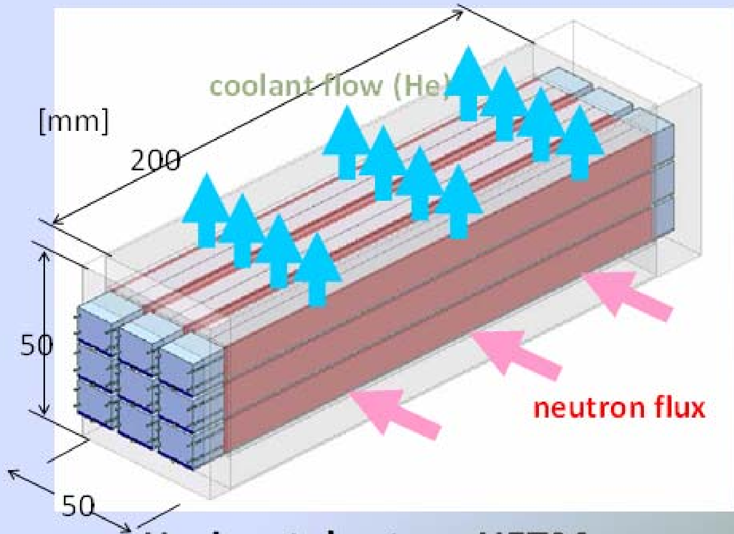
Objective: To provide the full detailed engineering file of HFTM (Horizontal set-up).

Project Plan:

1. Conceptual design of heater-integrated plate and capsule (H-I).
2. Fabrication and basic performance tests of model of H-I
3. Engineering design of prototype of H-I
4. Performance tests of prototype H-I in He loop
5. Engineering design of full scale HFTM

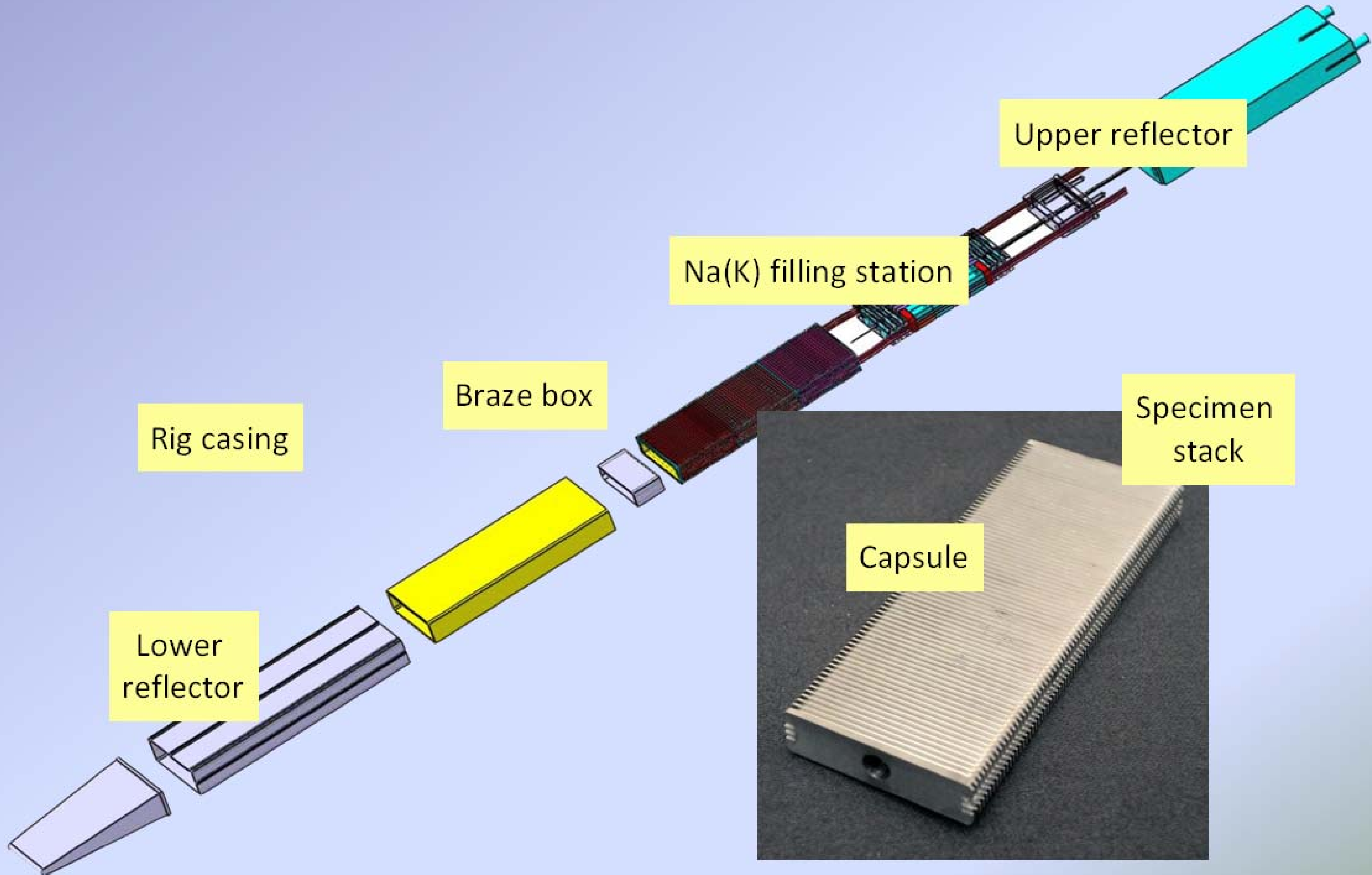


Heater-integrated plate and capsule

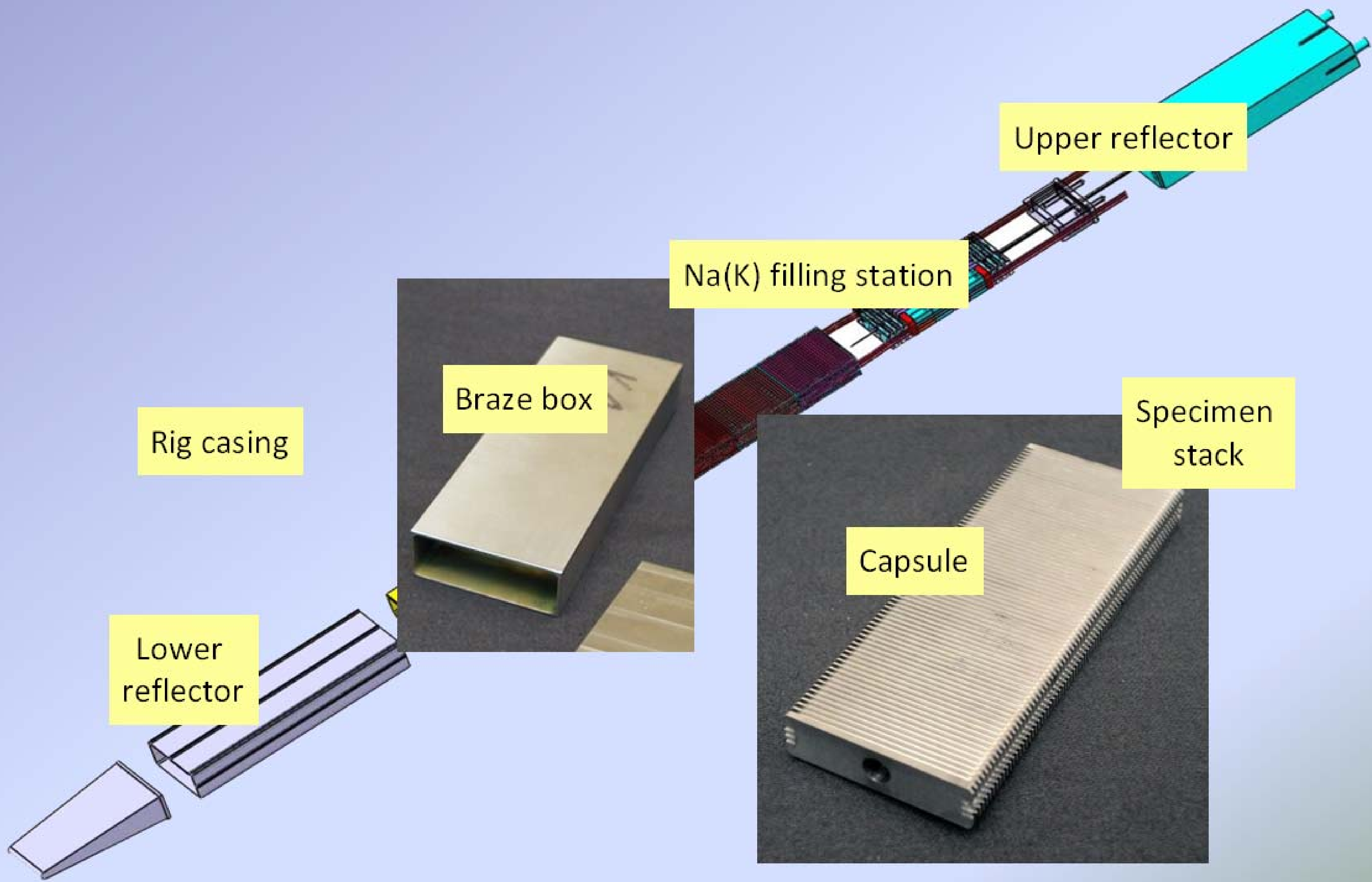


Horizontal set-up HFTM

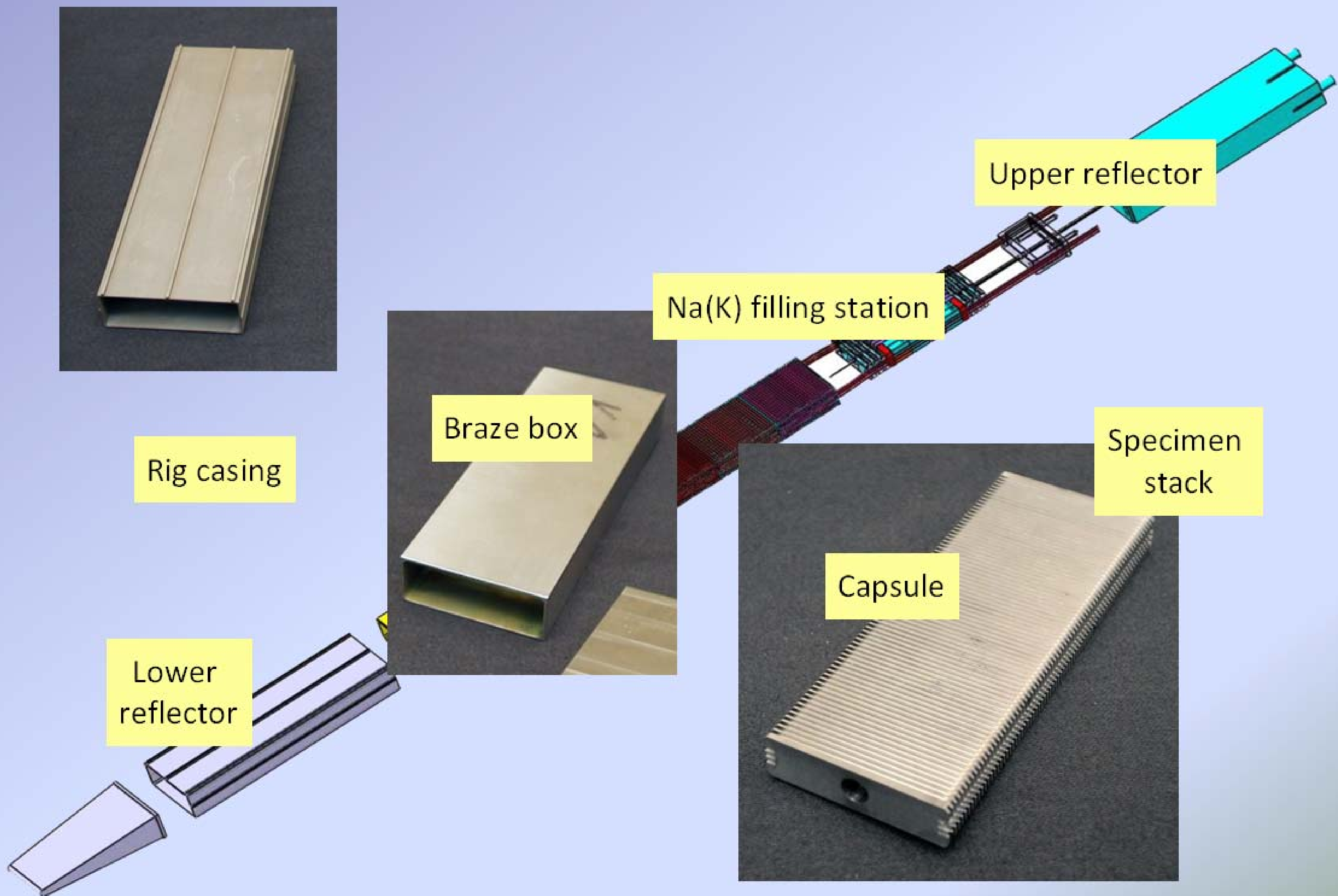
Materials and Manufacturing – Rig



Materials and Manufacturing – Rig



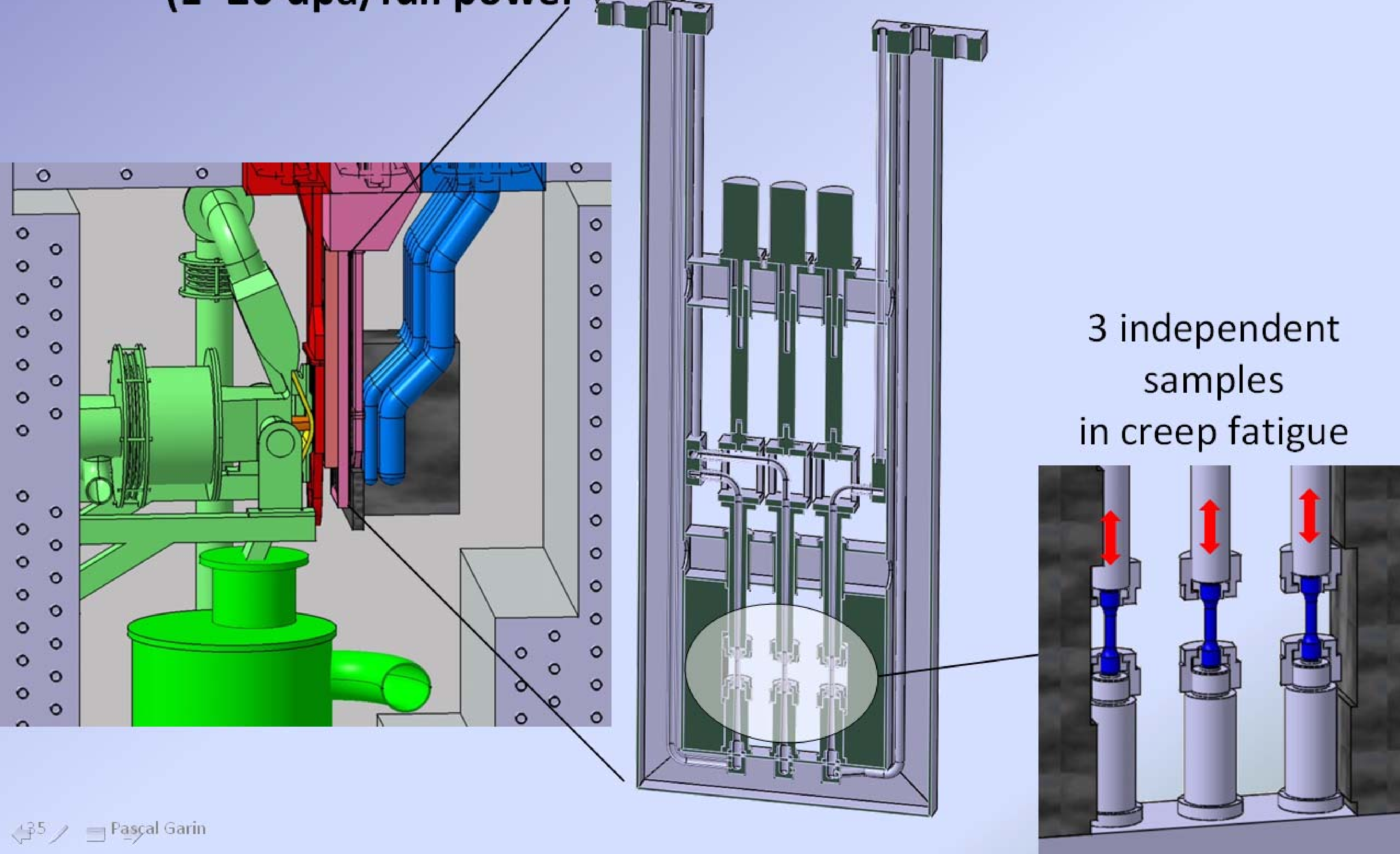
Materials and Manufacturing – Rig



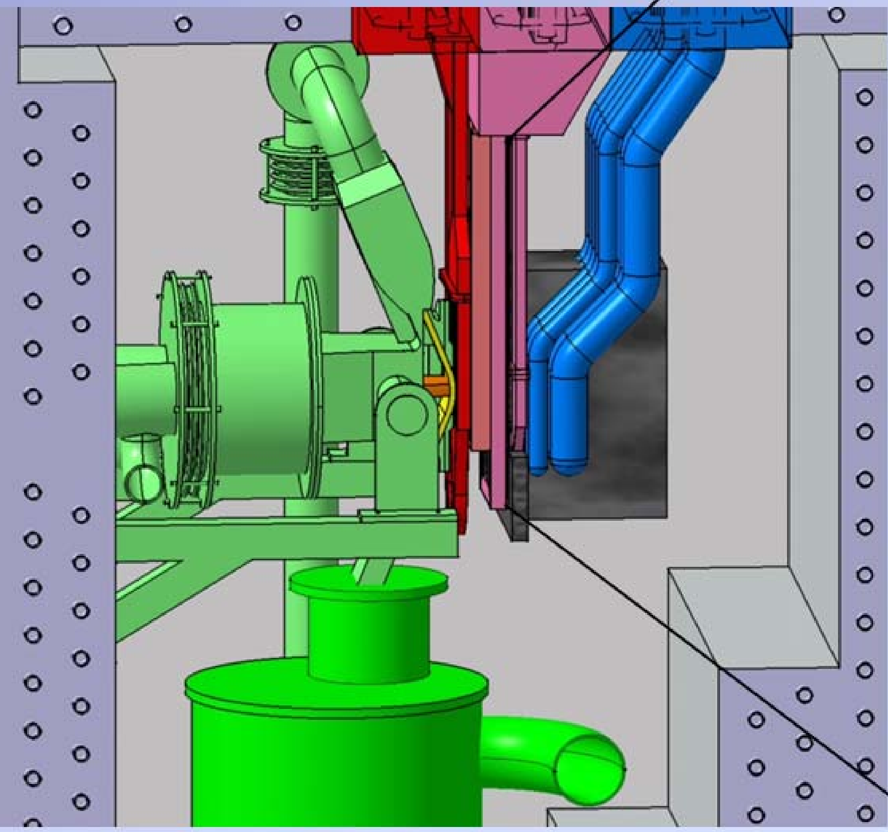
Materials and Manufacturing – Rig

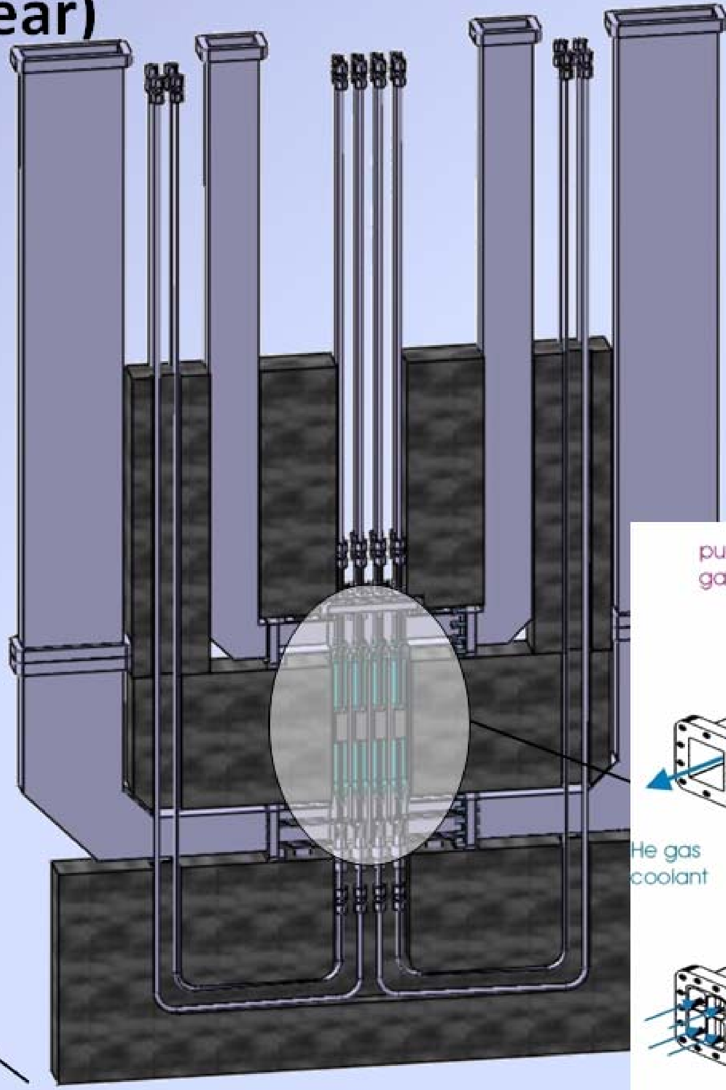
IFMIF Medium Flux Test Module

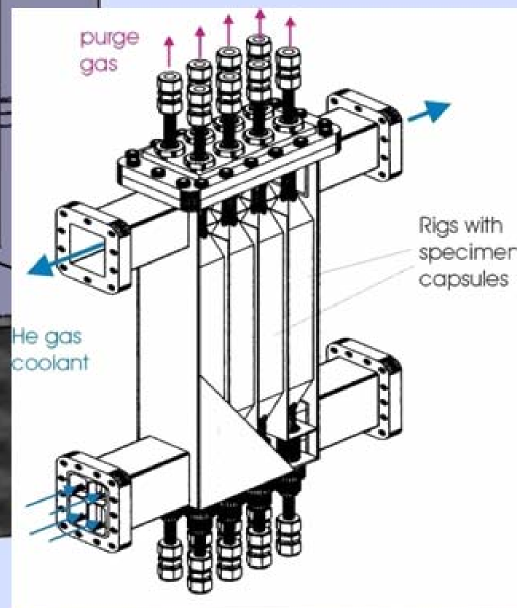
(1–20 dpa/full power year)



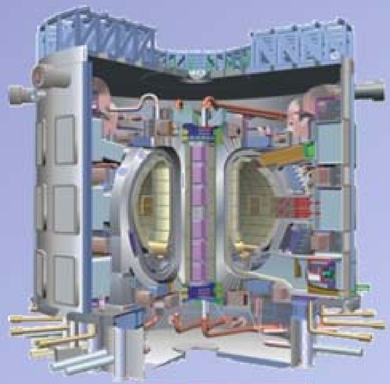
IFMIF Medium Flux Test Module
(1–20 dpa/full power year)



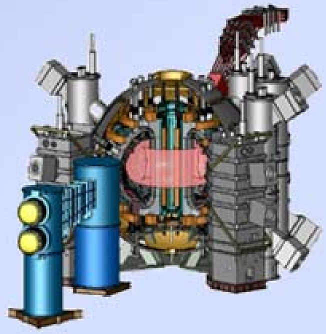




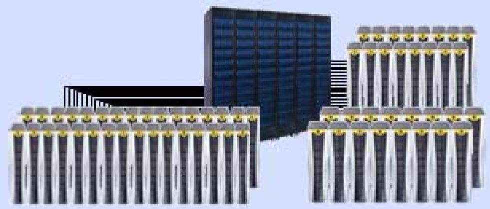
Principles of “Broader Approach”

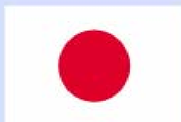


JT60-SA

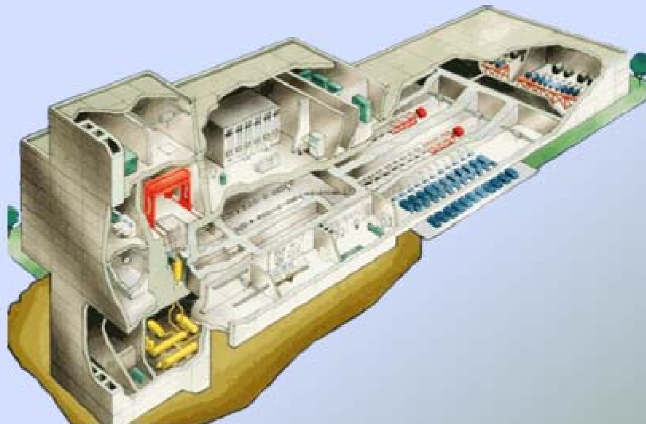


IFERC





IFMIF/EVEDA



Main Contributors to the studies

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ENEA

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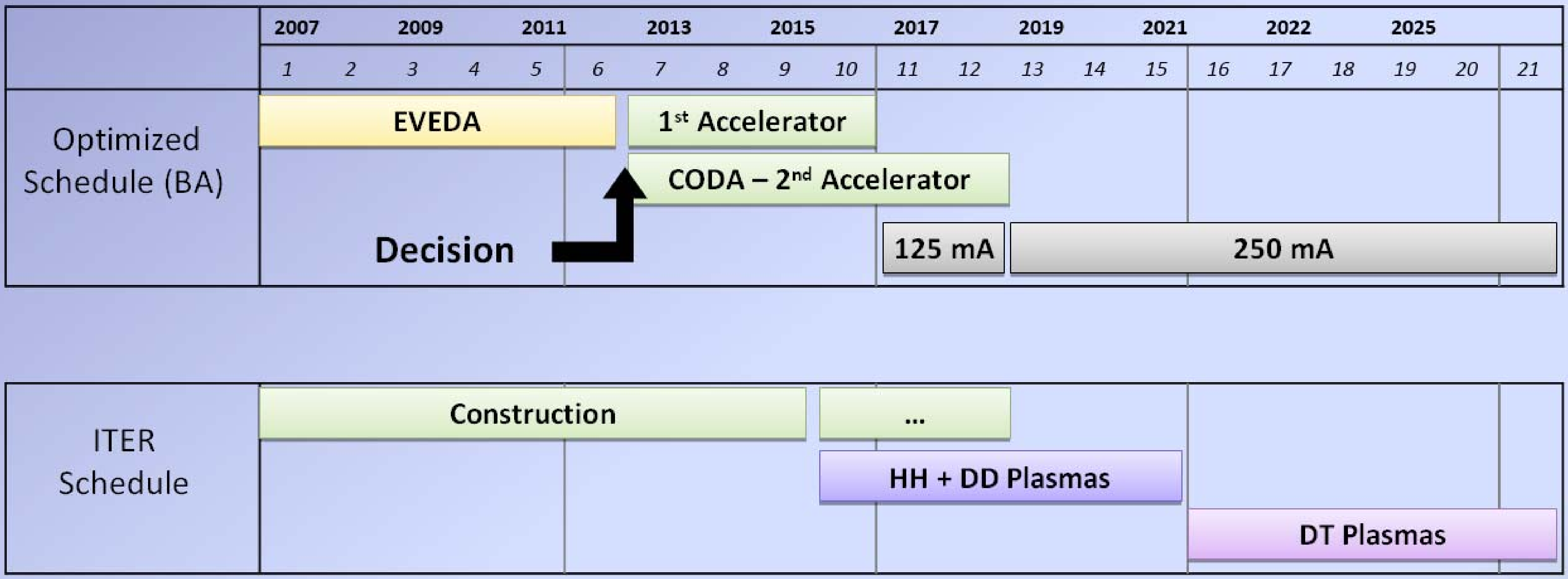
IFMIF and ITER Time Schedules



- Acronyms
  - **EVEDA**: Engineering Validation and Engineering Design Activities
  - **CODA**: Construction, Operation and Decommissioning Activities

Contributions on IFMIF at this conference

- **Beam Dump Design for the IFMIF-EVEDA Accelerator** – B. Brañas, J.M. Gómez, A. Ibarra, D. Iglesias (CIEMAT, Madrid), D. López, J. Sanz (UNED, Madrid)
- **RF Power System for the IFMIF-EVEDA Prototype Accelerator** – I. Kirpitchev, MA. Falagán, A. Ibarra, P. Méndez, M. Weber (CIEMAT, Madrid), A. Mosnier (CEA, Gif-sur-Yvette)
- **A Diagnostics Plate for the IFMIF-EVEDA Accelerator** – I. Podadera Aliseda, B. Brañas, A. Ibarra, C. Oliver (CIEMAT, Madrid), P.-Y. Beauvais, J. Marroncle, A. Mosnier (CEA, Gif-sur-Yvette)
- **Conceptual Design of the Operation Control System for IFMIF-EVEDA Prototype Accelerator** – H. Sakaki (JAEA, Tokai-mura), Y. Okumura (JAEA, Rokkasho-mura)
- **A Beam Raster Scanning Device for IFMIF** – O. Caretta, T.R. Davenne, C.J. Densham (STFC/RAL, Chilton, Didcot, Oxon), E. Surrey (EFDA-JET, Abingdon, Oxon)
- **High Energy Beam Transport Line for the IFMIF-EVEDA Accelerator** – C. Oliver, B. Brañas, A. Ibarra, I. Podadera Aliseda (CIEMAT, Madrid), N. Chauvin, A. Mosnier, D. Uriot (CEA, Gif-sur-Yvette)
- **Design and Beam Dynamics Simulations of Superconducting Half-wave Resonators for IFMIF Linac** – N. Chauvin, A. Mosnier, P.A.P. Nghiem, D. Uriot (CEA, Gif-sur-Yvette)
- **KONUS Dynamics and H-mode DTL Structures for EUROTRANS and IFMIF** – C. Zhang, M. Busch, H. Klein, H. Podlech, U. Ratzinger, R. Tiede (IAP, Frankfurt am Main)
- **Conceptual Design of an RF-input Coupler for the IFMIF RFQ Linac** – S. Maebara, S. Moriyama (JAEA, Tokai), Y. Okumura (JAEA, Rokkasho), T. Fujii (JAEA, Naka)
- **Beam Dynamics of the IFMIF-EVEDA RFQ** – M. Comunian, A. Pisent (INFN/LNL, Legnaro, Padova), E. Fagotti, P.A. Posocco (Consorzio RFX, Padova; INFN/LNL, Legnaro, Padova)
- **The IFMIF-EVEDA Accelerator Activities** – A. Mosnier (CEA, Gif-sur-Yvette), A. Ibarra (CIEMAT, Madrid), A. Facco (INFN/LNL, Legnaro, Padova)
- **IFMIF-EVEDA RFQ Design** – A. Pisent, M. Comunian, A. Palmieri (INFN/LNL, Legnaro, Padova), E. Fagotti, P.A. Posocco (Consorzio RFX, Padova; INFN/LNL, Legnaro, Padova), A. Pepato (INFN- Sez. di Padova, Padova), F. Grespan (INFN/LNL, Legnaro, Padova; Università degli Studi di Milano, Milano)
- **The Superconducting CH-Linac for IFMIF and Plans for EVEDA** – H. Podlech, A. Bechtold, M. Busch, F. Dziuba, H. Klein, H. Liebermann, U. Ratzinger, R. Tiede, C. Zhang (IAP, Frankfurt am Main)