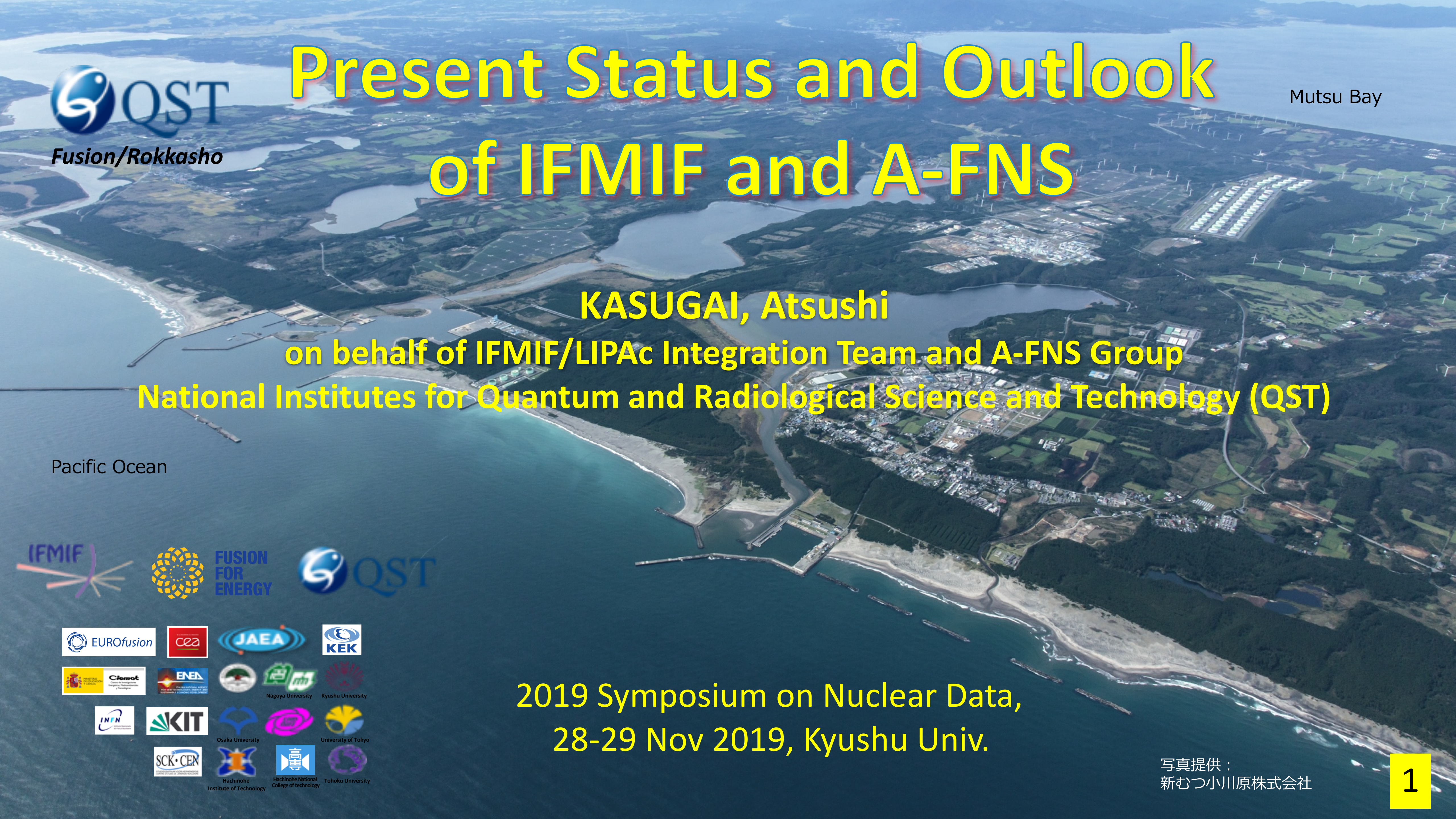
Present Status and Outlook of IFMIF and A-FNS

Fusion/Rokkasho

KASUGAI, Atsushi

on behalf of IFMIF/LIPAc Integration Team and A-FNS Group

National Institutes for Quantum and Radiological Science and Technology (QST)



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Tohoku University

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28-29 Nov 2019, Kyushu Univ.

Outline

Introduction & Recent results of IFMIF/EVEDA

Fusion/Rokkasho

Japanese Policy to promote R&D for DEMO

Advanced Fusion Neutron Source A-FNS in Japan

A-FNS project based on IFMIF/EVEDA

Outline of A-FNS

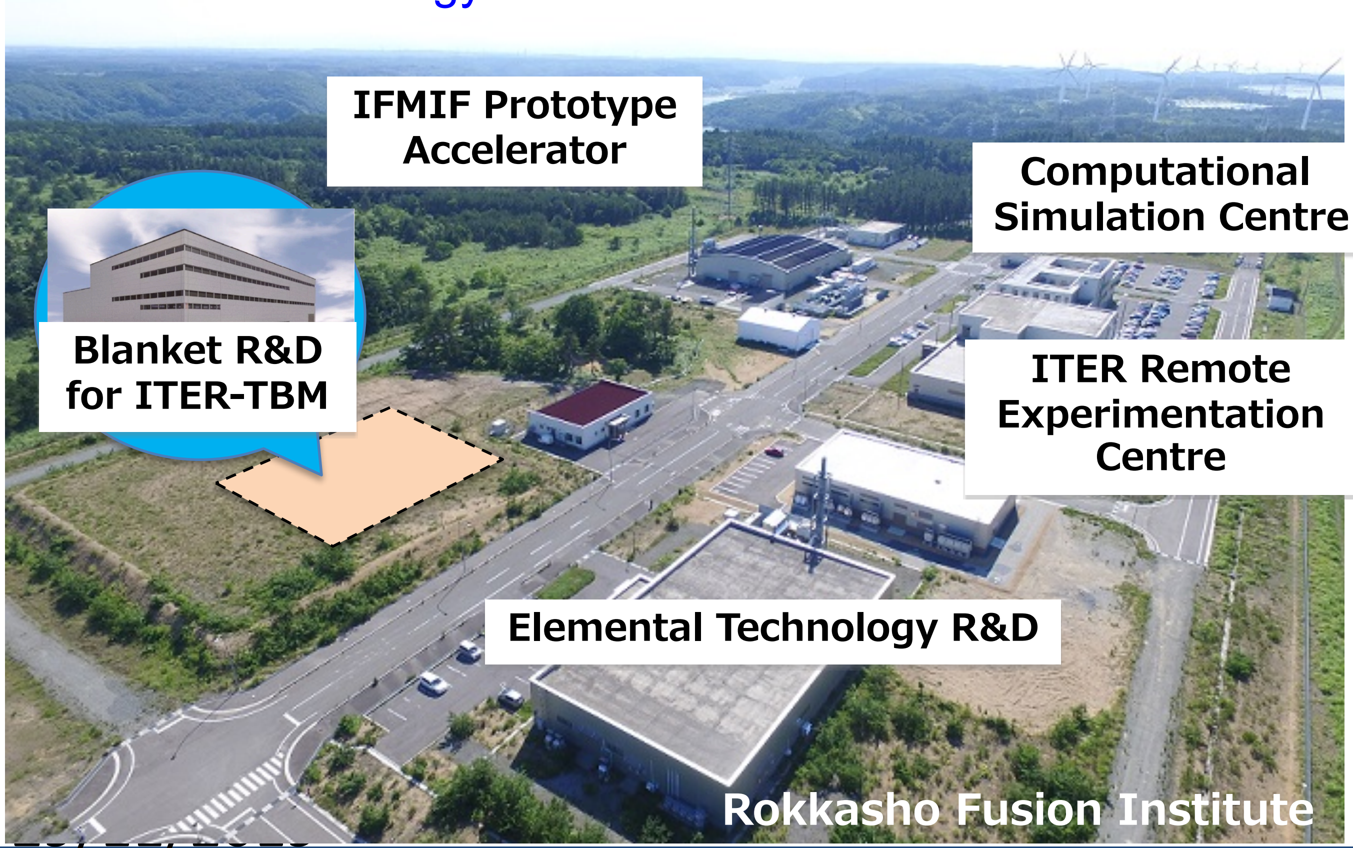
Conceptual design report of A-FNS

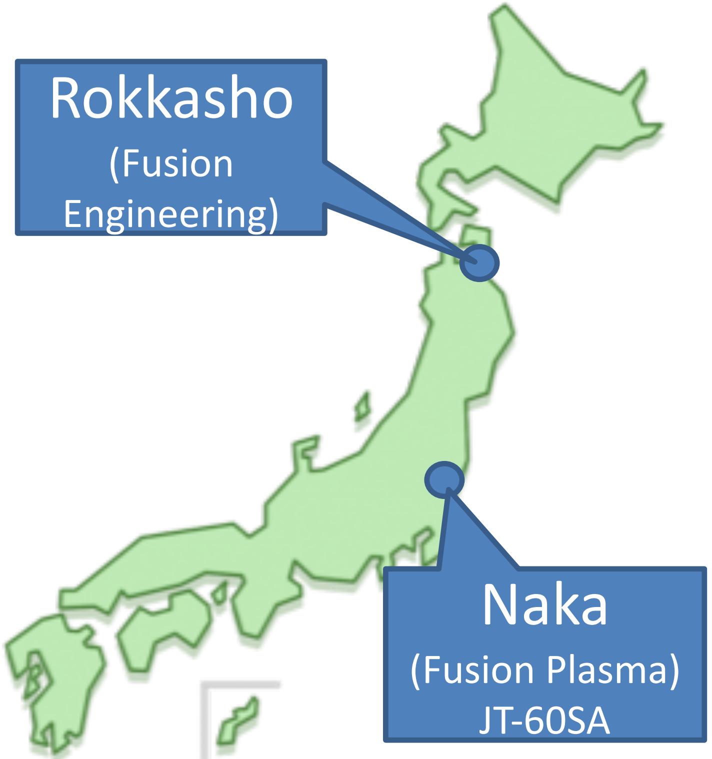
Fusion/Rokkasho

Rokkasho Fusion Institute

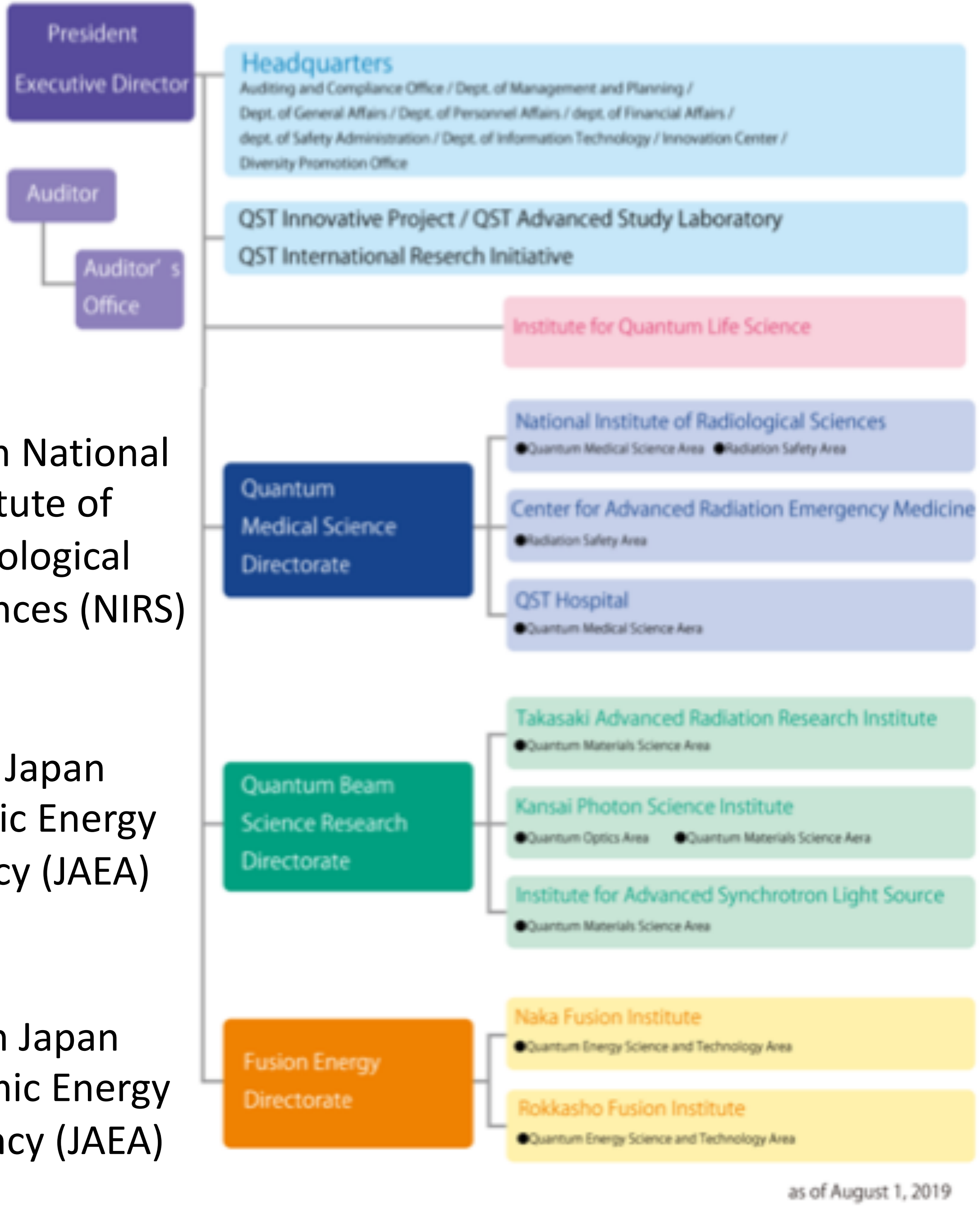
- Fusion Engineering R&D Center towards DEMO -

- Rokkasho Fusion Institute was originally established in 2007 to implement the Broader Approach Activities, such as the IFERC (International Fusion Energy Research Center) and IFMIF/EVEDA (International Fusion Materials Irradiation Facility/ Engineering Validation and Engineering Design Activities) projects.
- Up to now, ITER Remote Experimentation Centre, Computational Simulation Centre, IFMIF Prototype Accelerator, Elemental Technology R&Ds are carried out in addition to the ITER Test Blanket Module R&D.





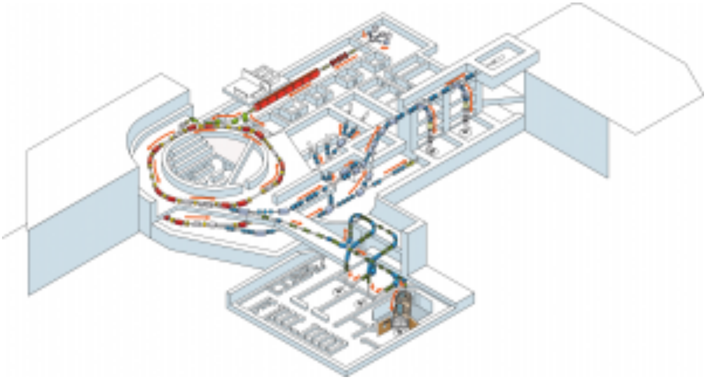
National Institutes for Quantum and Radiological Science and Technology (QST)



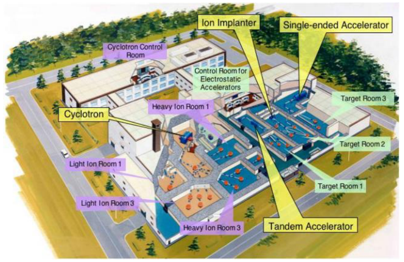
From National Institute of Radiological Sciences (NIRS)

From Japan Atomic Energy Agency (JAEA)

From Japan Atomic Energy Agency (JAEA)



HIMAC heavy particle beam cancer treatment system

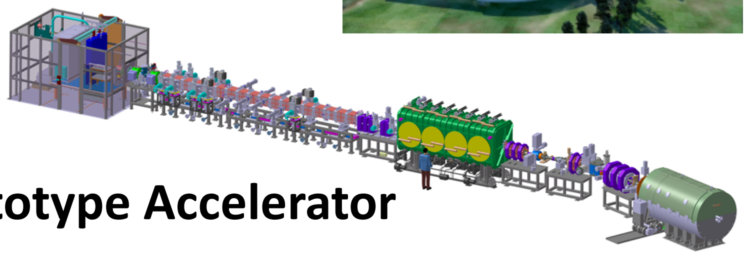


TIARA

J-KAREN

3GeV Synchrotron

JT-60SA



LIPAc Linear IFMIF Prototype Accelerator

Step for Realization of Fusion Energy

Broader Approach

After signature ITER
November 2006

BA Signed in February 2007
Entered into force on June 2007

Test device

(Scientific feasibility)

Realization of High temperature plasma

JT-60

Fusion gain (DT-equivalent) =1.25(world record)
Ion temperature =520 million K

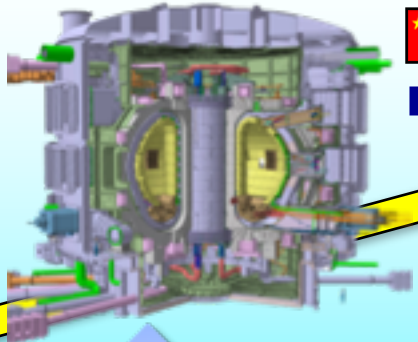
JA-EU Collaboration

In Japan

Experiment reactor
- Present -

(Scientific and engineering feasibility)

ITER (International Thermonuclear Experimental Reactor
Demonstrate sustainment of burning plasma 500MW



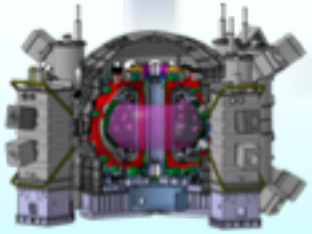
ITER Org.、7 Parties

Site: France Saint-Paul-lès-Durance

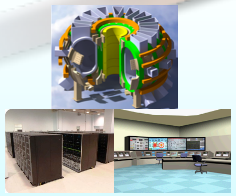
Fusion Power of 0.5GW

Support ITER

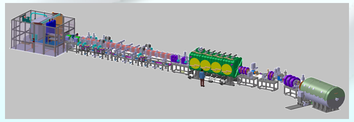
Complement ITER



JT-60SA project
【Naka in Ibaraki】



IFERC project



IFMIF/EVEDA project
【Rokkasho in Aomori】

Broader Approach activities for Fusion Energy

DEMO

(Engineering demonstration and economical feasibility)

Fusion DEMO

Electricity generation
Economical prospects

Establish Engineering Basis for DEMO

Accelerator type Neutron source (for Material R&D)

Why a Fusion Neutron Source?

- Selection and qualification of candidate materials for fusion reactors
- Generation of engineering data for design, licensing and safe operation of DEMO up to end-of-life
- Completion, calibration and validation of databases (mainly generated from fission reactors research)
- Material testing and simulation carried out simultaneously to correlated fundamental understanding of radiation response of materials

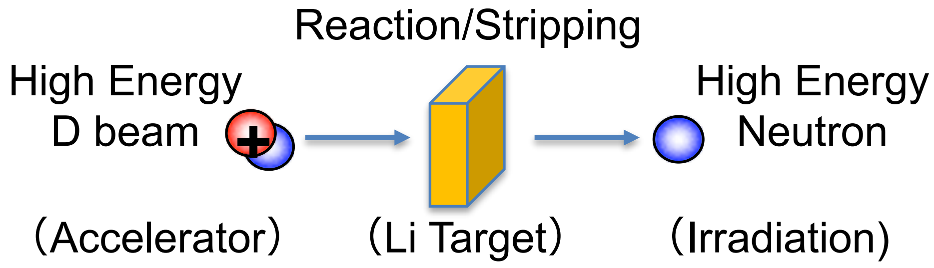
International Advisory Panels pointed out Fusion Neutron Source as essential need toward Fusion Power Plant

→ best fulfilled with a D-Li stripping source → IFMIF concept

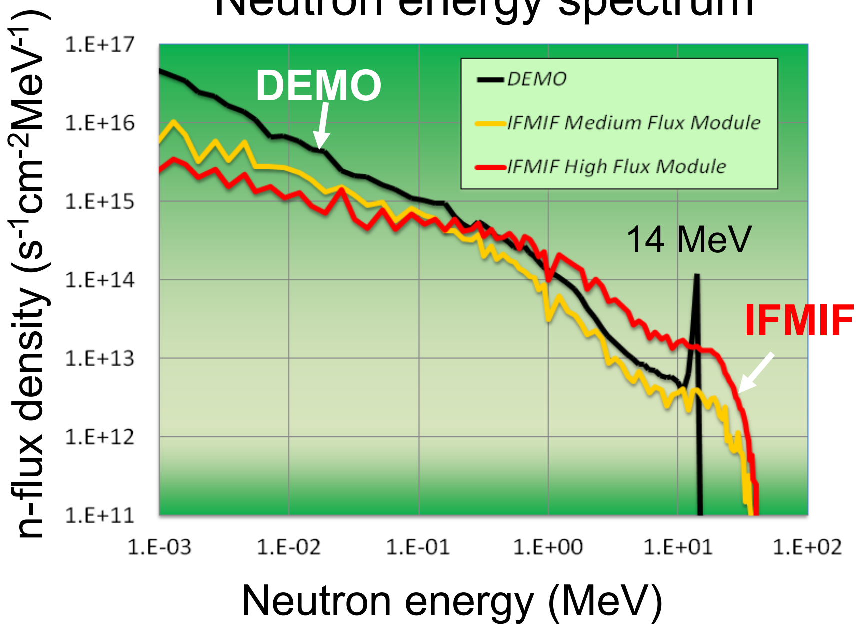
Fusion Material Irradiation Facility with Accelerator

- IFMIF is the world's highest beam current (125 mA x 2), highest power (5 MW x 2) accelerator to confirm soundness of fusion material under strong neutron irradiation from Fusion Demo.

Beam driven Neutron



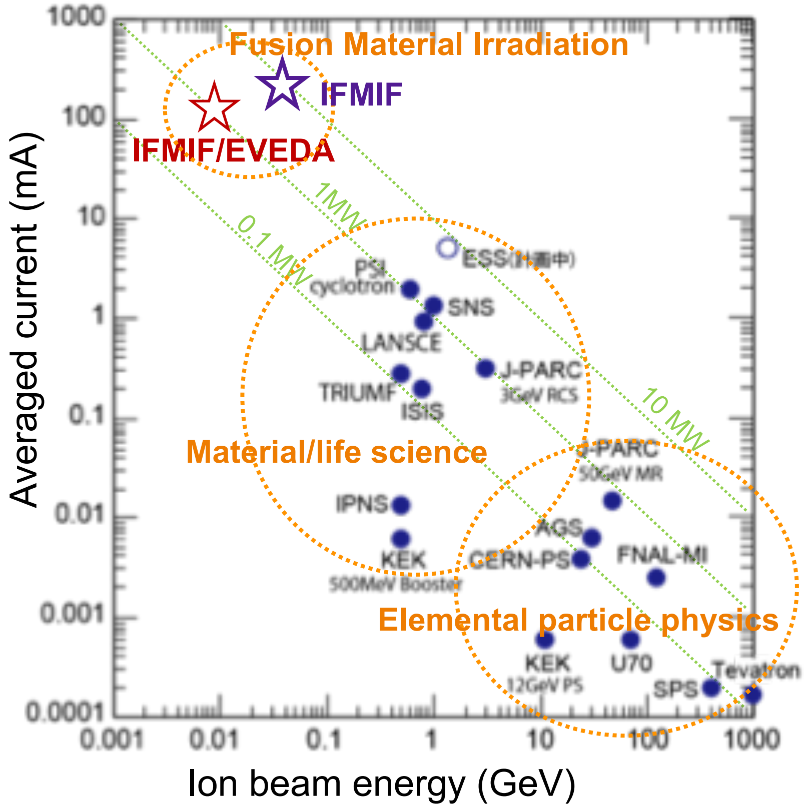
Neutron energy spectrum



IFMIF

(International Fusion Materials Irradiation Facility)

Accelerator Operational condition

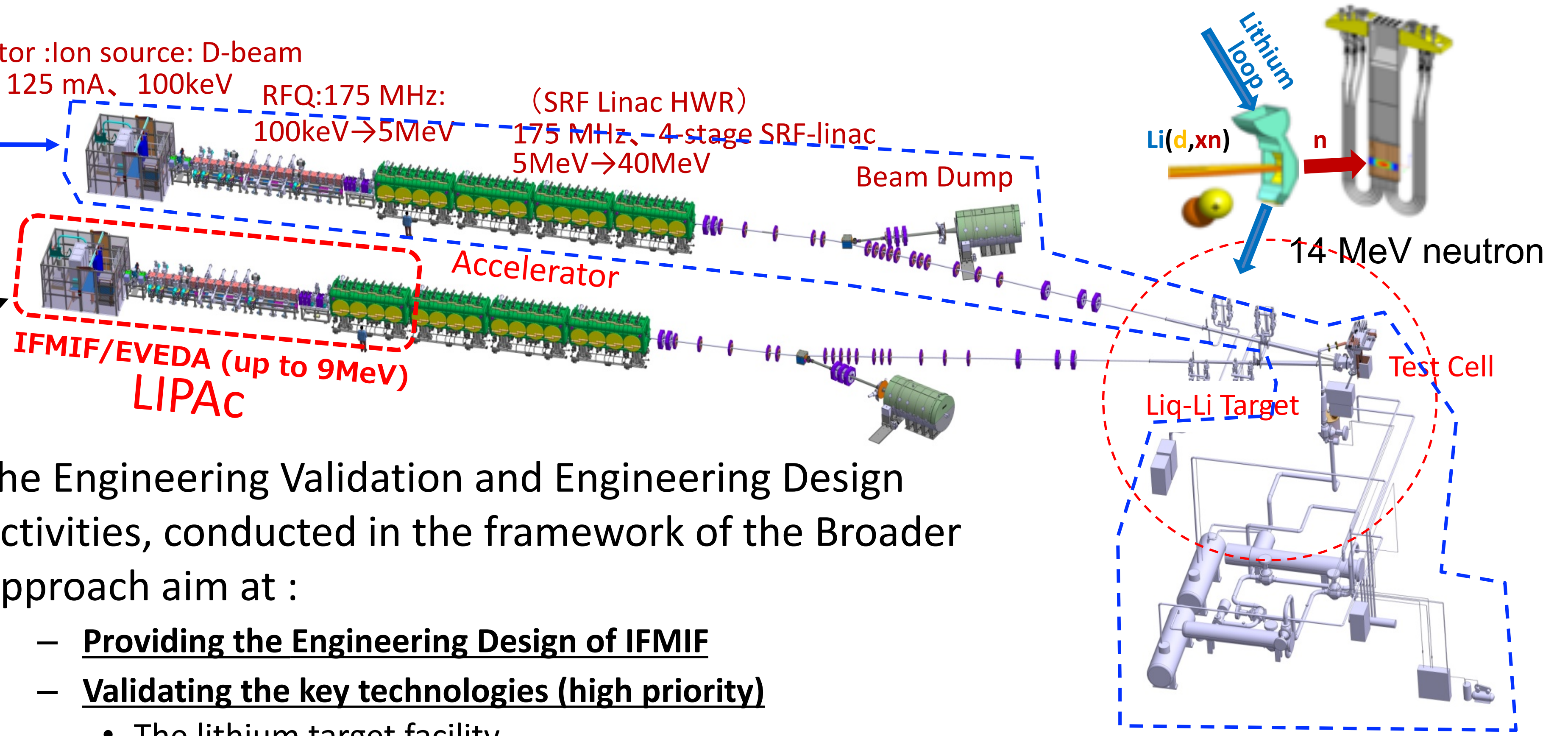


IFMIF Concept

IFMIF（International Fusion Materials Irradiation Facility) is an accelerator based neutron source using Li(d,n) reactions aiming at providing a material irradiation database for the design, construction, licensing, and safe operation of Fusion DEMO.

under consideration

A-FNS for Japan
DONES for EU



<u>L</u>inear <u>I</u>FMIF <u>P</u>rototype <u>Ac</u>celerator (LIPAc) to be tested in Rokkasho – Japan, Accelerator's technological feasibility is being tested through the design, manufacturing, installation, commissioning and testing activities of a 1:1-scale prototype accelerator from the injector to the first cryomodule (125 mA D^+ beam CW)

The Engineering Validation and Engineering Design Activities, conducted in the framework of the Broader Approach aim at :

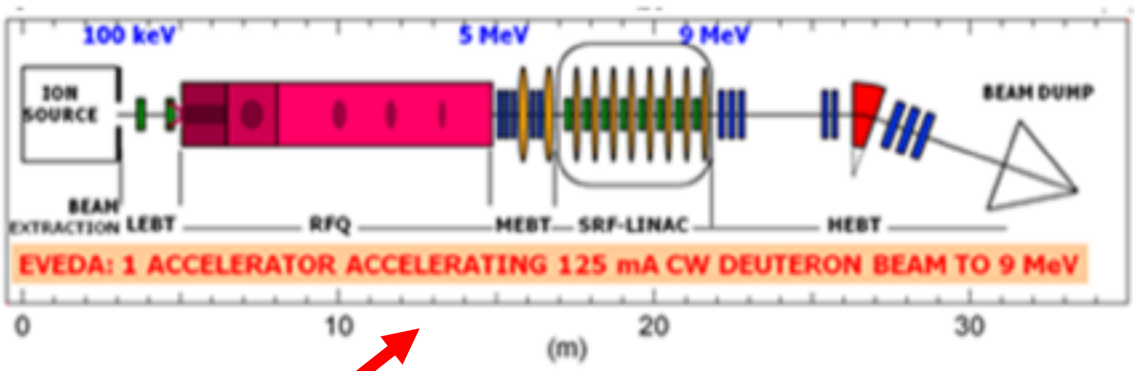
– **<u>Providing the Engineering Design of IFMIF</u>**
– **<u>Validating the key technologies (high priority)</u>**
  - The lithium target facility
  - The high flux modules with full remote handling
  - **The low energy part of accelerator**

IFMIF/EVEDA

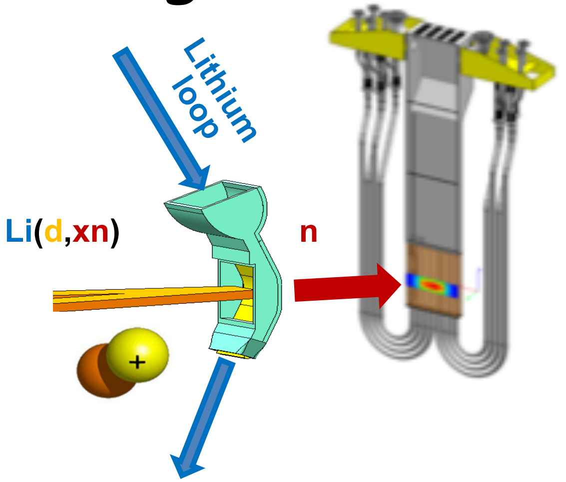
- The main objective of IFMIF/EVEDA (Engineering Validation and Engineering Design Activities) is to prepare for construction of the IFMIF intense 14 MeV neutron source for DEMO relevant materials testing.
- Engineering Design and Validation of Key Components in IFMIF, such as Linear IFMIF Prototype Accelerator (LIPAc), Lithium Target and Irradiation Test Cell are carried out.

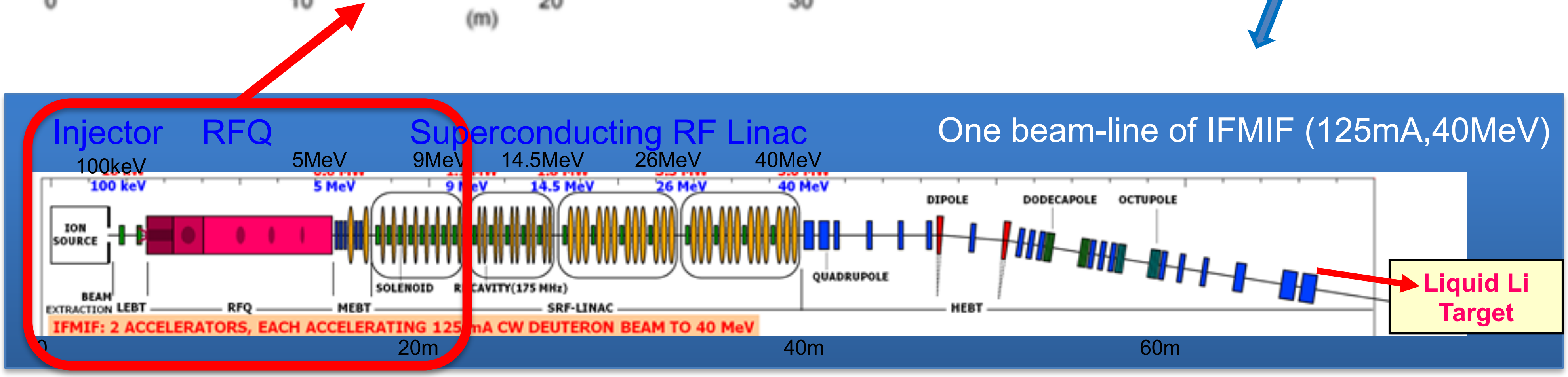
Linear IFMIF Prototype Accelerator

(125mA,9MeV, D^+ beam)



Lithium Target ***Test cell***



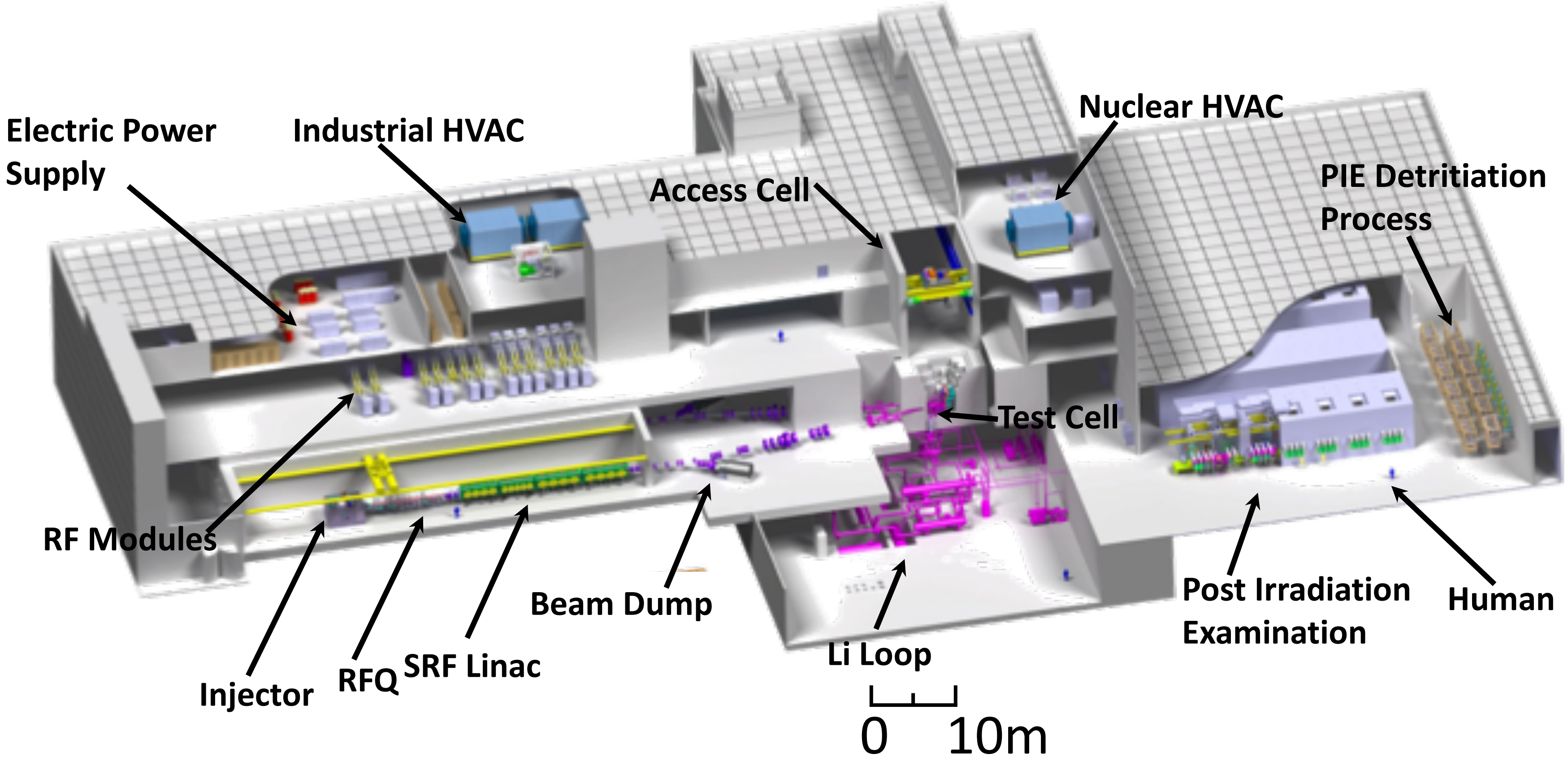


EVEDA = EDA +EVA Phases

Engineering Design Activities – EDA phase

Successfully delivered on schedule

Validation Activities – EVA phase

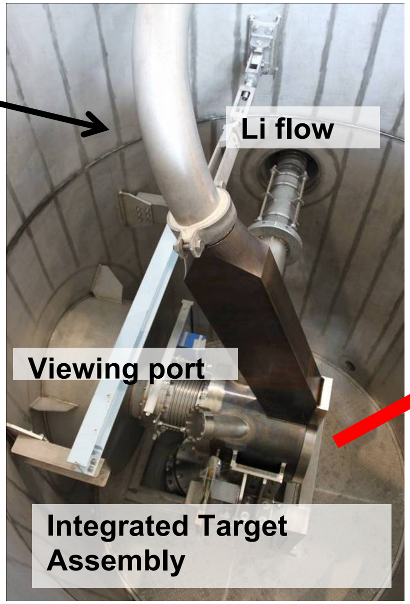


Target Facility

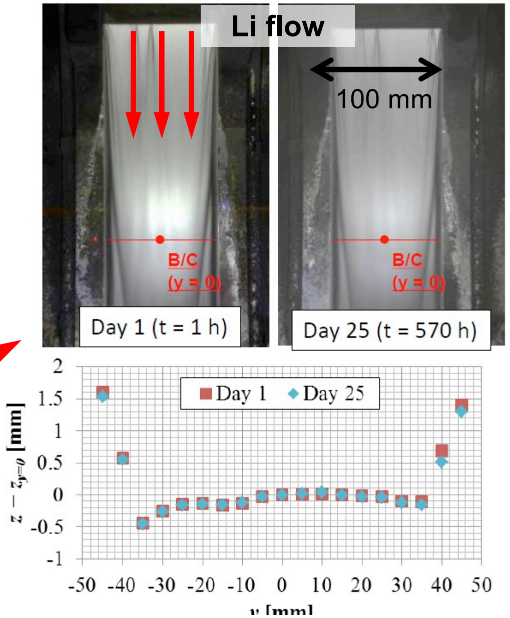
- Stable Liquid Lithium flow of 15 m/s was demonstrated on the **Lithium Test Loop** in 2014.
- The Lithium Test Loop was disassembled in 2017.

Lithium Test Loop at JAEA Oarai

Containment vessel located at top of the stage

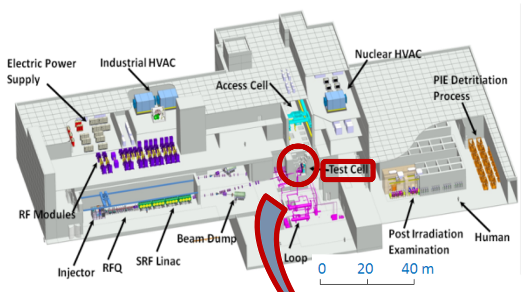


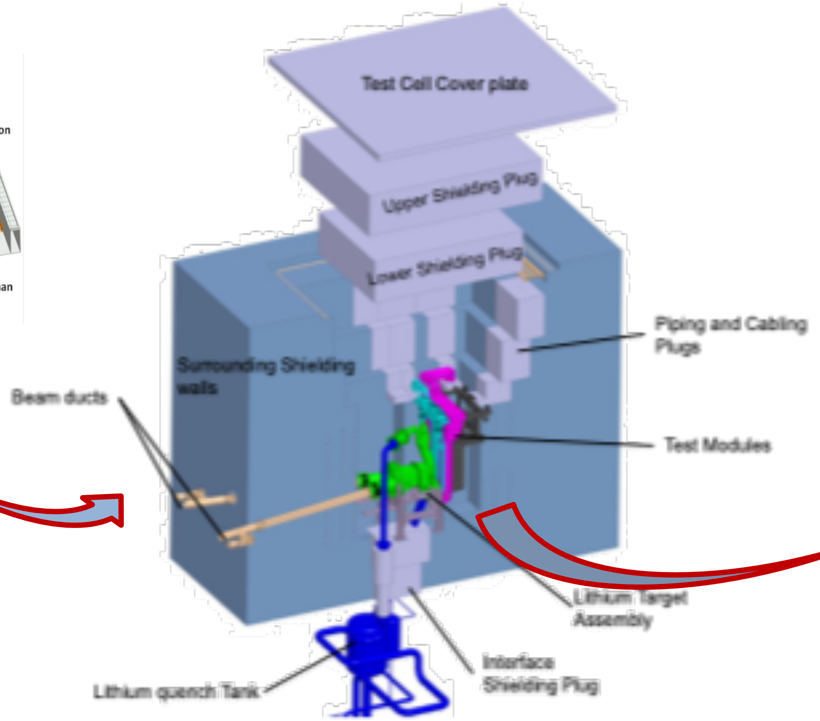
Stability of liquid lithium flow of 15 m/s at 1st day and 25th day

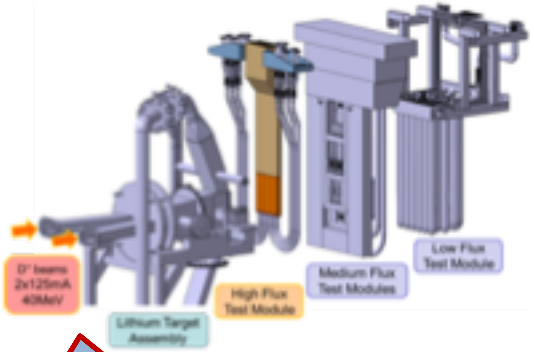


Achievements: satisfying requirements
Stability in thickness: 25 ± 1 mm
Flow rate: 15 m / s （Max. 20m /s)
Total operation time: 1300 hours

Test Facility







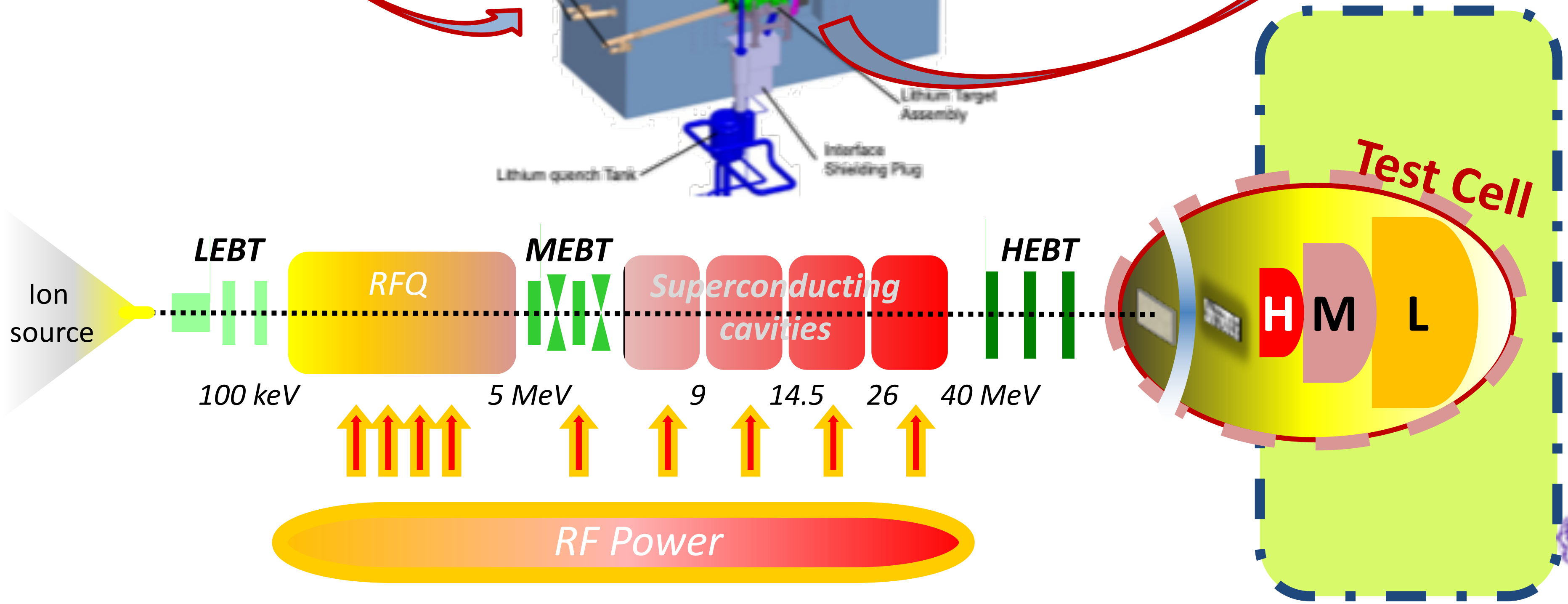
HFTM

20 dpa/fpy in 500 cm^3

12 x 80 small specimens

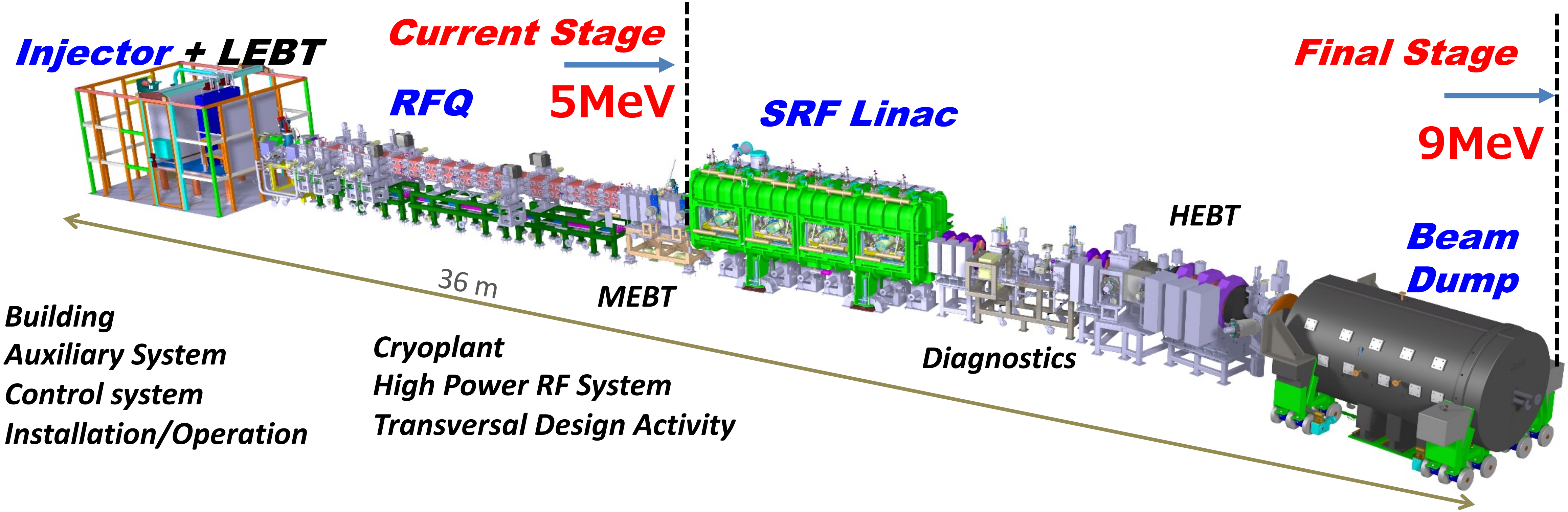
independently cooled

within +/3% T



LIPAc (Linear IFMIF Prototype Accelerator)

- Mission of LIPAc is to demonstration of feasibility of intense D^+ beam acceleration of 125 mA, 9MeV.
- Under the control of implementing agencies of EU (F4E) and Japan(QST) in BA activity, key components are mainly procured by EU research institutions, and the assembly and installation are mainly done by JA (QST) at Rokkasho.
- Test and operation are done to pursue the mission by the EU-JA Joint team.



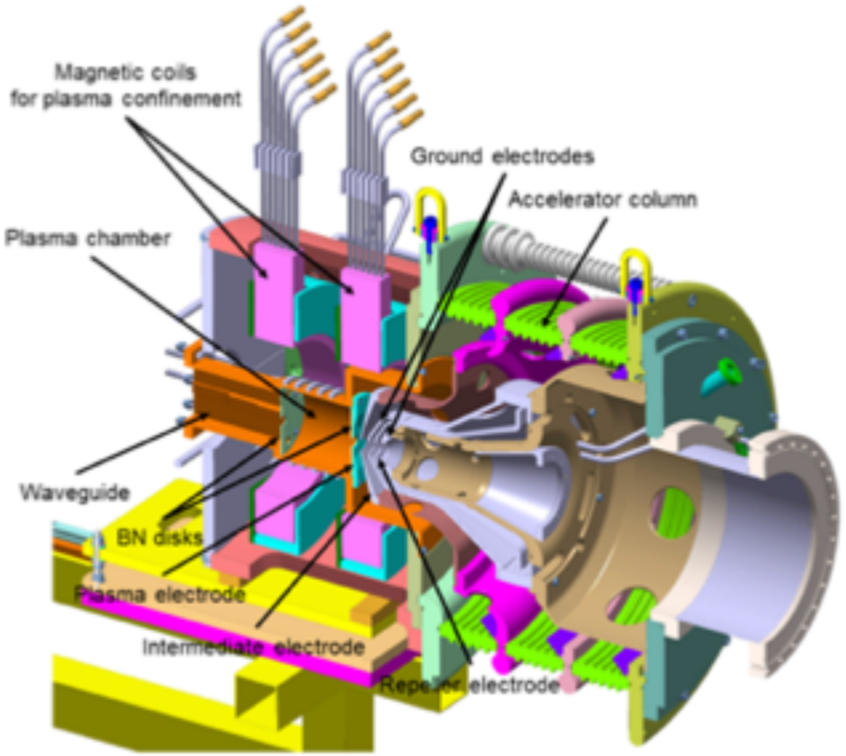
Equipment designed and constructed in Europe, Installed and commissioned in Rokkasho

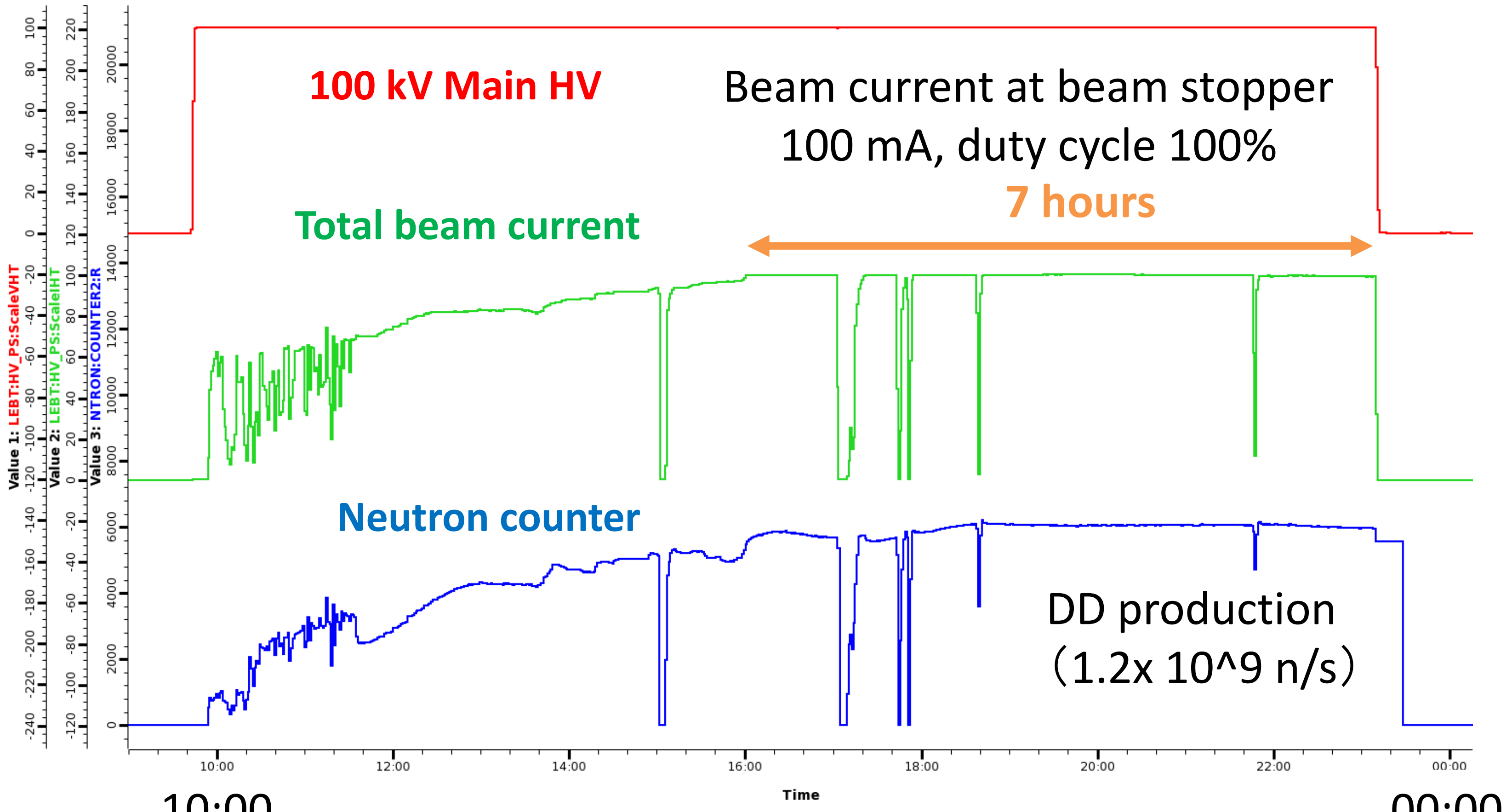
High duty cycle operation (Injector only)

CW operation (7 hours) at 100 mA have been performed

Total time was 11.5 hours

Total extracted current of 100 mA with 9mm-PE





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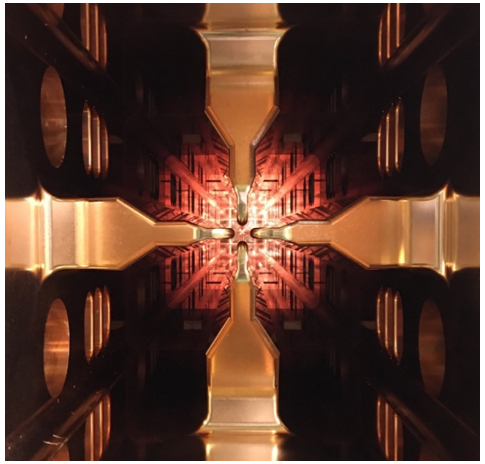
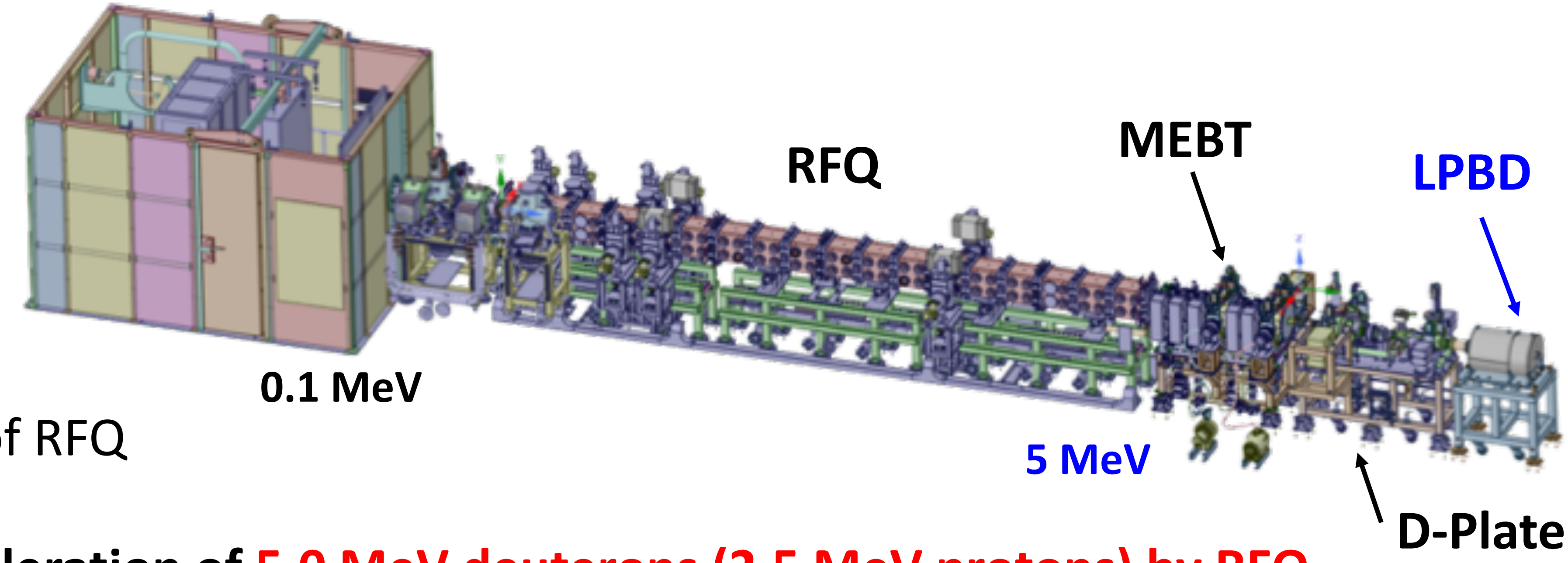
RFQ Experiment

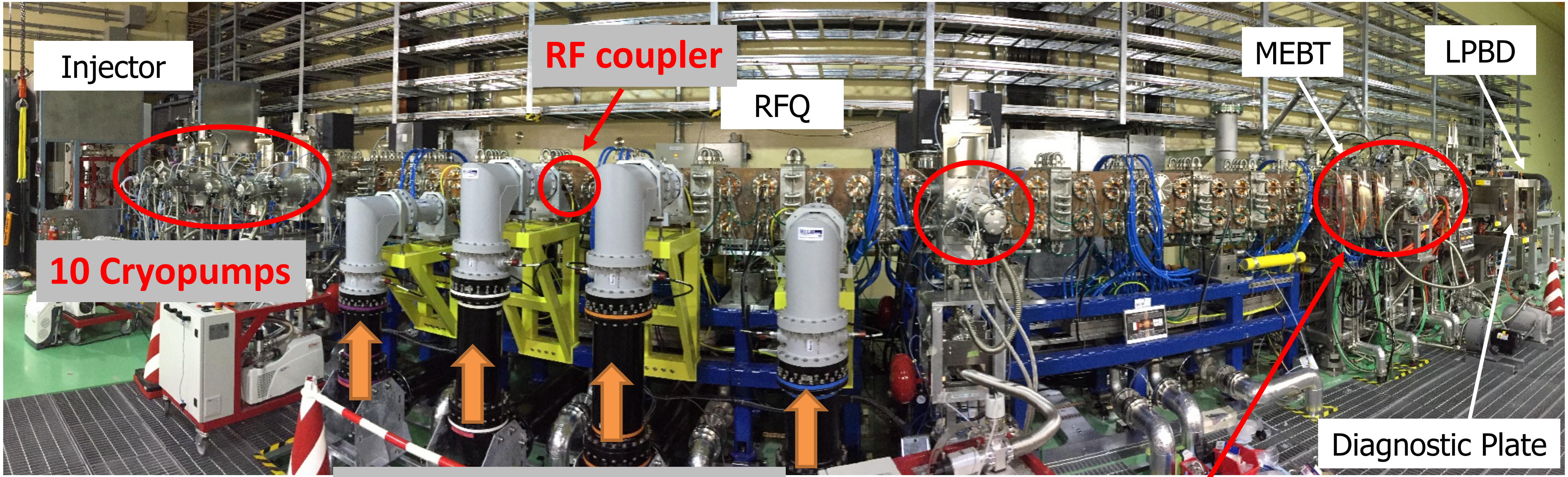


Cross Sectional view of RFQ



- Demonstrates acceleration of 5.0 MeV deuterons (2.5 MeV protons) by RFQ.
- Target current is 125 mA deuteron in short pulse mode (Half for proton).
- The beam is stopped by Low Power Beam Dump (LPBD) with capacity of 1 ms / 1 Hz at 5 MeV, 125 mA (625kW, 0.625 kW in average).
- RFQ is the longest in the world (9.8 m).
- RF power of 560 kW is required for creating electric field for deuteron acceleration (Vane voltage of 132 kV).

RFQ Installation



8-Coaxial RF wave guides

5 Quadrupoles,
2 Bunchers

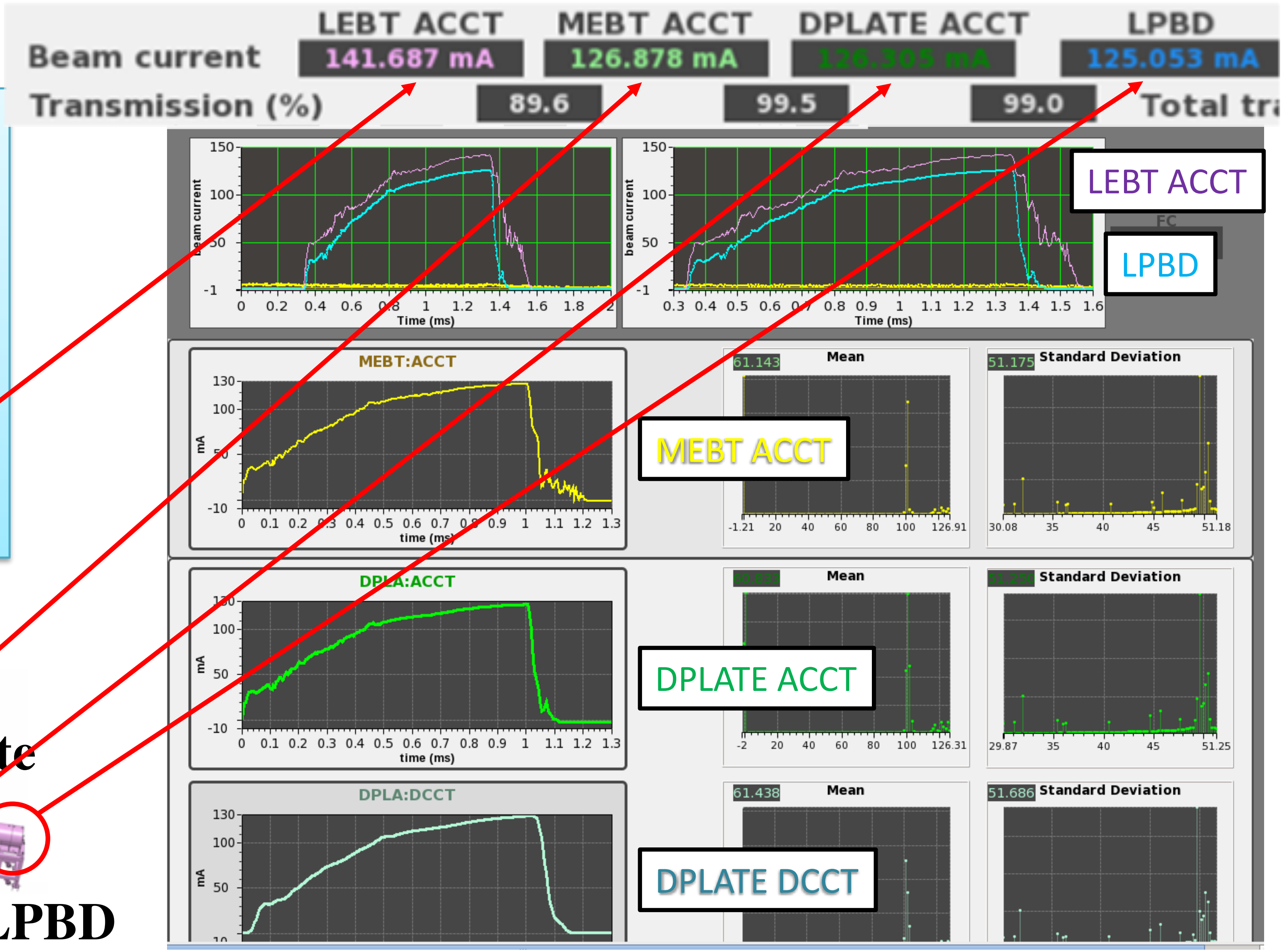
- **RF is injected from eight different RF couplers.**
- **MEBT has two bunchers that perform matching to the Supercoducting RF Linac.**

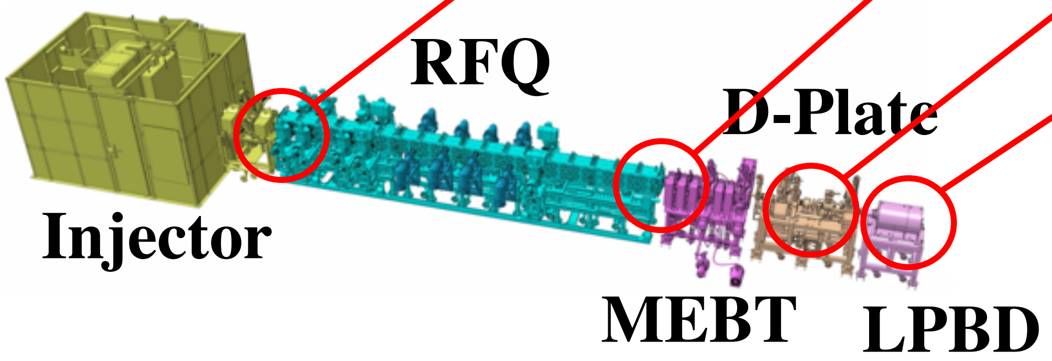
RFQ installation was completed in October 2017.

125 mA D+ Acceleration reached!

24 July 2019, 19:13

- **166 mA** extracted from source (D^+ fraction~85%, $\varepsilon_{n.rms}$~0.2π mm mrad)
- **142 mA** injected to RFQ
- RFQ vane voltage ~**132 kV** (nominal design value)
- RF pulse ~1 ms, 1 Hz
- **127 mA** exit from RFQ (Tr~90%)
- **125 mA** transported to LPBD
- Beam energy ~5 MeV





NEXT STEP toward 9 MeV and/or CW

RFQ+Short (completed)

RFQ+Long

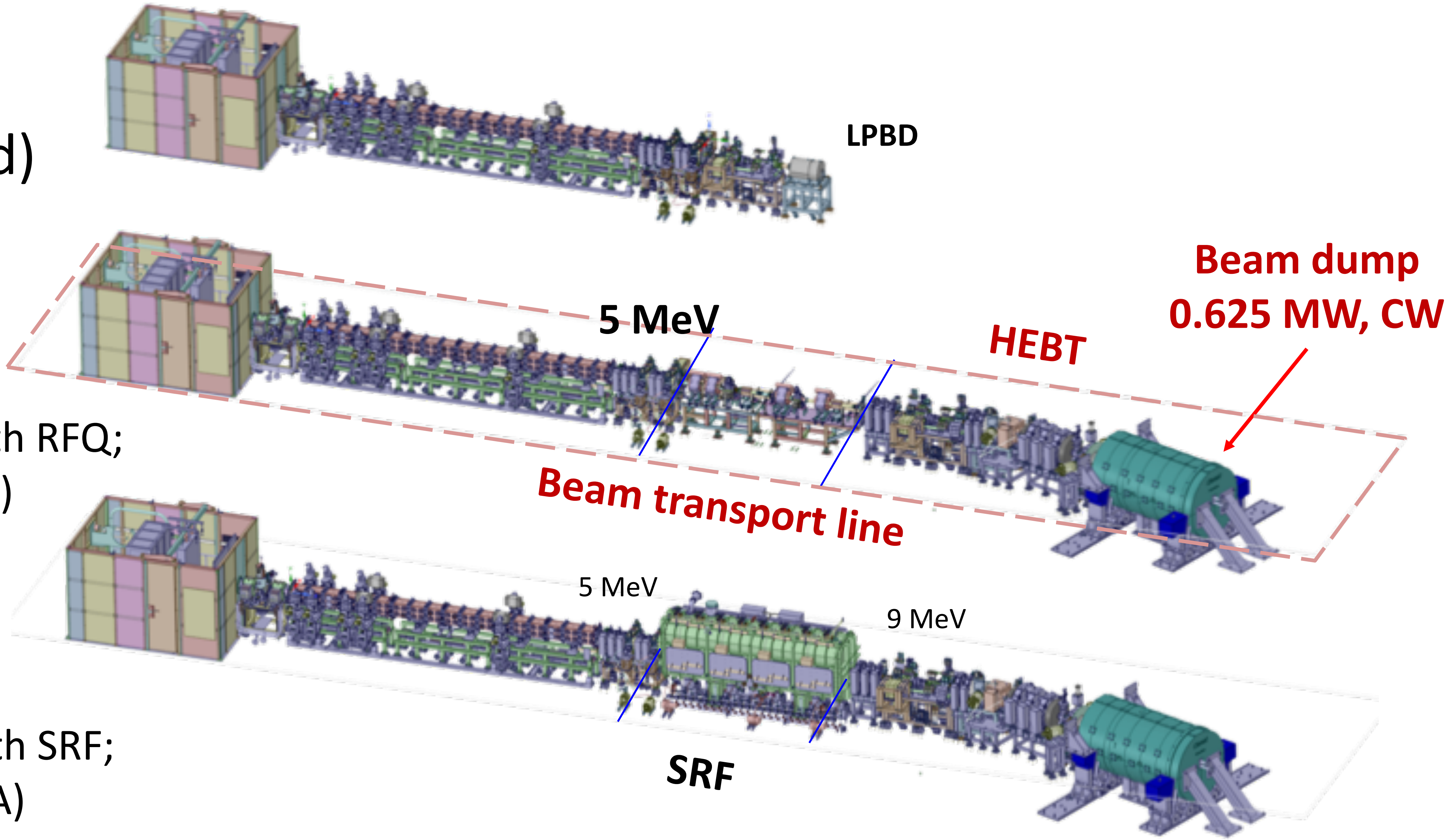
(2020)

(Long pulse with RFQ; 5MeV/125mA)

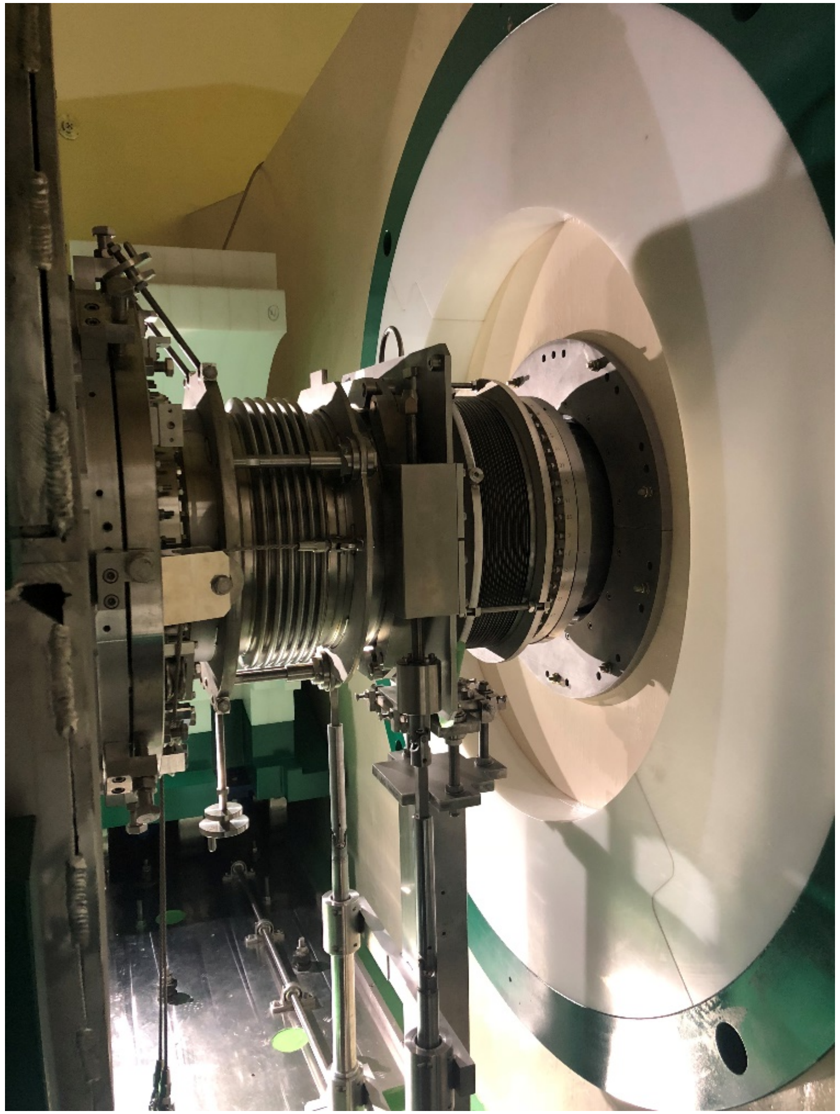
SRF

(2021-2025)

(Long Pulse with SRF; 9MeV/125mA)



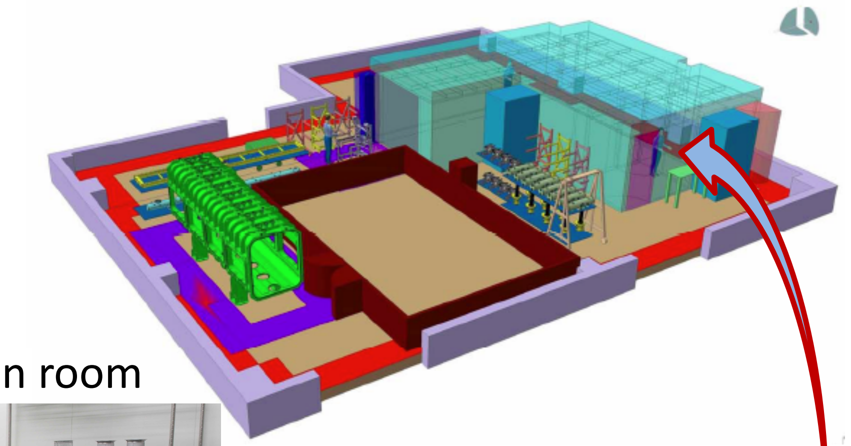
Beam dump installation completed in Nov 2018



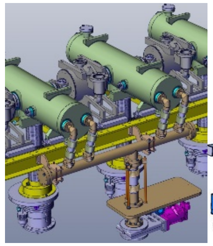
SRF Linac Assembly

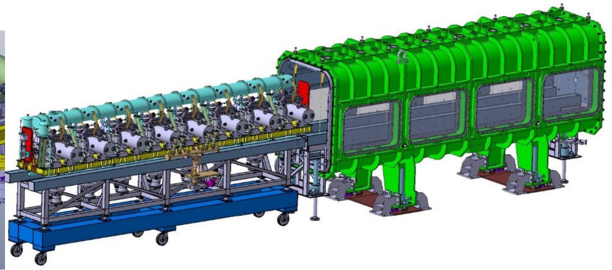
Components under assembly in Rokkasho

- A clean room has been built in Rokkasho under the responsibility of QST in the DEMO Joint Research Building
- F4E is responsible the assembly, CEA provide assistance
- Almost all components delivered on site



Rokkasho clean room





CEA/Saclay's clean room

A-FNS

QST Fusion/Rokkasho

Japanese Policy to promote R&D for DEMO

- In Japanese Fusion Strategy decided by Science and Technology Committee on Fusion Energy in MEXT, three stages are set to judge the Demo Reactor construction just after a successful DT operation in ITER (2035~).
- The International collaborations in ITER and BA activities are essential on the R&Ds towards DEMO.

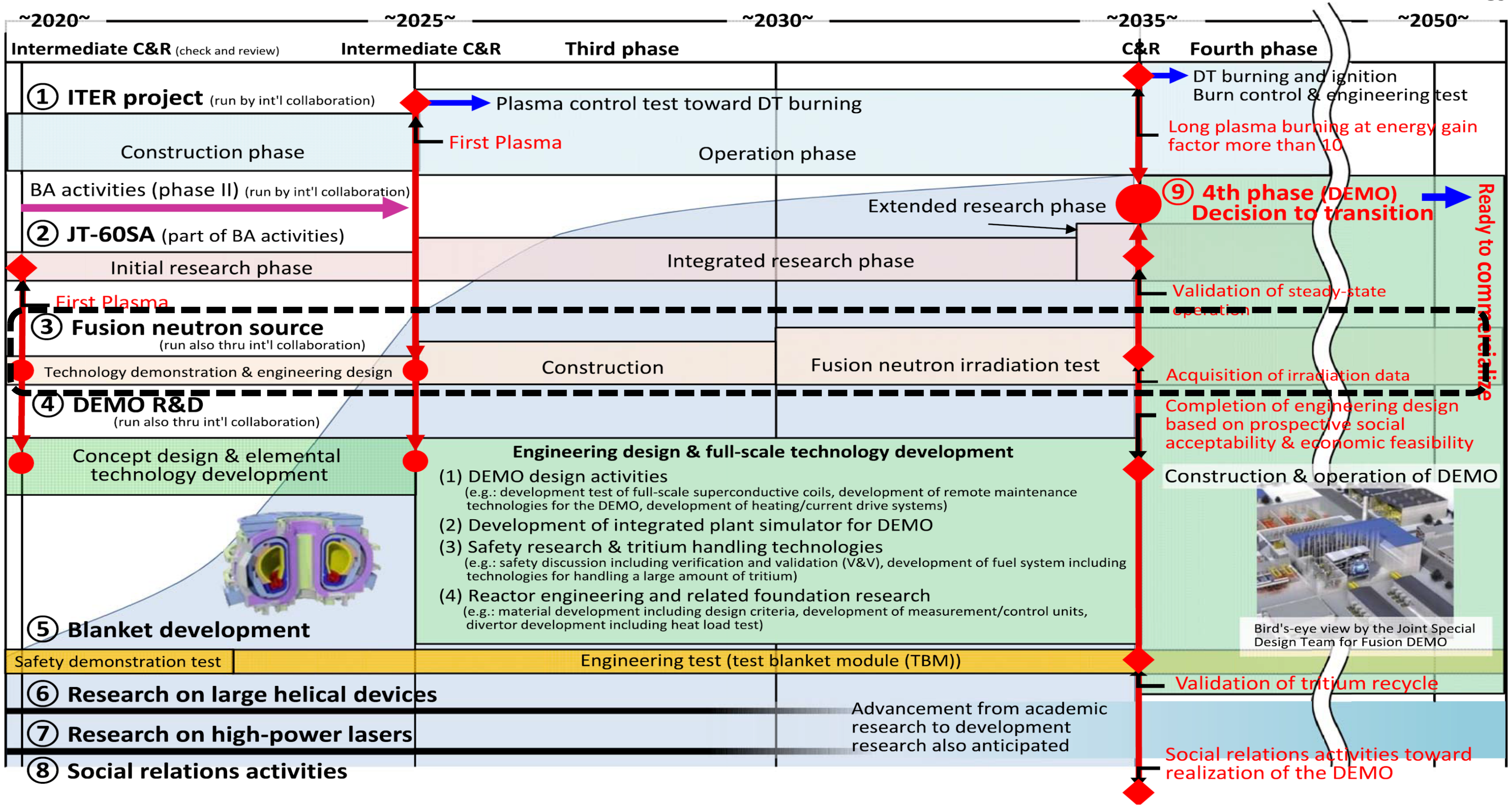
Check and Review Items in the Strategy (extracted summary)

Items	1st intermediate C&R (in ~2020)	2nd intermediate C&R (in ~2025)	Judgment criteria to the DEMO (in ~2035)
① Burn control by ITER	・to create a technical target achievement plan for ITER	・to reflect ITER's collaborative research in the ITER target	・ITER maintains fusion power of Q=10 and validates burn control.
② Steady state operation technique for DEMO	・ to start JT-60SA operation	・JT-60SA achieves a high-beta non-inductive current drive.	・to gain prospects for non-inductive steady operation by ITER. ・JT-60SA validates the stationary operation.
③ Integrated technologies by ITER	・ to build an integrated technologies in JT-60SA construction	・to launch ITER operation.	・to establish integrated technologies in ITER operation
④ Material development	・to complete the concept design of the nuclear fusion neutron source.	・to start the construction of a nuclear fusion neutron source ・to validate the principles of lithium-securing technology.	・to collect initial irradiation data for DEMO material ・to establish lithium-securing techniques
⑤ Reactor engineering (Blanket)	・to collect the data for blanket design from the cold testing facility	・to build ITER-TBM No. 1, ・to complete the safety verification tests	・ITER collects tritium ・to validates the evaluation technique for tritium behavior with the nuclear fusion neutron source
⑥ DEMO Design	・to draw up a basic concept design of the DEMO reactor.	・to complete the DEMO reactor's concept design	・ to complete the DEMO reactor engineering design
⑦ Social relations	・to draw up an awareness activity promotion plan.	・to conduct social relations activities.	・to proceed with social relations activities toward DEMO construction.

Japanese Roadmap toward Fusion DEMO Reactor

- In Japanese Fusion Strategy, three stages are set to judge the Demo Reactor construction just after a successful DT operation in ITER (2035~).

July 24, 2018
Science and Technology Committee on Fusion Energy
Council for Science and Technology



A-FNS Project in Japan Program

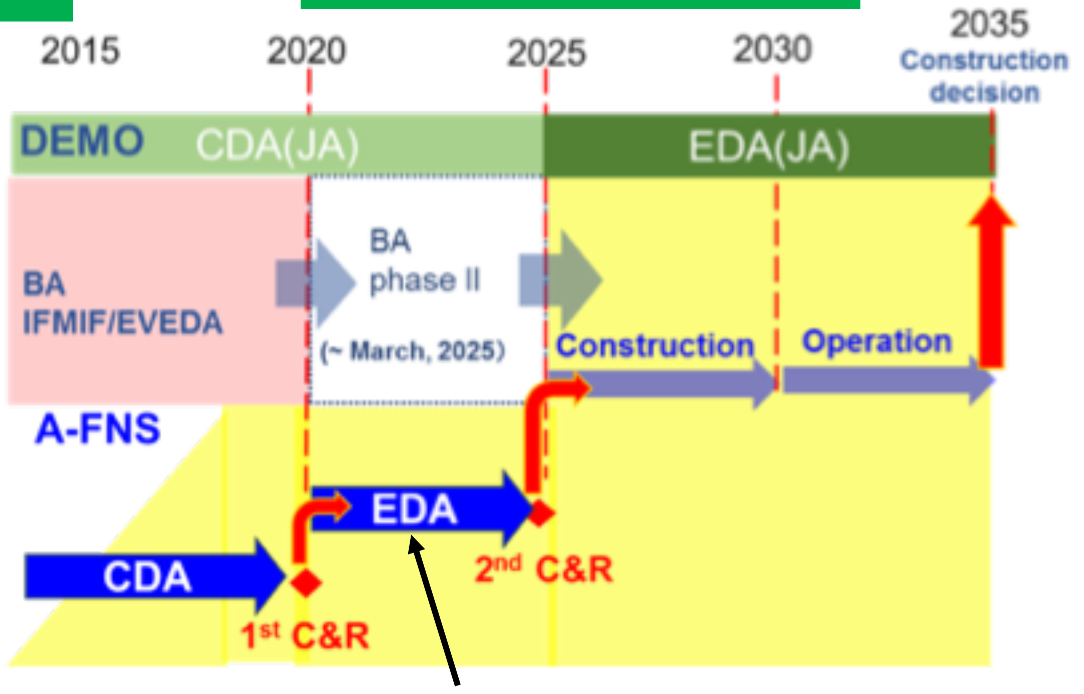
"Japan's road map and action plan to promote R&D for a fusion DEMO reactor" decided in 2017 requires that the material irradiation data should be acquired for a decision in the 2030s to start construction of a DEMO reactor.

Main objectives of A-FNS

1. Evaluation on material property of fusion material for neutron irradiation around 2035
2. Study on tritium production and release properties of fusion blanket
3. Evaluation on irradiation effect of diagnostic and controlled devices for DEMO reactor

Multipurpose usage for industrial radioisotopes production and neutron beam application

Formal Schedule



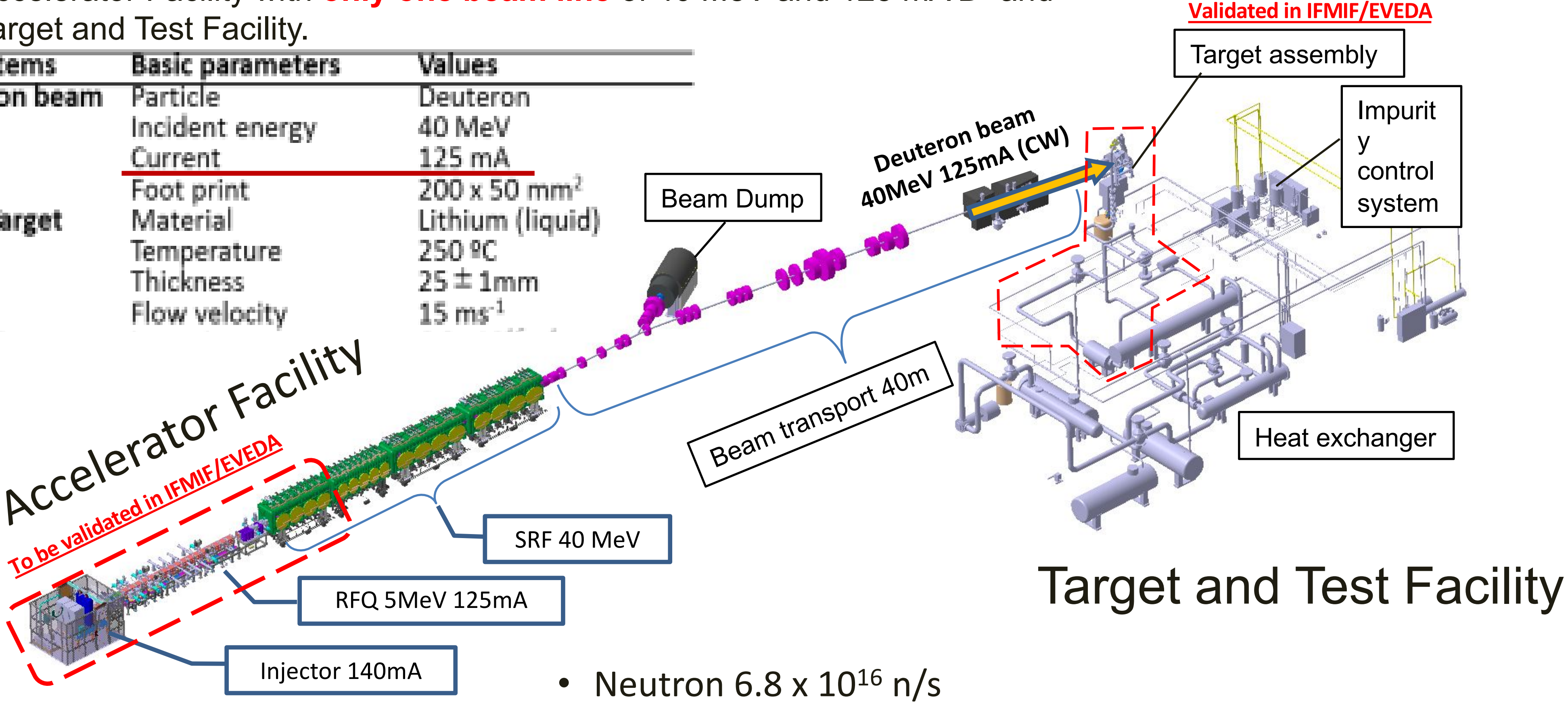
Continue A-FNS detail design

A-FNS Concept

A-FNS consists of

Accelerator Facility with **only one beam line** of 40 MeV and 125 mA D^+ and Target and Test Facility.

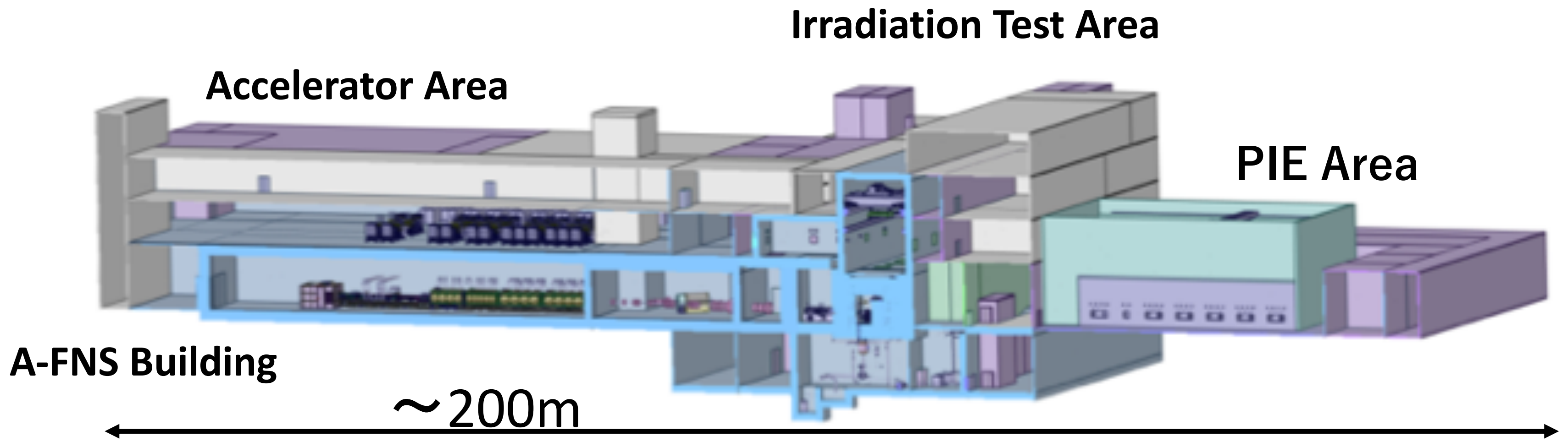
Items	Basic parameters	Values
Ion beam	Particle	Deuteron
	Incident energy	40 MeV
	Current	125 mA
	Foot print	200 x 50 mm^2
Target	Material	Lithium (liquid)
	Temperature	250 ºC
	Thickness	25±1mm
	Flow velocity	15 ms^{-1}



- Neutron 6.8 x 10^{16} n/s
- Average flux 6.0 x 10^{14} n/cm2/s
- Tritium production rate 3.5 g/fpy
- Be-7 production rate 0.75 g/fpy (Fpy: full power year)

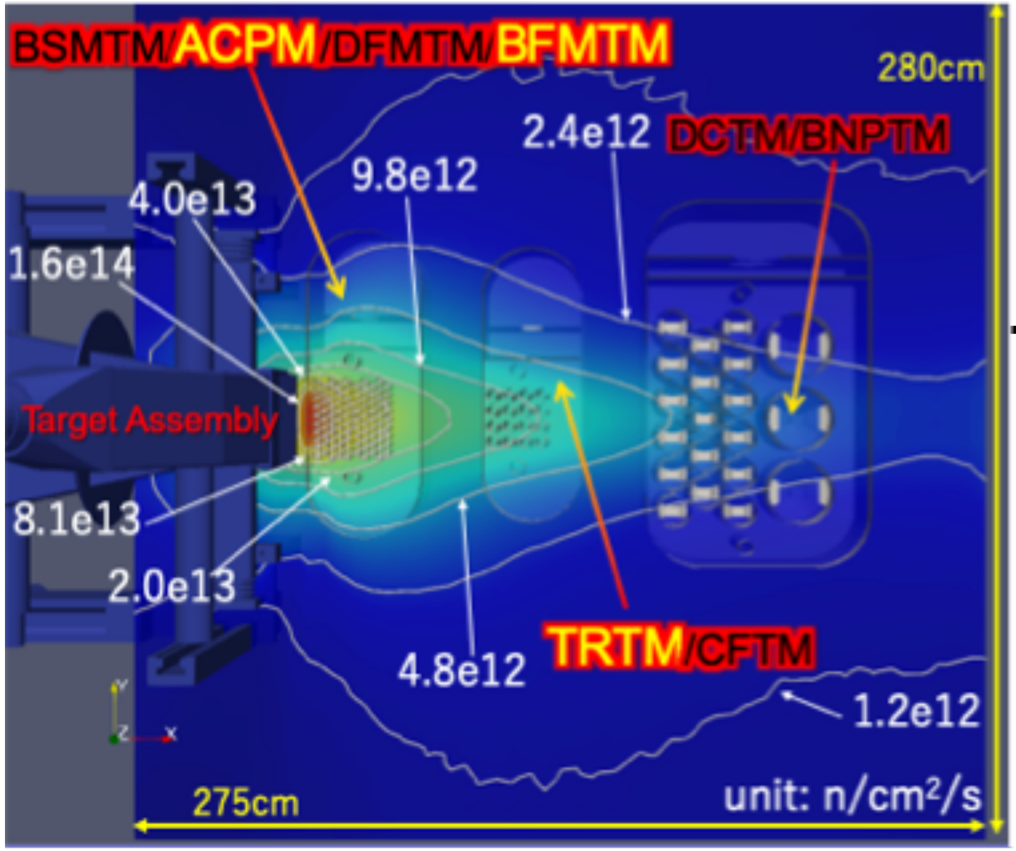
A-FNS facility & the Concept

- ✓ One line of IFMIF Accelerator（125mA）. Design will be based on IFMIF Engineering Report.
- ✓ Li Target loop is almost same of IFMIF/EVEDA. R&D. Purification validation will be done in BA Phase II.
- ✓ Many Irradiation modules will be proposed for Fusion Material Tests. This concept is Japanese original idea.
- ✓ Remote handling maintenance using side pull-out with all shielding plugs (Japanese Idea).
- ✓ Multi purpose Neutron Source for Industrial use.
- ✓ All Japan flamework with industry and university.



Irradiation Test Modules

Many Fusion Material Test Modules



A-FNS is utilized like multi-purposes neutron source.

For Fusion Material Test

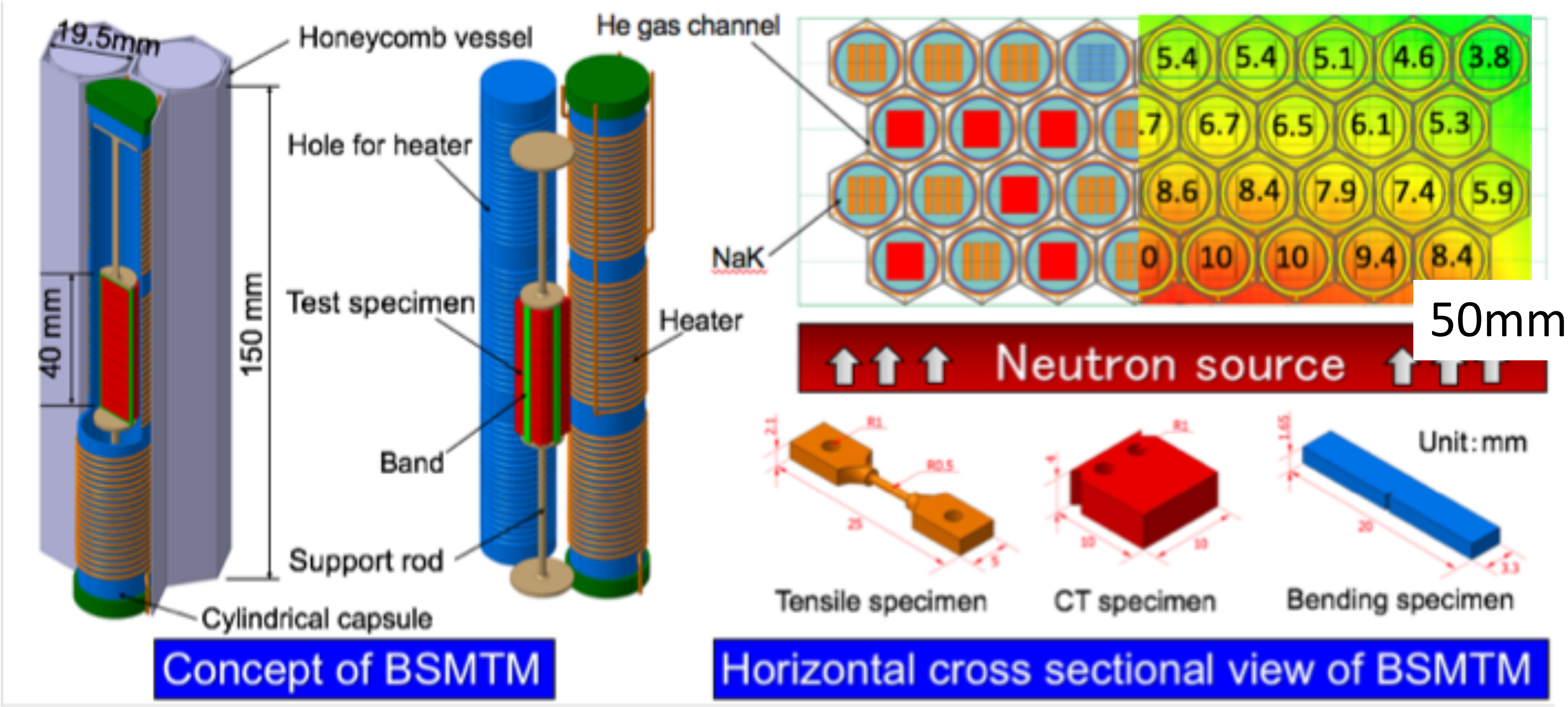
- Neutron flux measurement (NFMM)
- Blanket structure material test (BSMTM)
- Blanket functional material test (BFMTM)
- Divertor functional material test (DFMTM)
- Active corrosion production (ACPM)
- Tritium release test (TRTM)
- Creep fatigue test (CFTM)
- Diagnostic controlling device test (DCTM)
- Blanket nuclear property test (BNPTM)

For Industrial Use

- RI production (RIPM), Low Energy irradiation
- Neutron beam hole (NBHS), Gas & liquid loop

Design Example of Irradiation Module

- ✓ Concept of Honeycomb cylinder type for irradiation module of A-FNS. Consideration of thermal analysis, structure and maintenance by remote handling.
- ✓ Design of unified standardization capsules with BSMTM.
- ✓ Similar design concept of capsule of irradiation nuclear reactor.
- ✓ Simplified design and homogenization of irradiation condition suchi as temperature and DPA.



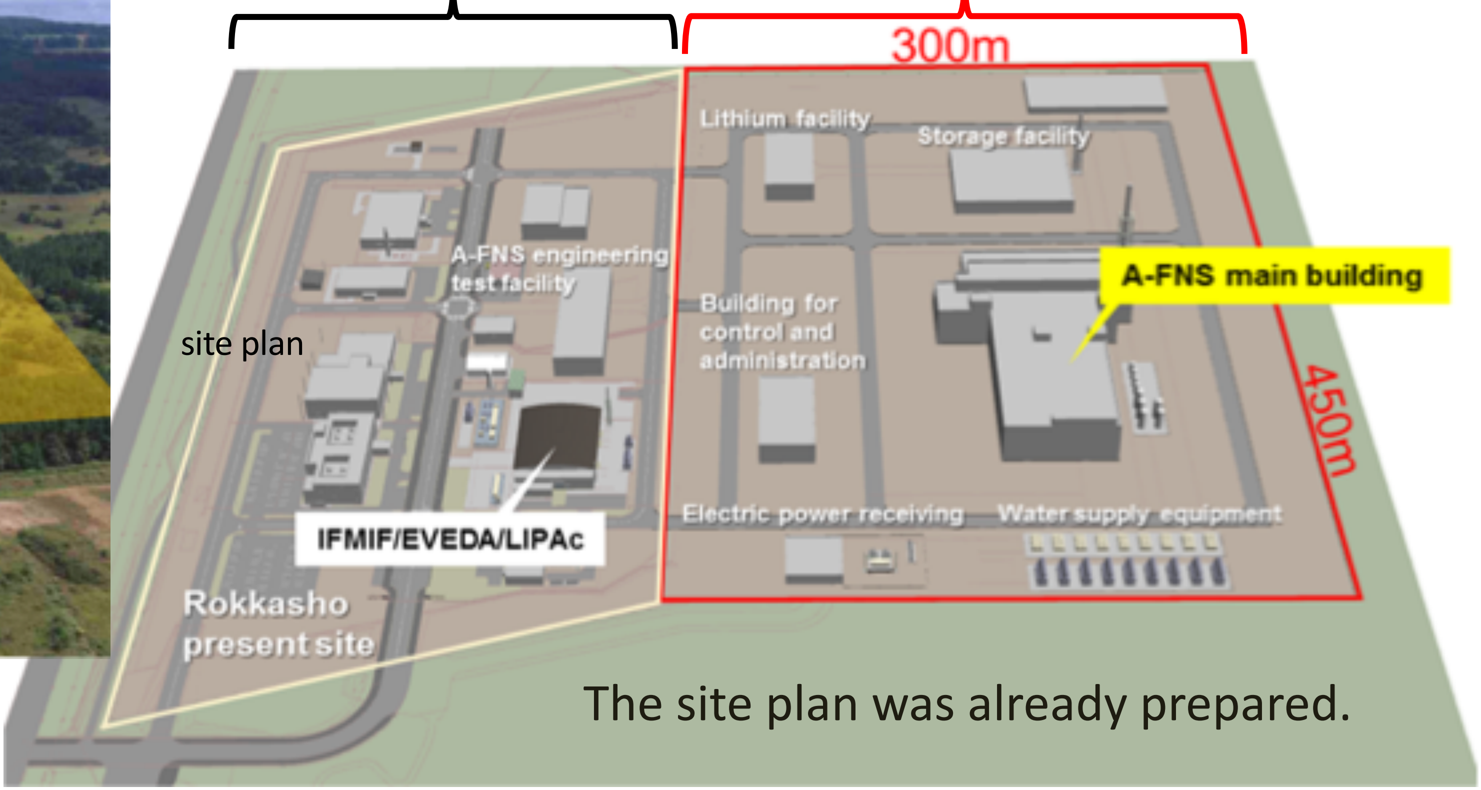
Site Plan of A-FNS

Candidate site

From the viewpoint of **utilization of IFMIF/EVEDA infrastructures**, we propose **Rokkasho Fusion Institute** in Aomori, Japan.

(Present)
Rokkasho Fusion institute

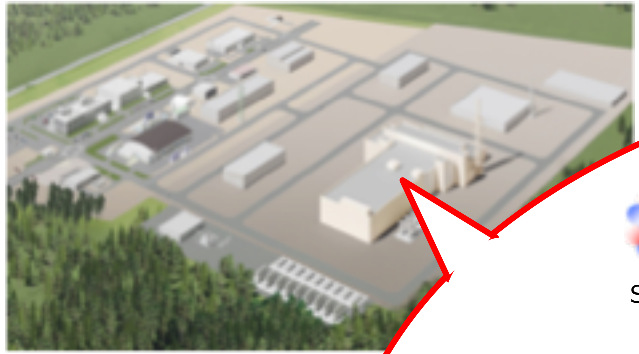
Additional area ~13.5 ha

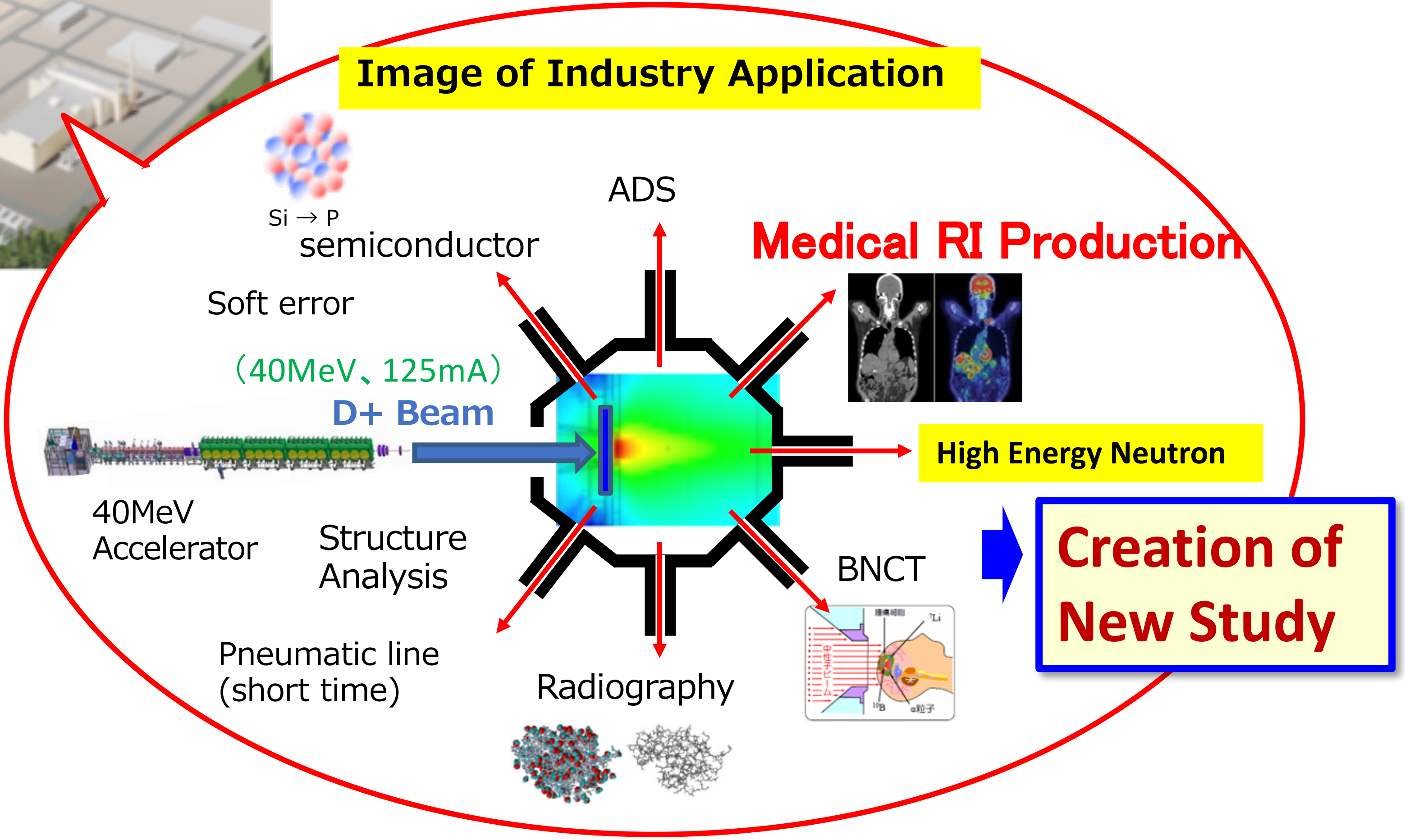


The site plan was already prepared.

Multi Purpose Application

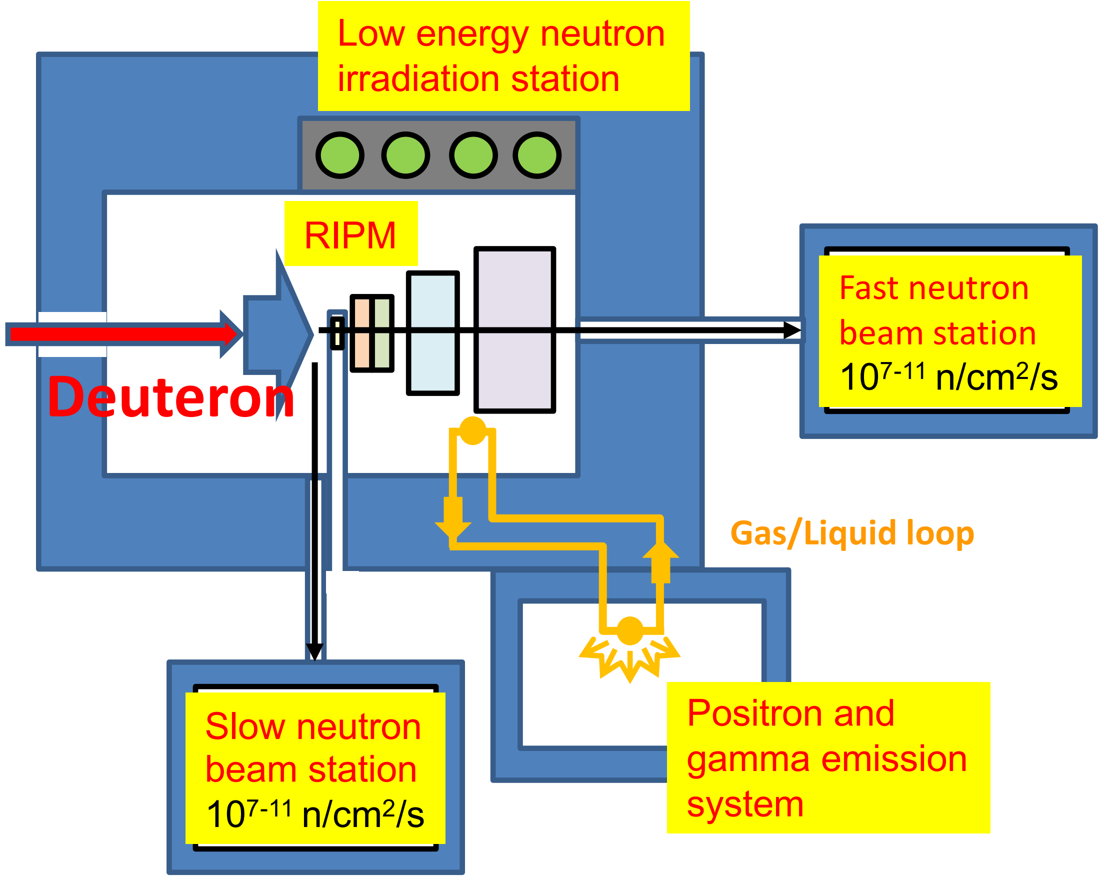
- A-FNS will provide not only fusion but also high-energy neutron irradiation field with high general-purpose properties covering domestic basic research, industrial, medical and energy applications.



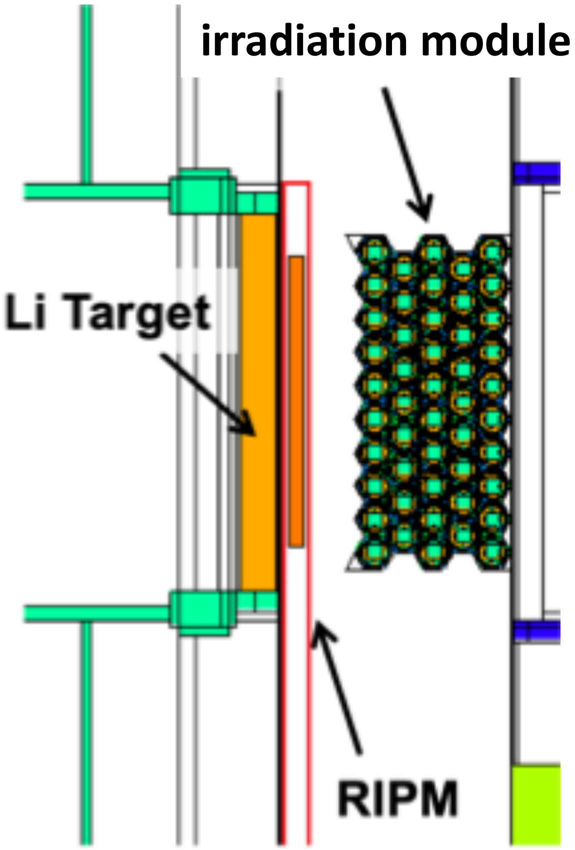


RI production & Beam Application

Moreover, we are planning to utilize as multipurpose usage of A-FNS. Therefore, we are progressing the design activity of RI production module for industrial and direct utilization of neutron beam station.



Mo-99 production in A-FNS



A-FNS can make Mo-99 over 100 TBq/week.
This amount covers the demand of Japan for one week.
Thickness of sample is enough thin not to have influence on irradiation module.

Other medical RI such as ^{64}Cu, ^{67}Cu, ^{90}Y etc. can be produced with high energy neutrons at A-FNS.

Conceptual design report of A-FNS

The CDR of A-FNS is to be compiled based on a Plant Integration Document（PID）in March 2020.

	Item level 1	Level2
1	Introduction	History of fusion neutron source Necessity of fusion neutron source development Objectives and contents of this CDR
2	Advanced Fusion Neutron Source	Design requirements Basic specifications configuration of the system Scenario and operation plan
3	Infrastructure	Overview, Site condition, Main building of A-FNS, Electric power receiving equipment, Water and Supply and Drainage equipment-supply, Air conditioning
4	Sub-system design	Accelerator, Target, Test Facility, Modules, RH, Maintenance, Control, Safety, PIE, Activation storage and related facilities
5	Summary	
Appendix		

Summary & Future Plan

- The LIPAc has showed the 5MeV acceleration on the RFQ. A long pulse demonstration will start with a CW dummy load before the installation of the SRF up to 9 MeV.
- Extension of BA activities, so called BA phase II, is under discussion to demonstrate the feasibility of 125 mA, 9MeV for long-days operation, in addition to R&D of EU/JA common issues.
- After the BA phase II, JA plans the construction of the *Advanced Fusion Neutron Source* (*A-FNS*) in Japan, which is one beam line system of the IFMIF as the same as DONES in EU, to satisfy the Japanese Action Plan towards DEMO.

Ultimate objective → to support the design, construction and operation of the future neutron source facility

Tentative schedule of IFMIF/EVEDA and A-FNS