FUSION FOR ENERGY | Big Science Business Forum 2022

Industrial Opportunities for IFMIF-DONES

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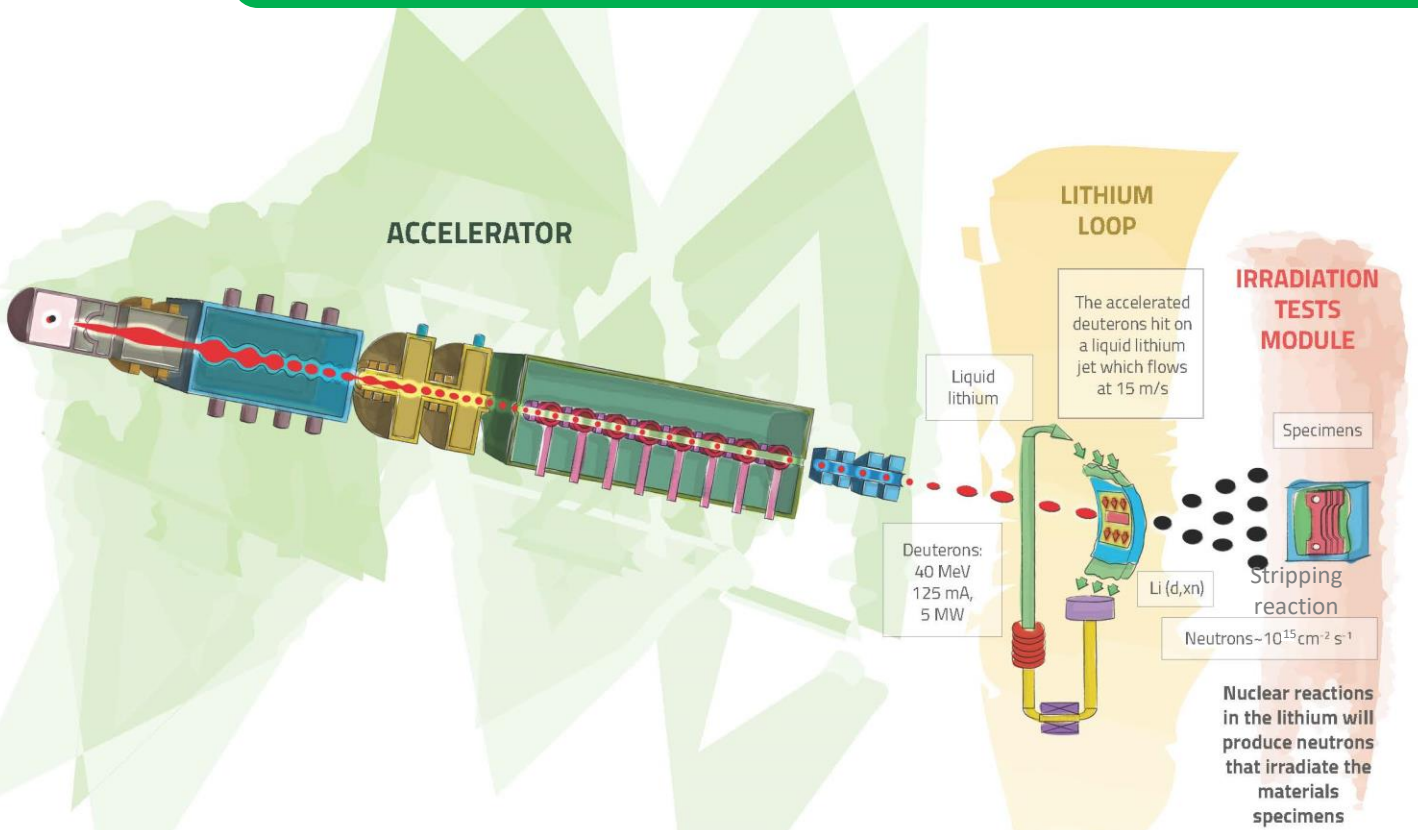
F4E DONES Coordinator

5 October 2022

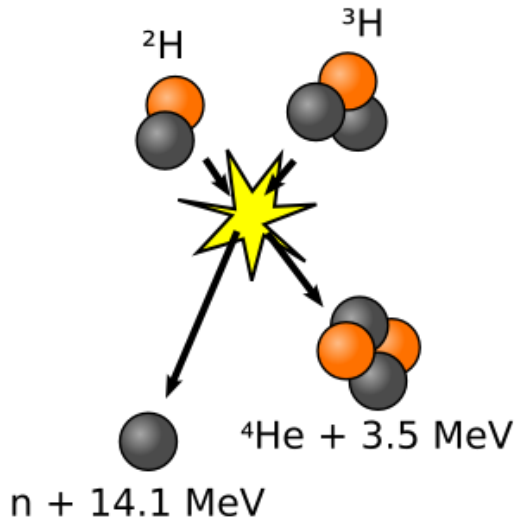
What is IFMIF/DONES?

An accelerator based fusion-like neutron source to be used for the characterization of the materials to be used in the DEMO Reactor



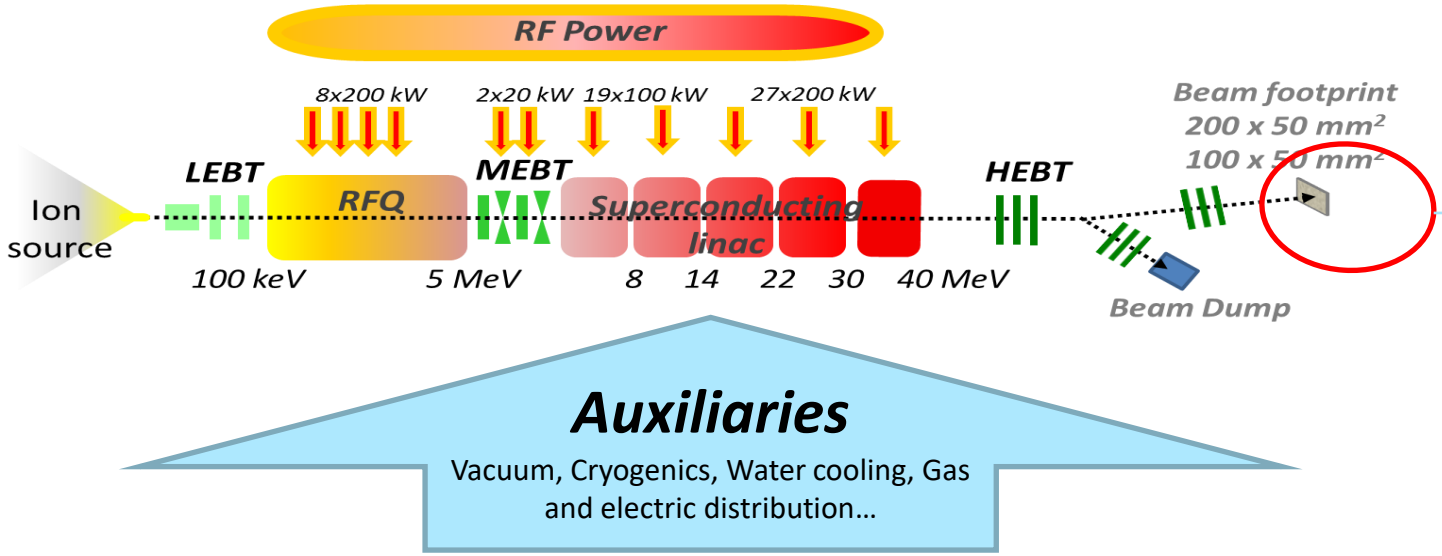
The first wall of the fusion reactor vessel will see 14.1 MeV neutrons

Due of DT reactions

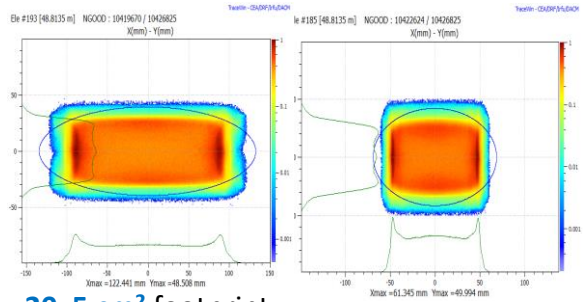


IFMIF/DONES Accelerator

175 MHz Solid State RF source



Beam footprint @ target



20x5 cm² footprint (reference)

10x5 cm² footprint (optional)

Auxiliaries

Vacuum, Cryogenics, Water cooling, Gas and electric distribution…

D+ CW 175 MHz SC LINAC

125 mA / 40 MeV → **5 MW**

Total length of ~**100 m**

Windowless liquid **Li target**

Hands-on **maintenance (Beam Loss<1 W/m)**

Remote Handling @ several components

Safety system with nuclear credit

Staged comissioning in five years (Injector CW / RFQ @10-20%
/SRF LINAC @ 1% / HEBT@ Target)

CW operation with 87% availability

IFMIF/DONES Accelerator Systems Layout

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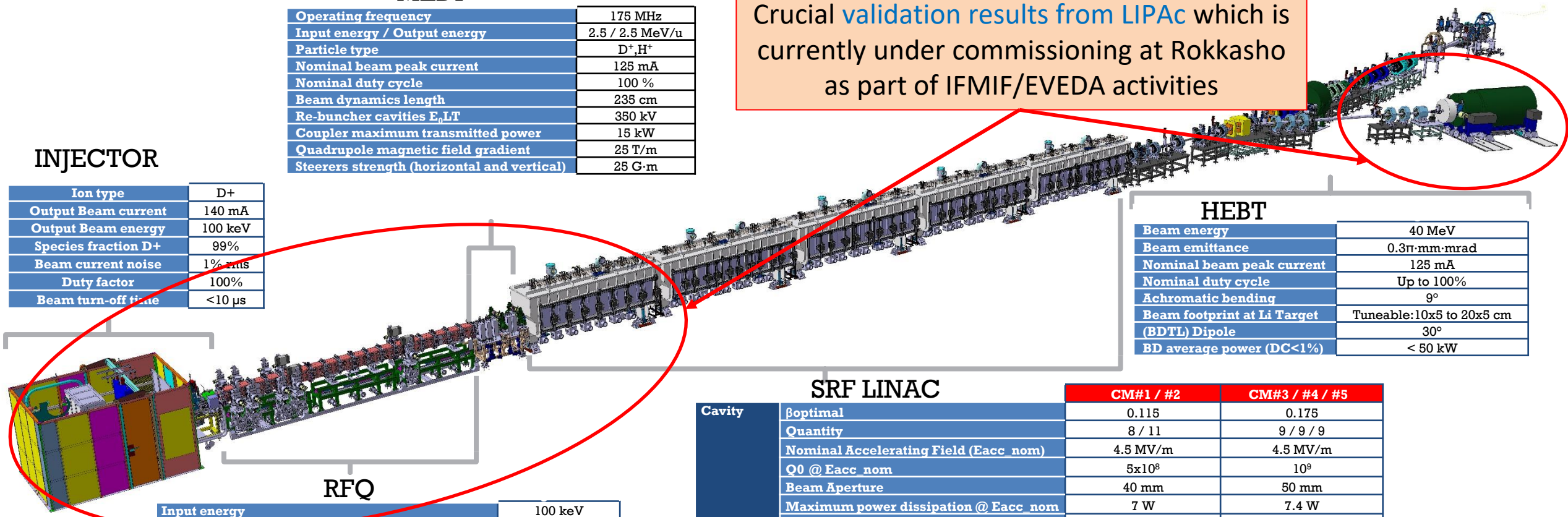
Crucial validation results from LIPAc which is currently under commissioning at Rokkasho as part of IFMIF/EVEDA activities



INJECTOR

Ion type	D+
Output Beam current	140 mA
Output Beam energy	100 keV
Species fraction D+	99%
Beam current noise	1% rms
Duty factor	100%
Beam turn-off time	<10 μs

MEBT

Operating frequency	175 MHz
Input energy / Output energy	2.5 / 2.5 MeV/u
Particle type	D^+, H^+
Nominal beam peak current	125 mA
Nominal duty cycle	100 %
Beam dynamics length	235 cm
Re-buncher cavities E_0LT	350 kV
Coupler maximum transmitted power	15 kW
Quadrupole magnetic field gradient	25 T/m
Steerers strength (horizontal and vertical)	25 G·m

RFQ

Input energy	100 keV
Output energy 5 MeV	5 MeV
Input D+ current	130 mA
Output D+ current	125 mA
RF Frequency	175 MHz
Max surface field	< 25.2 MV/m
Output rms emittance (norm.) transv.	< 0.30 π mm mrad
Output rms emittance longitudinal	<0.2 MeV deg
Duty factor	100%
Transverse zero current phase advance RFQ end	< 220 deg/m
Longitudinal zero current phase advance RFQ end	< 90 deg/m

HEBT

Beam energy	40 MeV
Beam emittance	0.3π·mm·mrad
Nominal beam peak current	125 mA
Nominal duty cycle	Up to 100%
Achromatic bending	9°
Beam footprint at Li Target	Tuneable:10x5 to 20x5 cm
(BDTL) Dipole	30°
BD average power (DC<1%)	< 50 kW

SRF LINAC

		CM#1 / #2	CM#3 / #4 / #5
Cavity	βoptimal	0.115	0.175
	Quantity	8 / 11	9 / 9 / 9
	Nominal Accelerating Field (Eacc_nom)	4.5 MV/m	4.5 MV/m
	Q0 @ Eacc_nom	$5x10^8$	10^9
	Beam Aperture	40 mm	50 mm
	Maximum power dissipation @ Eacc_nom	7 W	7.4 W
	Frequency at cold during vertical test (cavity untuned, no power coupler)	175.016 - 175.060 MHz	175.016 - 175.060 MHz
	Tuning Range	- 50 kHz	- 50 kHz
	Loaded cavity bandwidth	2.7 kHz	-
	Working Temperature	4.45 K	4.45 K
Power Coupler	Transmitted Power	100 kW CW	200 kW CW
	Qext	6.3x104	-
Solenoid	Magnetic field Bz on axis	6 T	6 T
	Sterrers Field	3.5 mT.m	3.5 mT.m
	Quantity	8 / 6	5 / 5 / 5
	Working Temperature	4.45 K	4.45 K

Linear IFMIF Prototype Accelerator (LIPAc)

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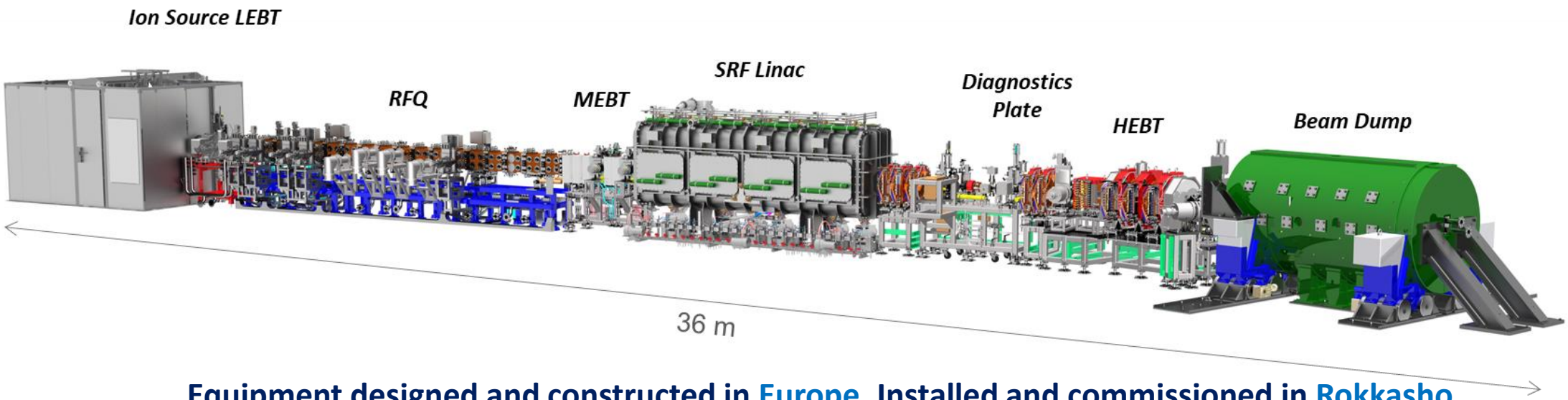
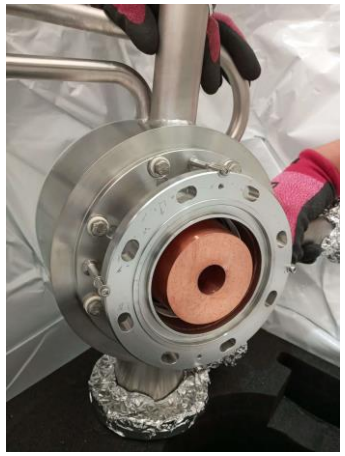
Japan-Europe scientific collaboration



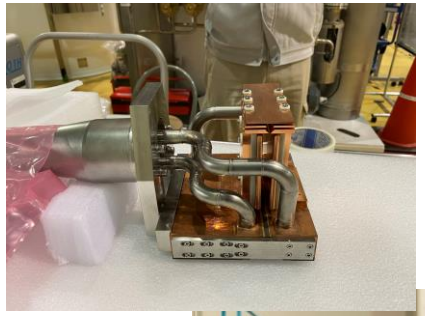
Equipment designed and constructed in Europe, Installed and commissioned in Rokkasho

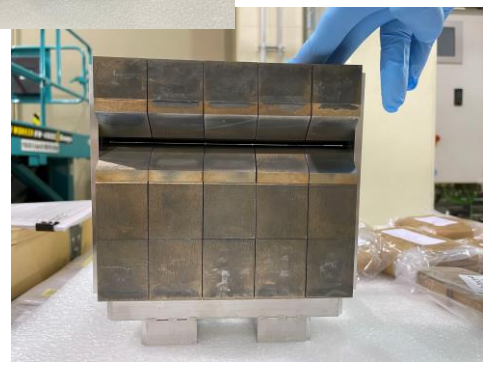
Injector

In operation since 2014, enhancement activities on going:

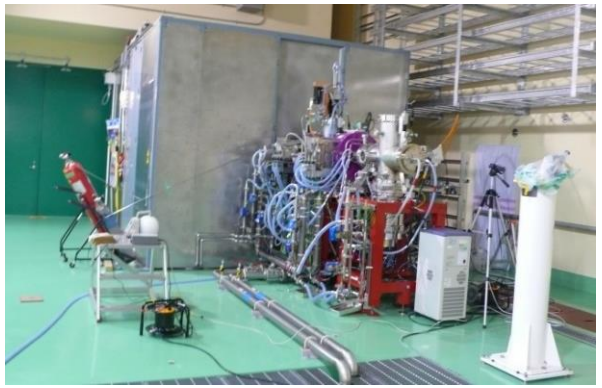


LEBT/RFQ Interface

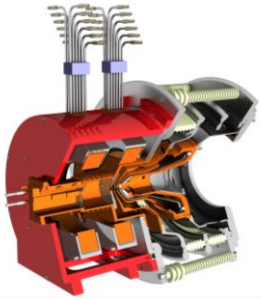


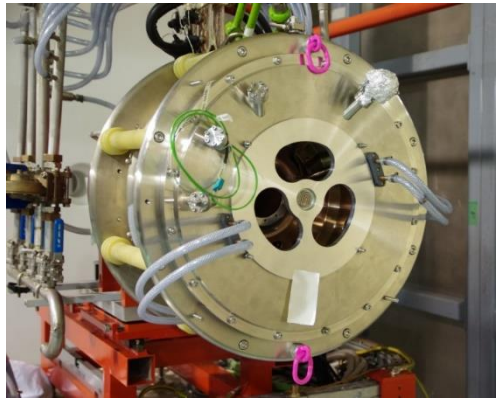


Emittance Measure Unit



Injector at Rokkasho

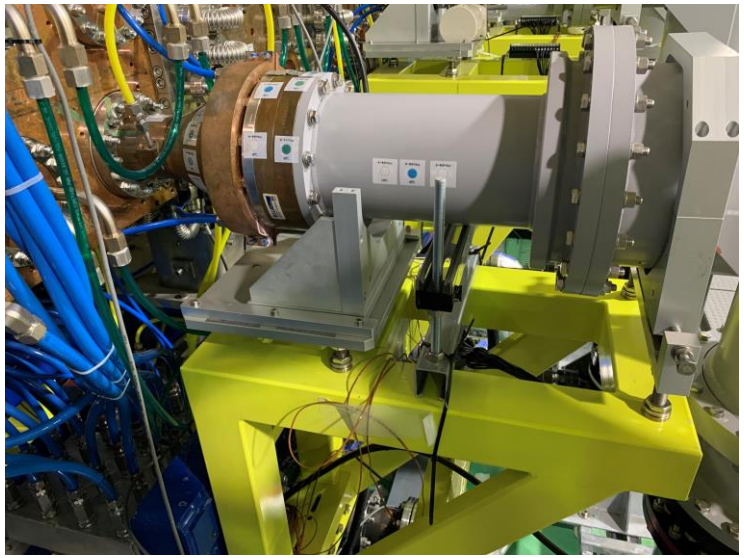




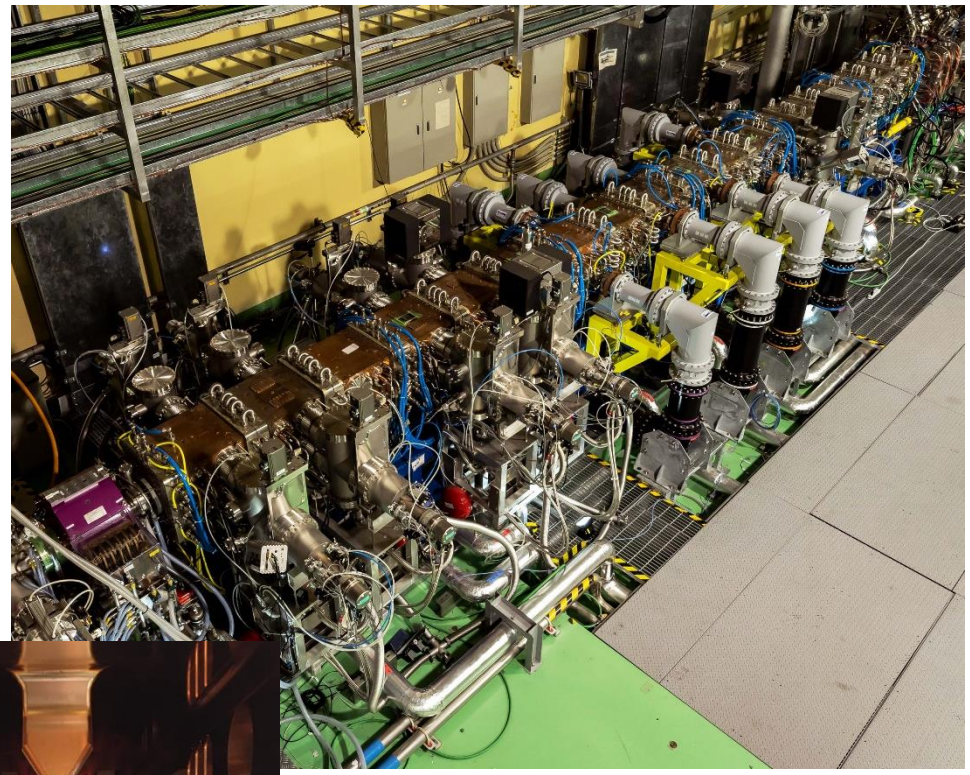
Accelerator Column

RFQ

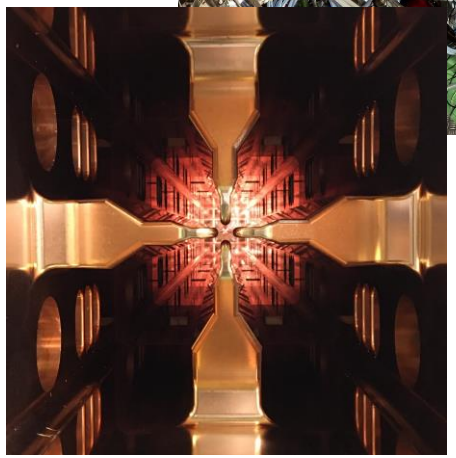
- Challenging manufacturing in 3D: machining accuracy of 0.05 mm achieved after brazing,
- Engineering validation on going…. Design validation related to the beam transmission in July 2019.



RFQ Coupler



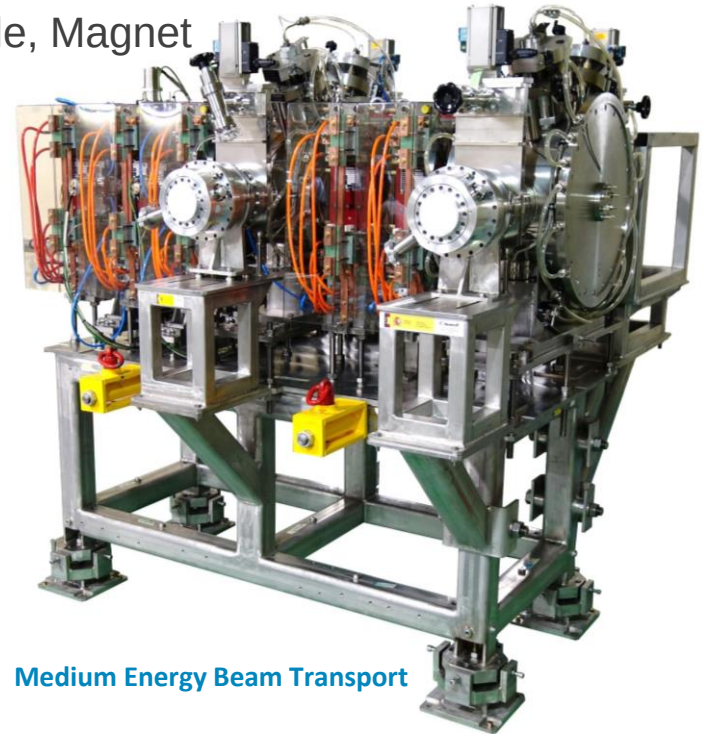
Top view of the RFQ section



Cross section of the RFQ

MEBT – HEBT – Beam Dump

- Engineering validation ongoing
- Main elements:
  - Quadrupole, Triplet, Dipole, Magnet
  - Buncher Cavities,
  - Scrapper,
  - Collimator.



Medium Energy Beam Transport

High Energy Beam Transport

Beam Dump

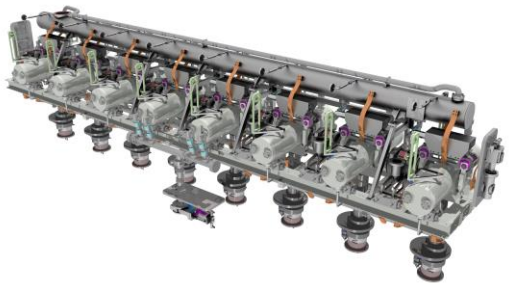
Superconducting Radio Frequency LINAC

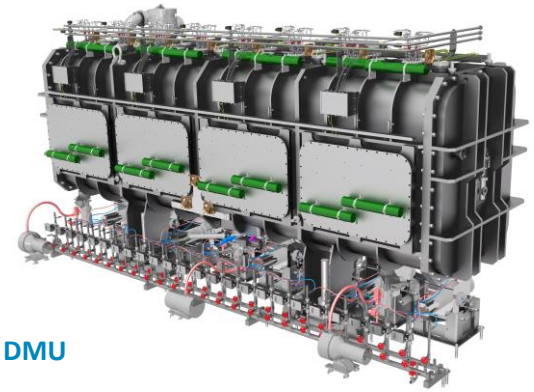
Assembly performed on site due to the transport constraints and the fragility of the whole assembled

- Main elements:
  - Cavities,
  - Solenoids,
  - Couplers,
  - Cryostat

Cryostat

Clean Room





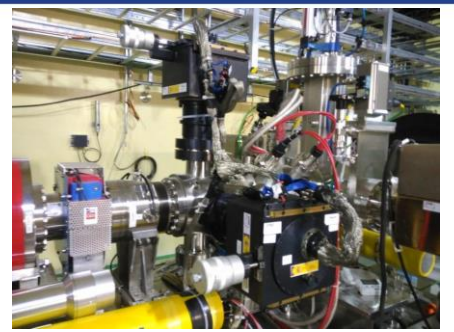
SRF LINAc DMU

Solenoids

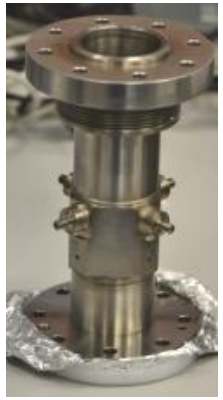
Assembly @ Rokkasho

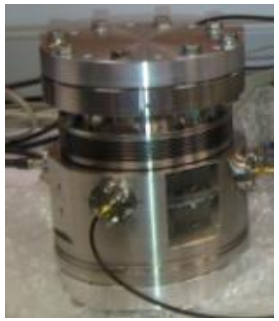
Diagnostics

Most of the LIPAc diagnostics design will be used for the low energy part of the IFMIF-DONES accelerator



Fluorescence Profile Monitors





Beam Profile Monitor

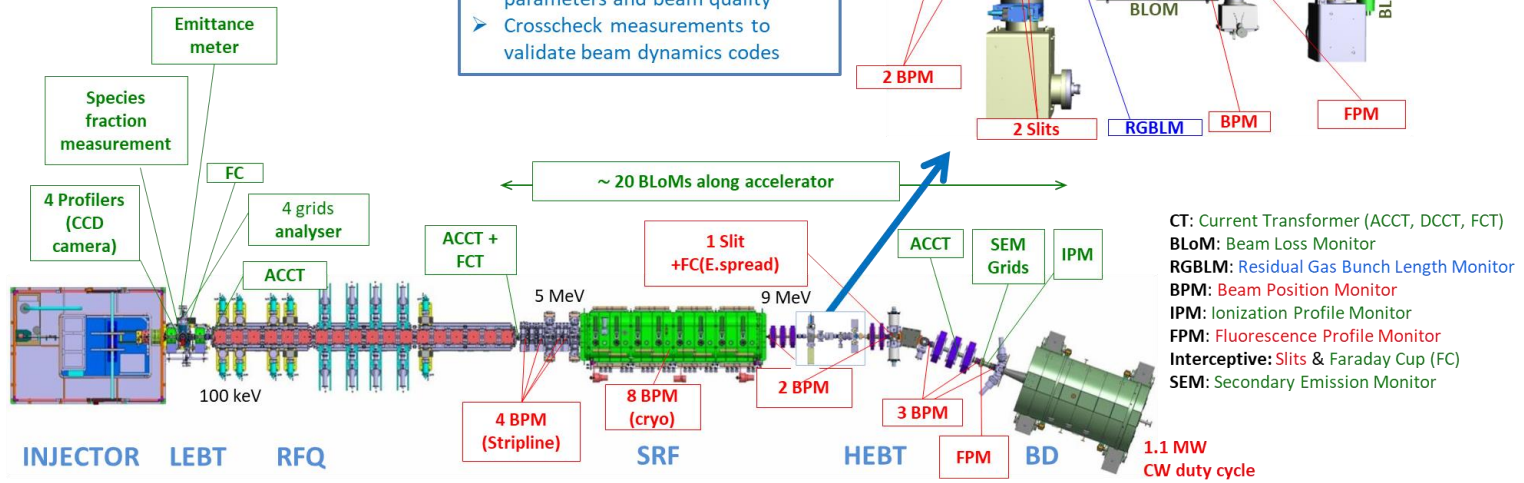
AC-CT

Challenges

- **High** beam current in CW **(d+ 125 mA)**
- **Low** beam energy **(5-9 MeV)**
- **High** beam power **(up to 1.12 MW)**

Goals

- Checkout of the BI operation along all beam commissioning
- Matching and tuning of RFQ and MEBT parameters
- Validate the operation as beam interlock systems
- Provide information about machine parameters and beam quality
- Crosscheck measurements to validate beam dynamics codes



LIPAc Diagnostic Layout

Diagnostics

Most of the LIPAc diagnostics design will be used for the low energy part of the accelerator…

For the high energy part, a **design update is required as well as new development** !!

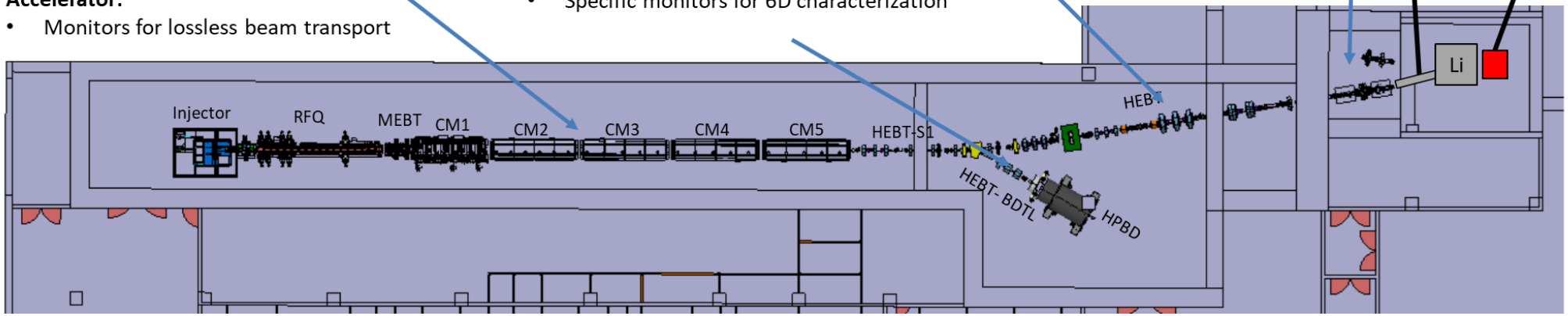
HEBT@TIR:
- Characterization and monitoring of beam profile @ footprint
- Beam monitors under high radiation environment (~10 Sv/h // 10^8 n/cm2-s) and Remote Handling maintenance

SRF LINAC:
- Measurement of microlosses (<1 W/m) @ cryogenic environment → CVD's
- Transverse profile @ Warm Sections

HEBT:
- Non-interceptive profile monitors in multipoles section

HEBT/BDTL:
- Specific monitors for 6D characterization

Accelerator:
- Monitors for lossless beam transport



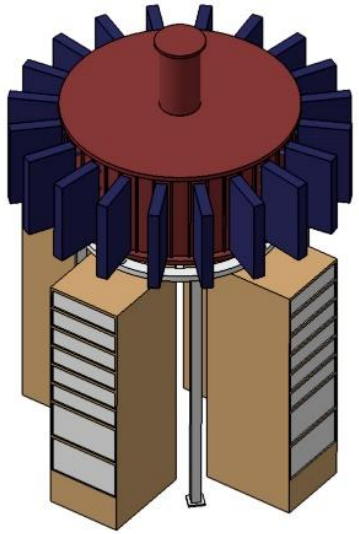
IFMIF-DONES Layout

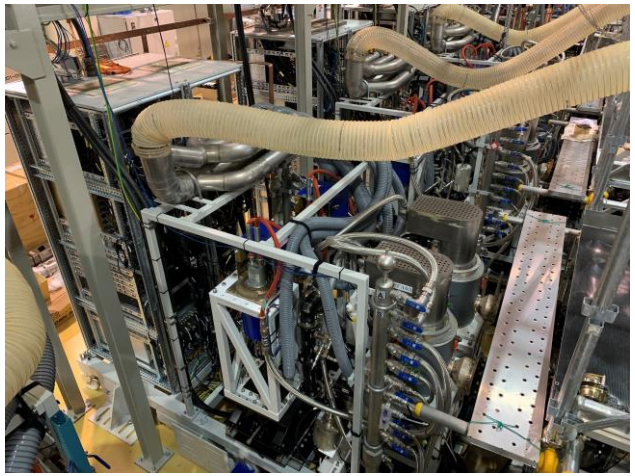
RF Power System

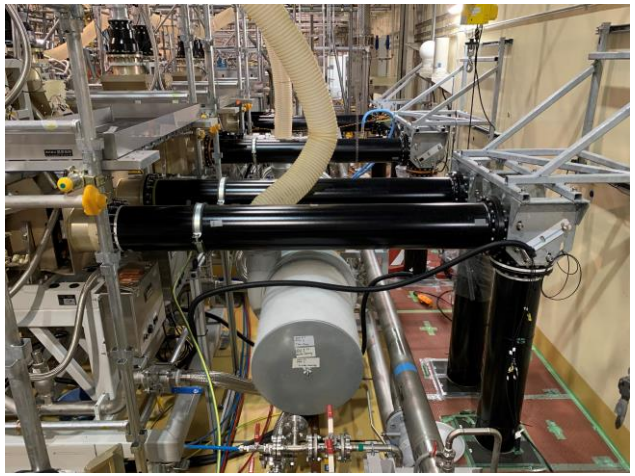
Two prototype alternatives under manufacturing and testing :

- Based on single cavity combiner and
- Based Progressive and hybrid combiners

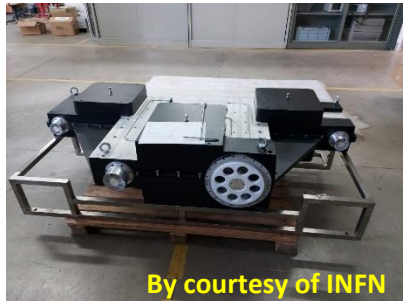
Replacement of the LIPAc RFQ-RF PS (Tetrode based) by SSPA ongoing….







Radio Frequency Power System tetrode based (@Rokkasho)

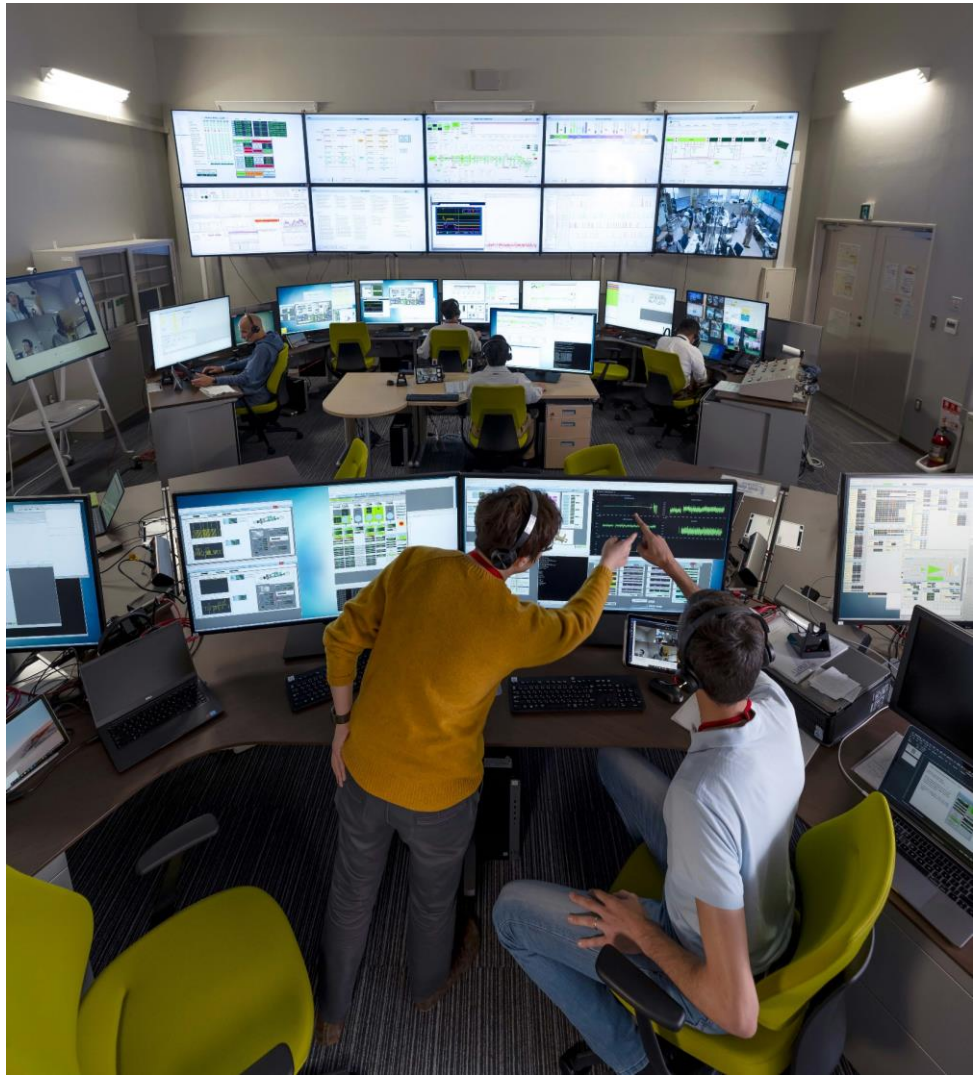


Control Systems

EPICS

LIPAc control systems are going through a major upgrade where development is focused on sorting out obsolescence issues and in general refurbishment of old systems:

- Boosting maintainability and reliability by replacing S7-300 systems with new PLC solutions (S7-1xxx),
- New timing and fast-data acquisition systems based looking to find the best modern architectures for the project (White Rabbit, microTCA, etc.),
- Improving machine availability by applying machine learning in maintenance and artificial intelligence in operations,
- Global EPICS upgrade (from base versions 3.x to 7.x).



IFMIF-DONES is already integrating LIPAc lesson leant
→ Communalities/Interfaces

….. specific design for remote handling is being developed.

Maintenance

Important activities to ensure a good reliability and availability…

- Operation Feedback,
- Design Improvement,
- Obsolescence…

One maintenance contract on LIPAc – RF Power System

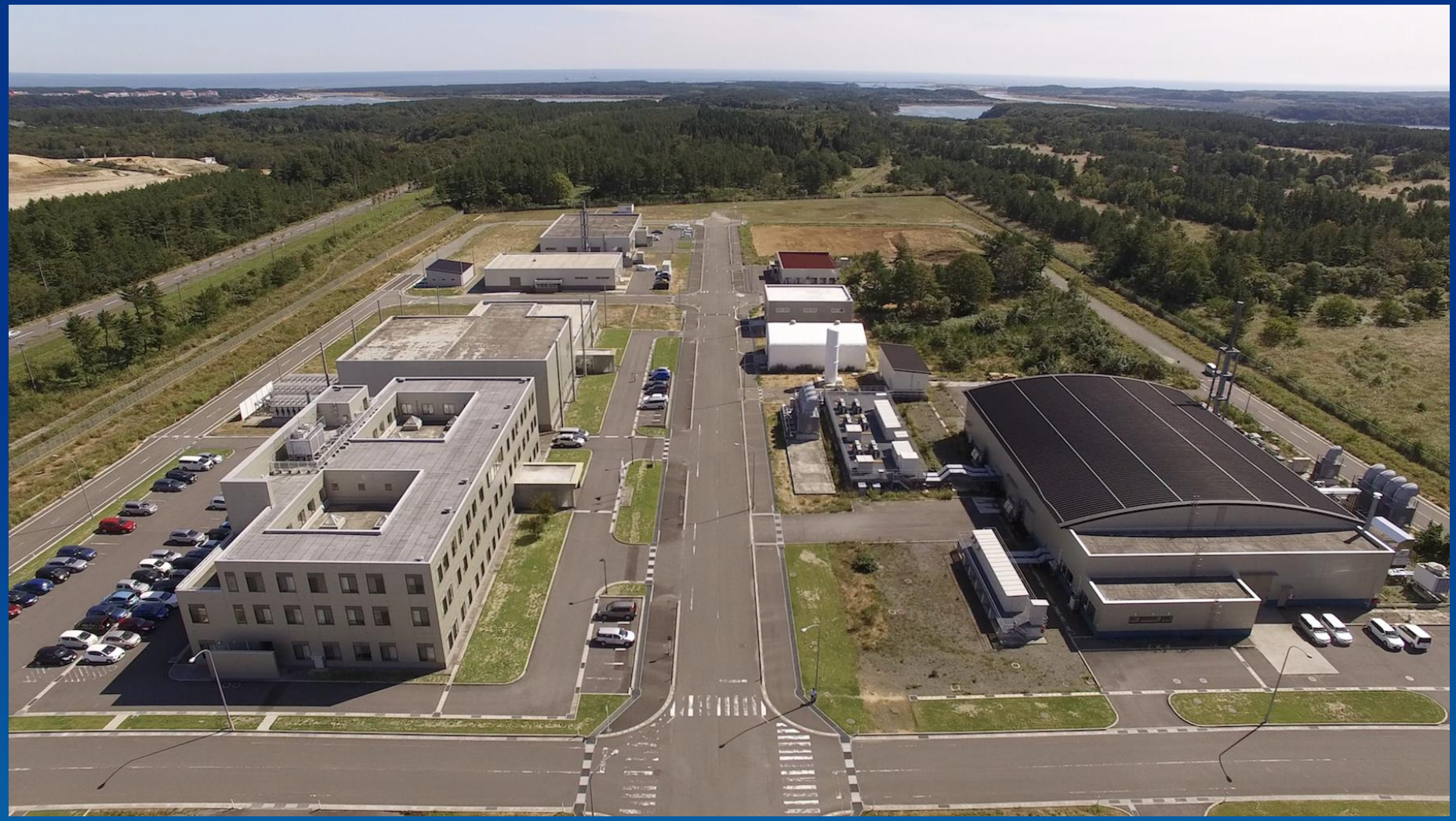
… currently in discussion and seeking for placing a maintenance contract:

- ✓ Obsolescence,
- ✓ Dedicated Accelerator Maintenance.

Company involved in LIPAc activities

ACAL BFI FRANCE SAS, AIR LIQUIDE, AIRTIFICIAL AEROPSACE & DEFENSE, AWGE TECHNOLOGIES, AMPEGON, BERGOZ, BTESA, CENTRONIC, CERAQUITAINE, CHAUDRONNERIE TOLERIE DES MOULINS, CIMLEC INDUSTRIE, CIVIDEC INSTRUMENTATION GMBH, ETTORE ZANON SPA, EXPLEO REGIONS, INDRA SISTEMAS, JEMA ENERGY, KOBOLD MESSRING GMBH, MARPHIL INTERNATIONAL, MAT-TECH, MOLLER WOLF-DIETRICH, NATIONAL INSTRUMENTS SPAIN, OCEM, OROLIA, RI RESEARCH INSTRUMENTS, SOCIETE D'OUTILLAGE DE PRECISION, SOLCERA, SPINNER, SUMITO CRYOGENICS OF EUROPE, TECHNETICS GROUP FRANCE, THALES AVS FRANCE, VAT.

LIPAc @ Rokkasho (Japan)



IFMIF-DONES @ Escúzar (Spain)

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