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APPROACHES TO HIGH POWER OPERATION OF J-PARC ACCELERATOR

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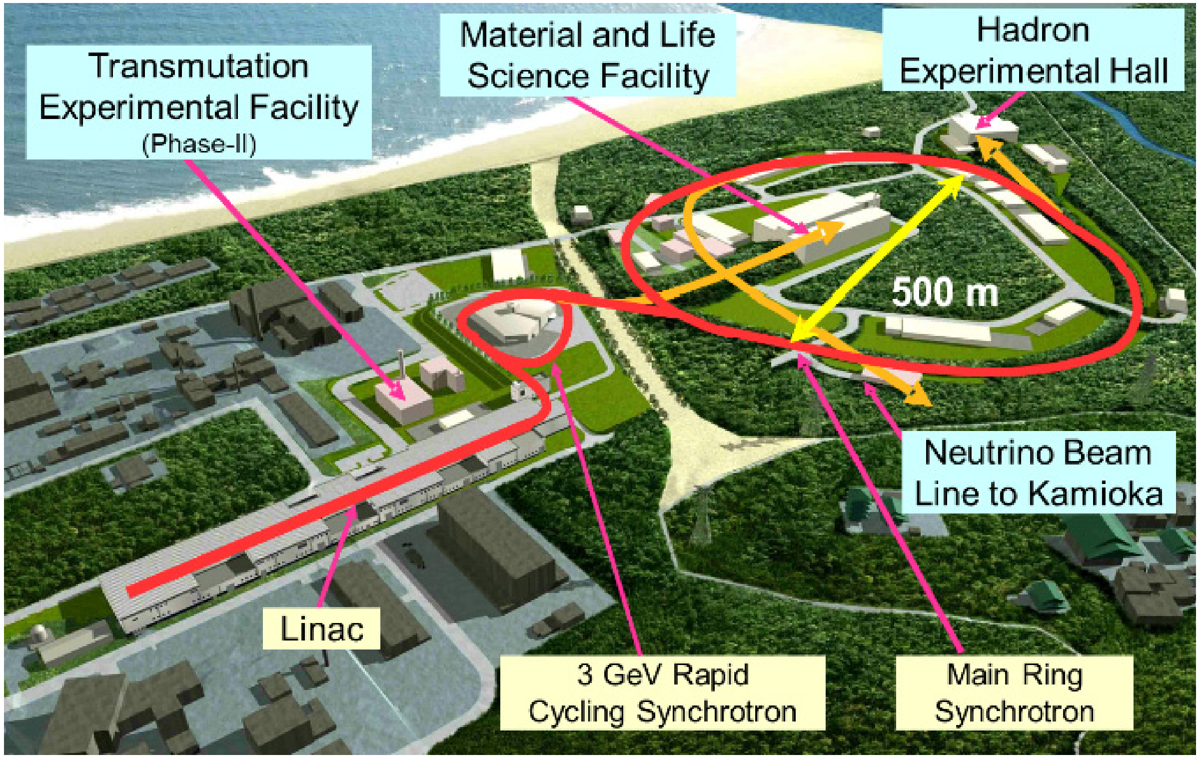
Introduction

Introduction: J-PARC Facility



A layout of J-PARC facilities

<u>Phase-I (ongoing)</u>

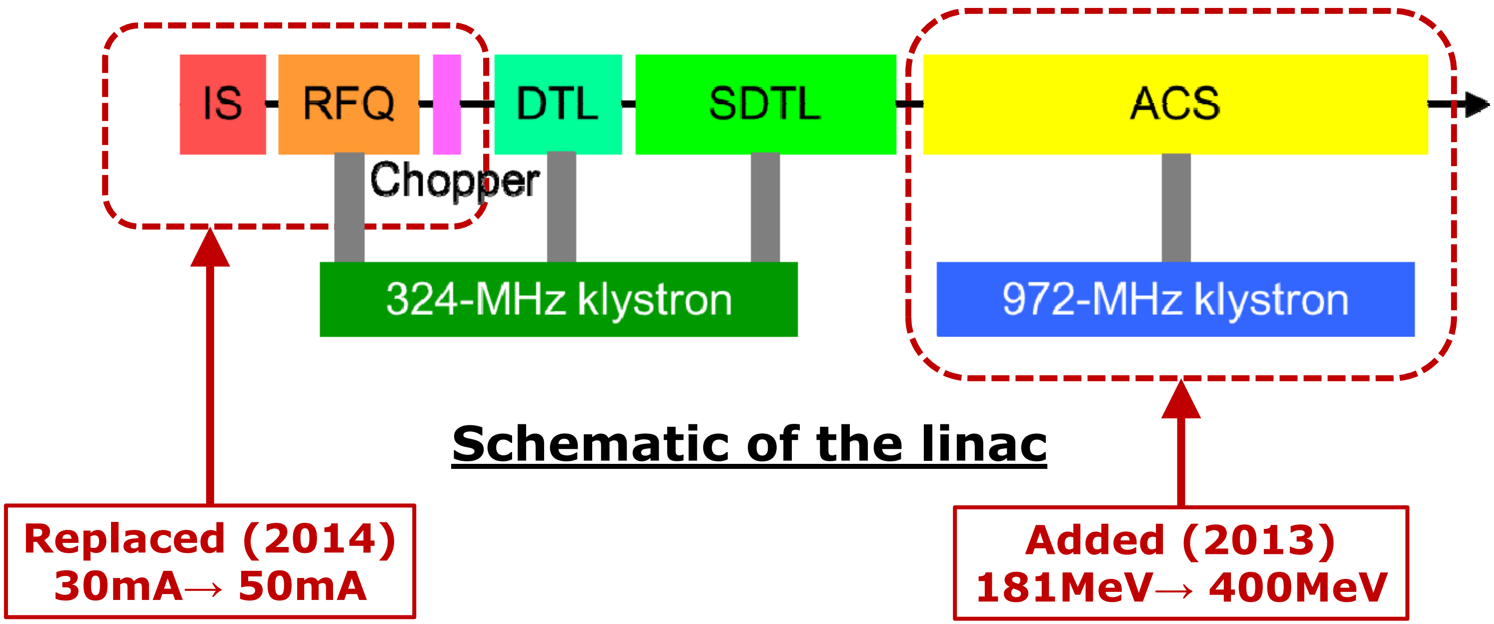
* 1 MW at RCS
* 0.75 MW at MR

<u>Phase-II (future)</u>

* 1.5 MW at RCS
* 50 Hz for TEF

Introduction: J-PARC linac

- The J-PARC linac started beam operation with 181 MeV and 30 mA in 2006.
- To realize the nominal performance, the beam **energy** (2013) and **intensity** (2014) upgrade were conducted.



Schematic of the linac

Completed Upgrade

- H⁻ ion source
- RFQ
- Beam chopper system
- ACS cavity
- Status after upgrade

Completed Upgrade plan: H^- ion source (1/2)

- Ion source upgrade requirement: 60 mA

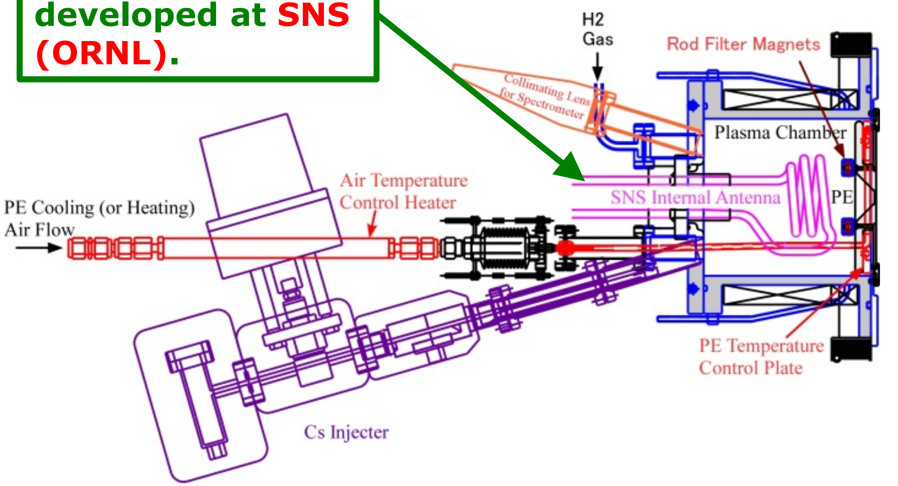
Achieved performance

	Previous IS	**Present IS**
Source plasma production	Arc discharge (LaB_6-FIL) , Cs free	RF discharge (internal antenna), Cs injection
H^- beam current	~20 mA (user op.) ~32 mA (max.) ~32 mA (max., **Cesiation**)	~45 mA (user op.) ~70 mA (max.)
Input power	25 kW @~20 mA	17 kW @~45 mA
H_2 gas flow rate	12 SCCM	21 SCCM
Continuous operation time	~1,000 h @~20 mA	2,200 h @~45 mA
Operation	Oct. 2006 – Jul. 2014	Sep. 2014 -

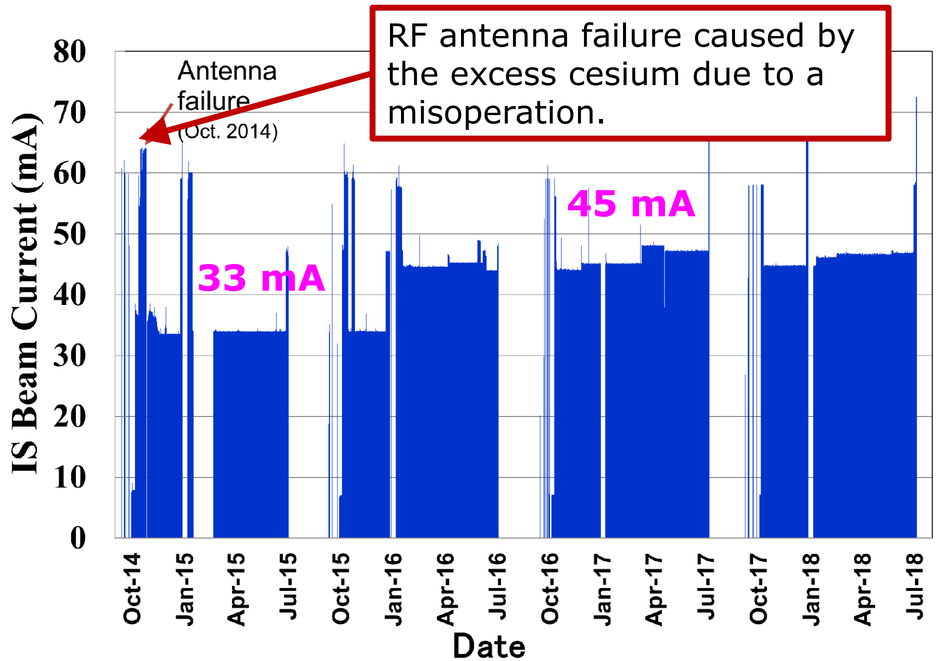
- The FIL-driven ion source almost satisfied the J-PARC's initial stage requirements of 30 mA, however, it was proven that the beam current level did not increase even by cesiation.

Completed Upgrade plan: H$^-$ ion source (2/2)

Internal-antenna developed at SNS (ORNL).



Schematic of RF-driven ion source (plasma chamber)

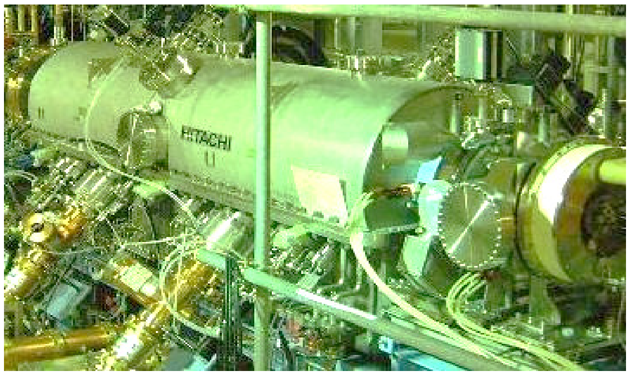


Operation history of the RF ion source

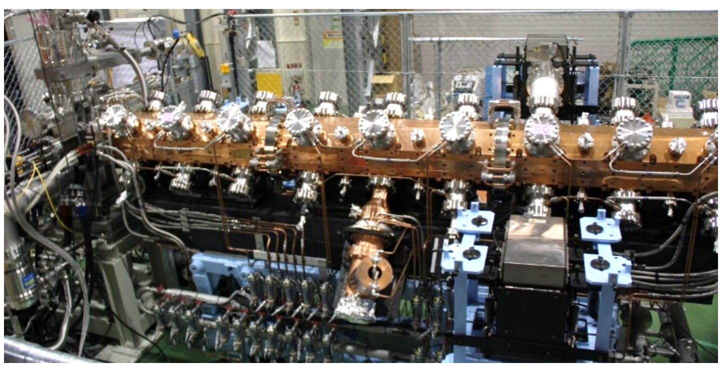
- The user operation was started with 33 mA. From Jan. 2016, the beam current increased to about 45 mA.
- The ion source has been successfully providing the beam with almost no serious trouble.

Completed Upgrade plan: RFQ (1/2)

Previous-RFQ (2006~2014)



Present-RFQ (2014~)



- At the beginning of the J-PARC linac operation, an RFQ with a design current of 30 mA was used. To achieve 1 MW, new RFQ with a design current of 50 mA was developed.
- The major engineering change between the previous and present RFQ is the design of the RF cavity structure.

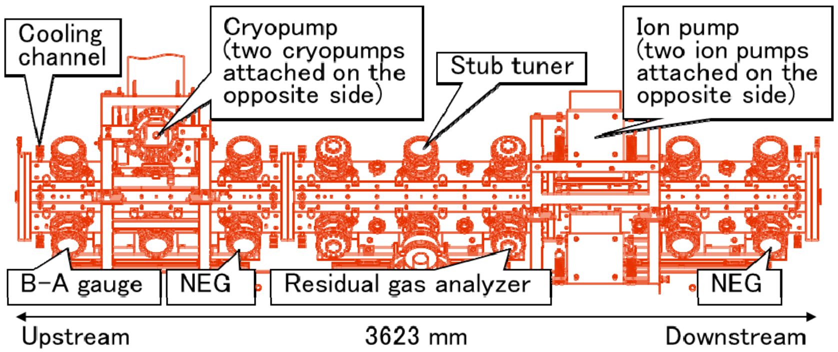
Previous-RFQ:

- The RF cavity is installed in a large vacuum vessel. It is difficult to obtain good vacuum quality because the surface area of this type is very large.

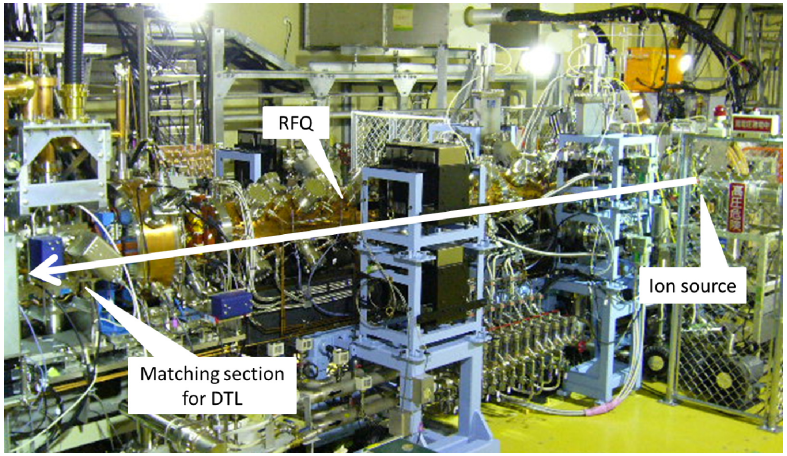
Present-RFQ:

- Vacuum-tight cavity structure is adopted. To this end, we adopted brazing for the assembly method.

Completed Upgrade plan: RFQ (2/2)



View of the RFQ vacuum devices



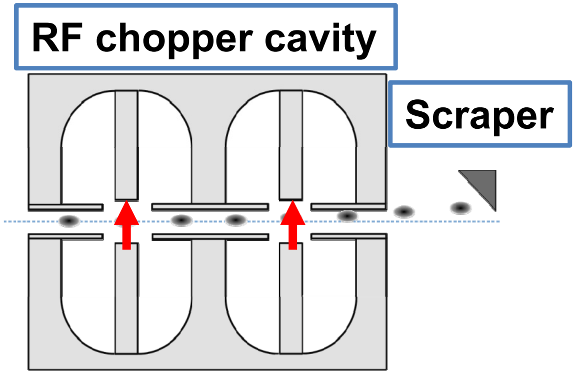
RFQ in the accelerator tunnel

- Vacuum system:
  - Three cryopumps (2700L/s for H_2),
  - Four ion pumps (400L/s for N_2),
  - Two NEG pumps (1000L/s for H_2),
  - Vacuum gauges, residual gas analyzer.
- Vacuum pumps are distributed longitudinally for all quadrant because the RFQ cavity is long and narrow shape.
- The B-A gauge shows the vacuum pressure is typically 1.5×10^{-5} Pa during the beam operation.

- After the off-line beam test, the RFQ was replaced in the summer of 2014.
- The present RFQ has been successfully operated without any serious trouble. The number of RFQ trip is about 15 times per day. These trip events reduce the beam availability by about 1%.

Completed Upgrade plan: Beam chopper (1/2)

- In order to produce the medium pulse structure, a beam chopper has been used after the RFQ. The chopper system consists of an RF chopper cavity and a scraper made of carbon fiber composition.



Schematic of the Beam chopper

- In 2014, the RF chopper cavity was replaced with a new one to decrease beam loss at the cavity.
  - Electrode separation: 10→14 mm
  - Diameter of the beam pipe: 14→24 mm (to compensate transverse size)
  - RF field in the gap: 1.6→2.6 MV/m (to compensate longitudinal size)
  - Peak driving power: 30→115 kW

- The new beam chopper has been successfully operated without any serious trouble. Significant beam loss is not observed.

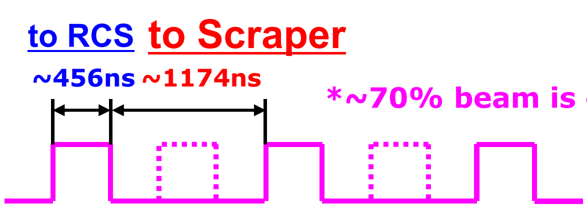
Chopper cavity off-line test before installation

Completed Upgrade plan: Beam chopper (2/2)

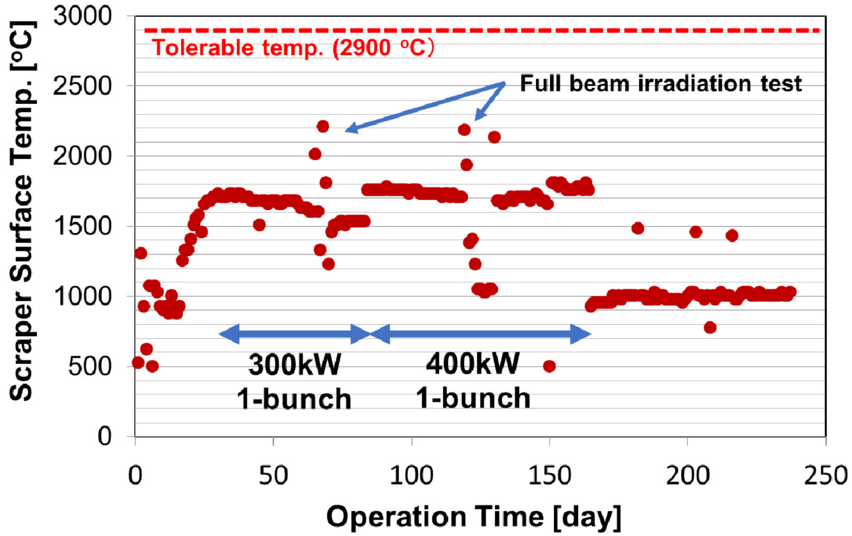
■The scraper in the chopper system is the key component to realize the intensity upgrade.

■Recently, 400 kW operation with **single-bunch** was conducted at the RCS.

➢ In the single-bunch operation, the scraper is receiving the heat flux about **1.3 times** larger than that of the 1 MW & double-bunch operation (our goal).



Intermediate bunch structure



Time variation of the temp. on the scraper surface

❑ At 400 kW and single-bunch operation, the temp. reached and saturated about 1800 ℃, which is sufficiently lower than the tolerable temperature of 2900 ℃.

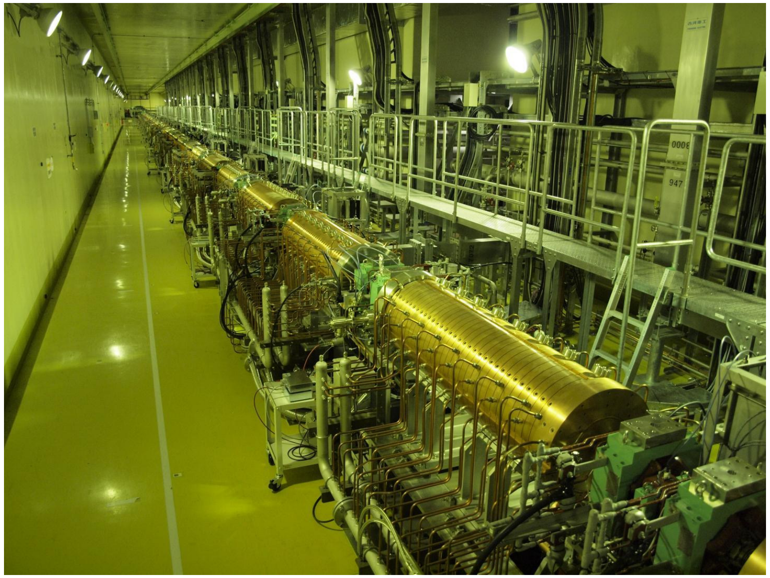
➢ **The scraper is capable of using at the 1-MW operation without problem.**

Completed Upgrade plan: ACS linac (1/2)

- To suppress the space-charge effect, which limits the obtainable beam power at the RCS, the beam energy from the linac was increased from 181 MeV to 400 MeV by adding ACS cavities.

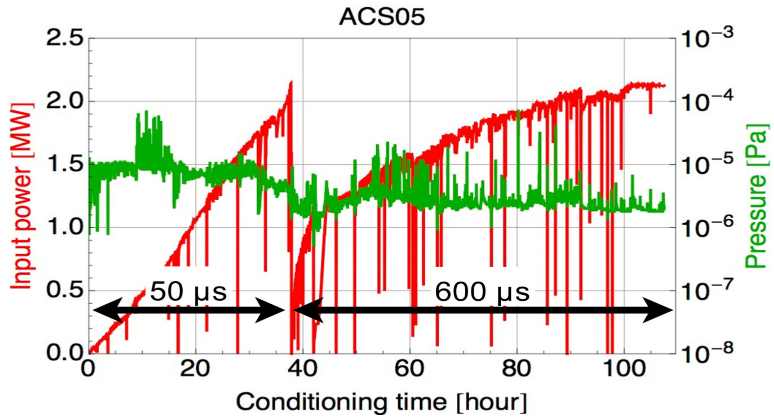
- **History of the ACS**

- In Mar. 2009, ACS modules of mass production started.
- In the end of 2010, the first mass-produced ACS module was completed and its high-power test was performed.
  - Only five modules could be tested before the installation due to the effect of huge earthquake in 2011.
- In Aug. 2013, installation to the beam line was started.
  - It took one day to complete for one ACS cavity.
- In Nov. 2013, high-power conditioning was started.
  - An average conditioning time is 149 hours.
- In Dec. 2013, the beam commissioning was started.
  - **400 MeV was achieved in Jan. 2014.**



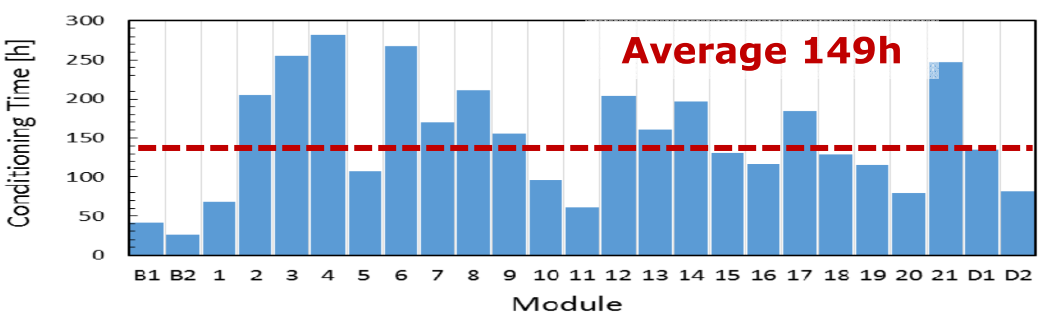
ACS in the accelerator tunnel

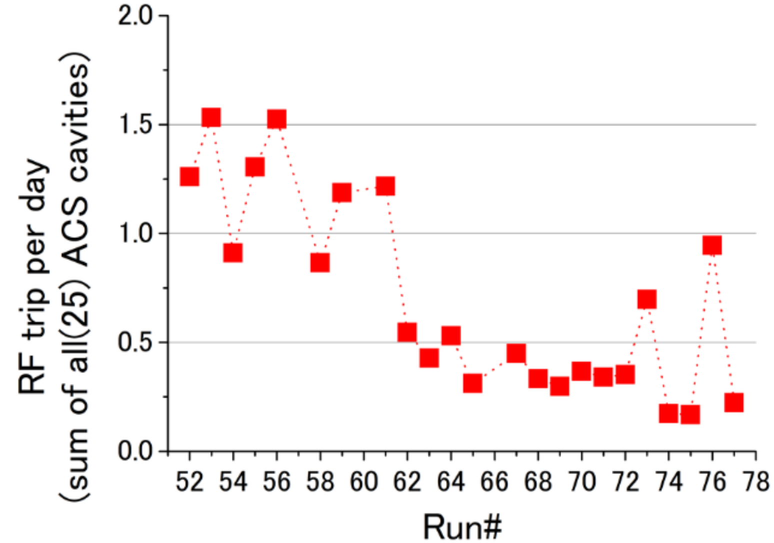
Completed Upgrade plan: ACS linac (1/2)



Typical conditioning history

- In the first step, we put short pulse RF (50μs) up to 2 MW.
- Then we put long pulse RF (600μs) up to 2MW.

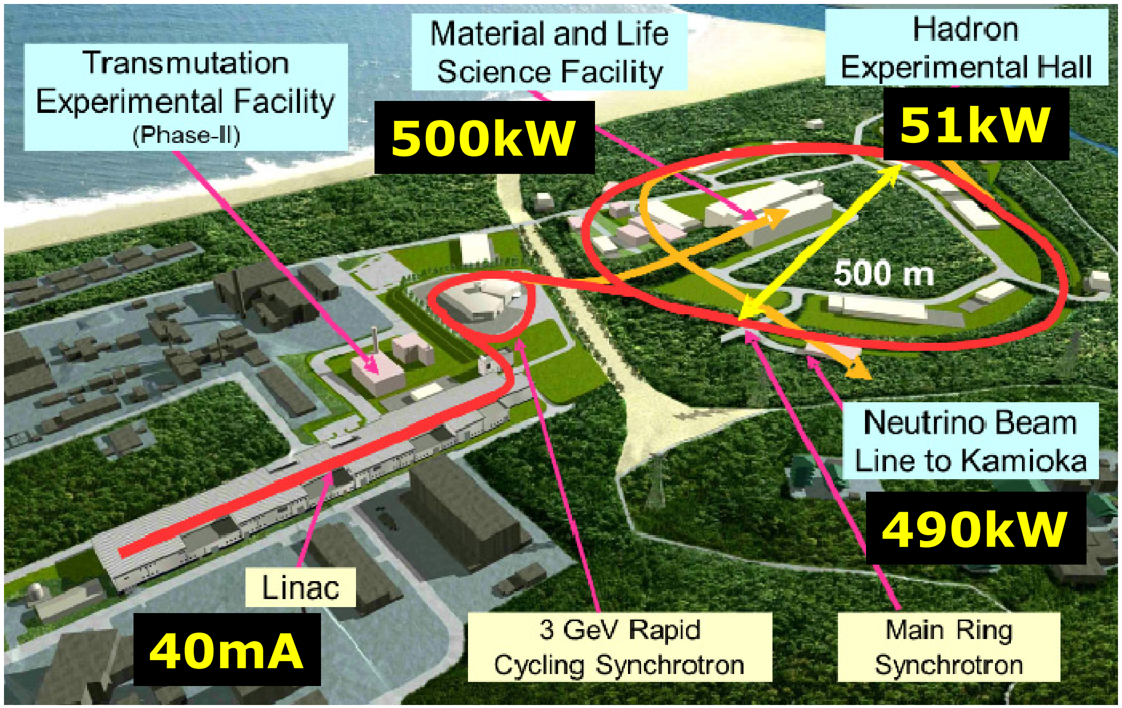




Time variation of number of ACS RF-trip

- ☐ The ACS cavities have been successfully operated without any serious trouble.
- ☐ The trip rate decreases with the time to an acceptable value of approximately 0.3 times per day.

Completed Upgrade plan: Status after upgrade



Achieved beam power for user operation (as of July, 2018)

- The linac is operated with **40 mA** and high availability of approximately **90%**.
  - The beam current will be increased to 50 mA after 2018 summer maintenance.
- MLF-1MW demonstration operation was conducted.
  - In Jan- 2015, the RCS demonstrated the beam acceleration and extraction of 1MW-equivalent with a single-shot operation mode.
  - In Jul- 2018, 1MW-1hour operation was successfully demonstrated.

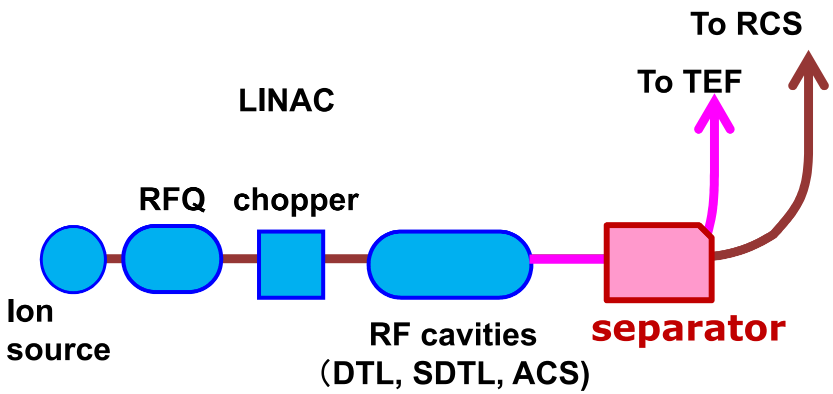
Future Upgrade Plan

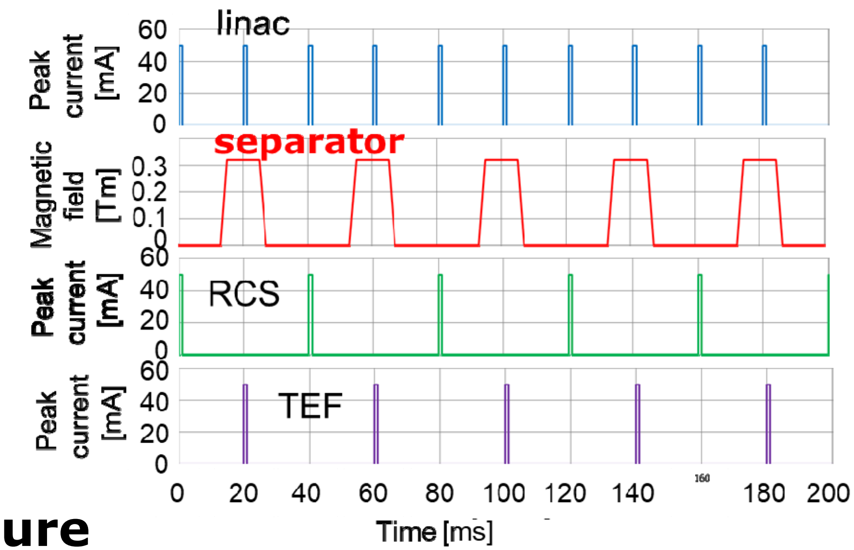
- Increase the RCS beam power to 1.5 MW
- Duplation the repetition rate for the TEF

Future Upgrade plan 1/2

- **Increase the RCS beam power to 1.5 MW:**
  - Peak current: **>60 mA**
  - Pulse length: **>600 μs**

- **Duplation the repetition rate for the TEF:**
  - Repetition rate: **50 Hz**





Beam structure

Future Upgrade plan 2/2

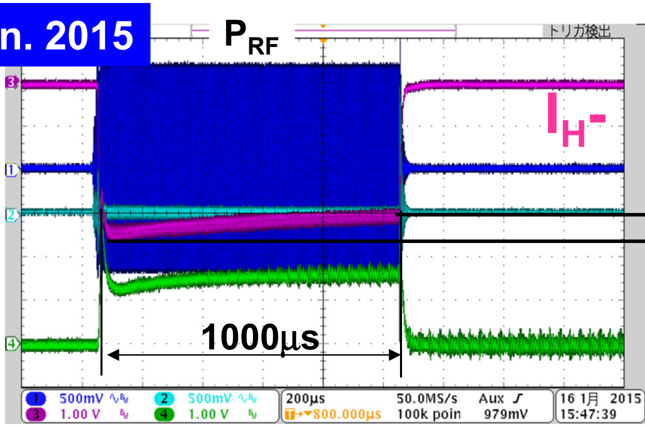
Summary of feasibility of Linac Upgrade

Peak current [mA]	Pulse length [μs]	Rep. rate [Hz]	Ion source	RFQ DTL SDTL ACS	RF system	Beam loss	Utility (water cooling)
60	500	25	◎	◎	○	○	○
50	600	25	◎	◎	○	○	○
50	600	50	○	◎	△	△	△

◎: No issues with present system or configuration.
○: No big issues but needs studies and may require minor modifications.
△: Issues but within reach, needs significant modifications.
×: Hard to reach, require major modifications

Future upgrade plan: High intensity ion source

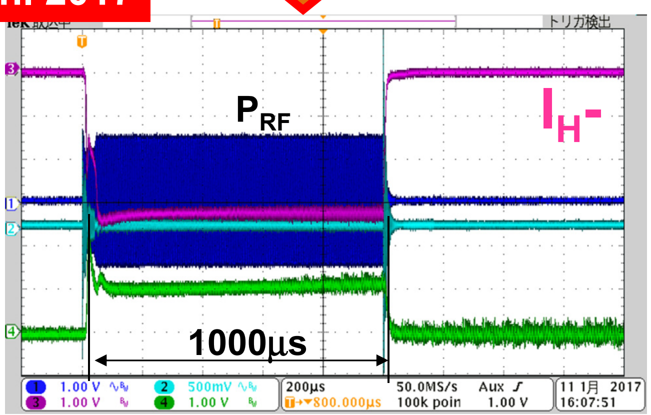
Jan. 2015



- I_{H^-}= 66 mA
- ε_{nrmsy}= 0.30 πmm·mrad
- P_{RF}= 40.6 kW
- 10% tilted

"Evacuation of impurities gas (N_2, Ar) strongly in the plasma generator."

Jan. 2017

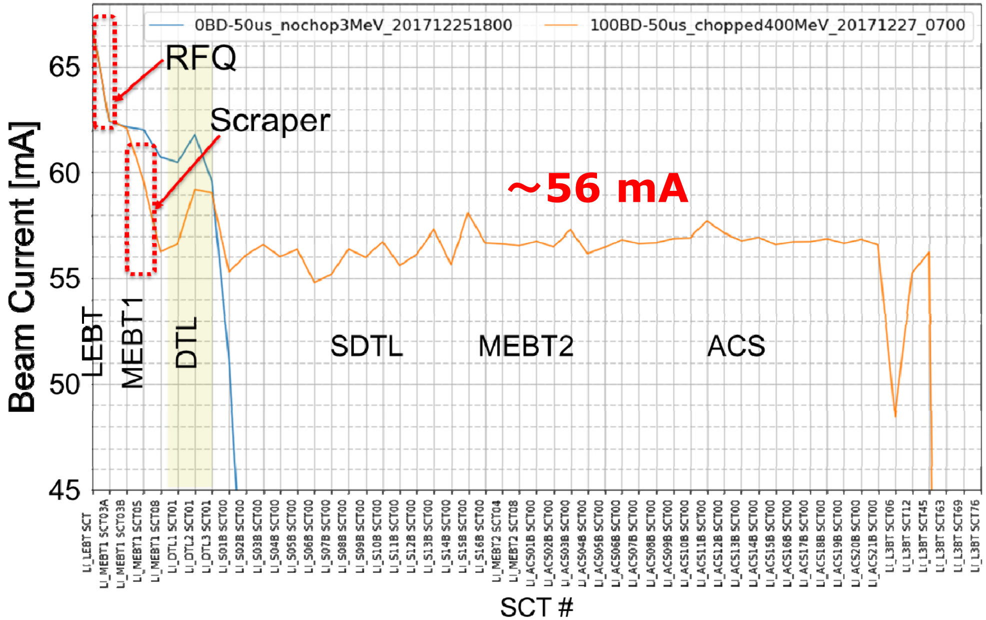


- I_{H^-}= 66 mA
- ε_{nrmsy}= 0.27 πmm·mrad
- P_{RF}= 26.4 kW
- Flat beam

- The ion source is the key component to realize the 1.5 MW upgrade plan. We have been performed the R&D work of the ion source at an off-line test-stand.
- These results show this ion source is satisfied with the requirement for the upgrade.

Future upgrade plan: Trial 60-mA beam study

- Trial beam study with **60 mA** was started in July 2017. The first 400-MeV and 56-mA beam at the linac exit was demonstrated in December, 2017.



Beam current along the beam line

- No significant beam loss was observed at DTL1 section.
  - The shift of the DT alignment due to the huge earthquake (2011) is not probably fatal to the 60-mA operation.
- Issues are the transmission in the RFQ and the MEBT1 scraper.
  - To avoid the decrease of the beam transmission,
    - Increasing the RFQ tank level
    - Re-optimization of the MEBT1 lattice
    - Adjustment of the scraper gap.
- Beam simulation result shows reduction of the beam halo from the ion source is effective to improve the RFQ transmission.
  - We will continue the R&D work of the ion source in the future.

Future upgrade plan: Klystron Power Supply

LINAC18
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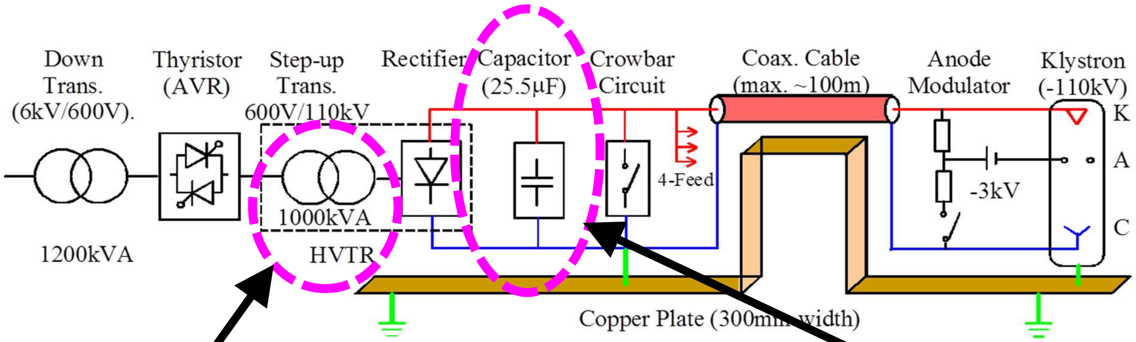
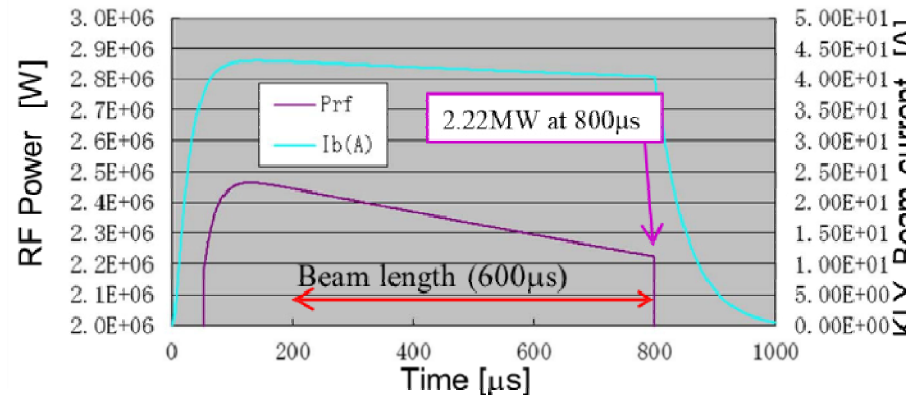


Block diagram of klystron power supply

- The apparent power of 1154 kW will be necessary for 50-Hz and 600-μs operation. It exceed the rated capacity of 1000 kVA of the HVTR.
  - Therefore, it is planned to add auxiliary power supplies.

- In case of 800-μs operation, the simulation result shows klystron output power drops from 2.47 MW to 2.22 MW along the pulse due to the capacitor bank droop.
  - The reduction is not fatal because the max. required power for 60-mA operation is 1.89 MW.



Summary

Summary

- In 2006, the J-PARC linac started beam operation with 30 mA (design) and 181 MeV.
  - To realize the nominal performance of 1 MW at RCS and 0.75 MW at MR, the beam intensity and energy upgrade were conducted. These upgrades were completed in 2014.
  - At present, the linac is operated with 40 mA and high availability of approximately 90%.

- We are considering two upgrade plans that increasing the RCS beam power to 1.5 MW and doubling the linac repetition rate to 50 Hz for the planned TEF.
  - We started trial beam studies with 60 mA in July 2017. 400 MeV and 56 mA beam at the linac exit was demonstrated in December, 2017. Further trial beam studies are planned to demonstrate 1.5 MW-equivalent beam at the RCS.
  - Although some hardware upgrades are required, these are not so serious except for beam loss. For the mitigation of beam loss, the beam simulation and experiment are ongoing.

Thank you for your attention !