Recent progress on R&D toward Neutral Beam Injector for ITER and JT-60SA

Rapporteur; Hiroyuki TOBARI
(Japan Atomic Energy Agency)

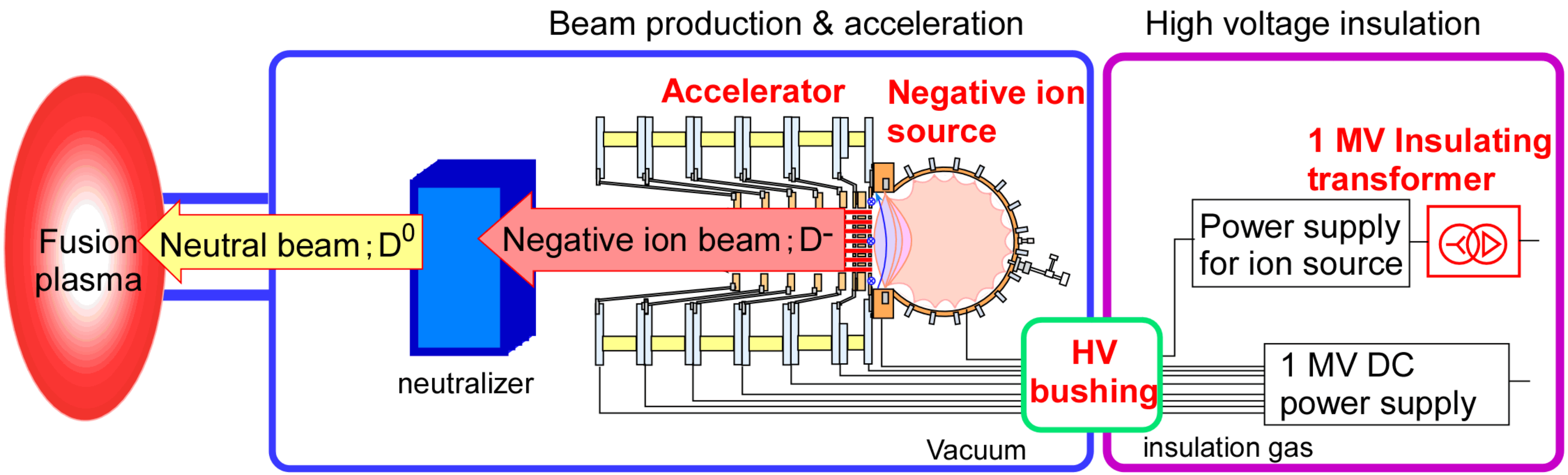
(FIP/2-5Ra)

Development of DC ultra-high voltage insulation technology for ITER NBI
H. Tobari et al., (JAEA)

(FIP/2-5Rb)

Progress in long pulse production of powerful negative ion beams for JT-60SA and ITER
A. Kojima et al., (JAEA)

Target and status on NBIs for ITER and JT-60SA



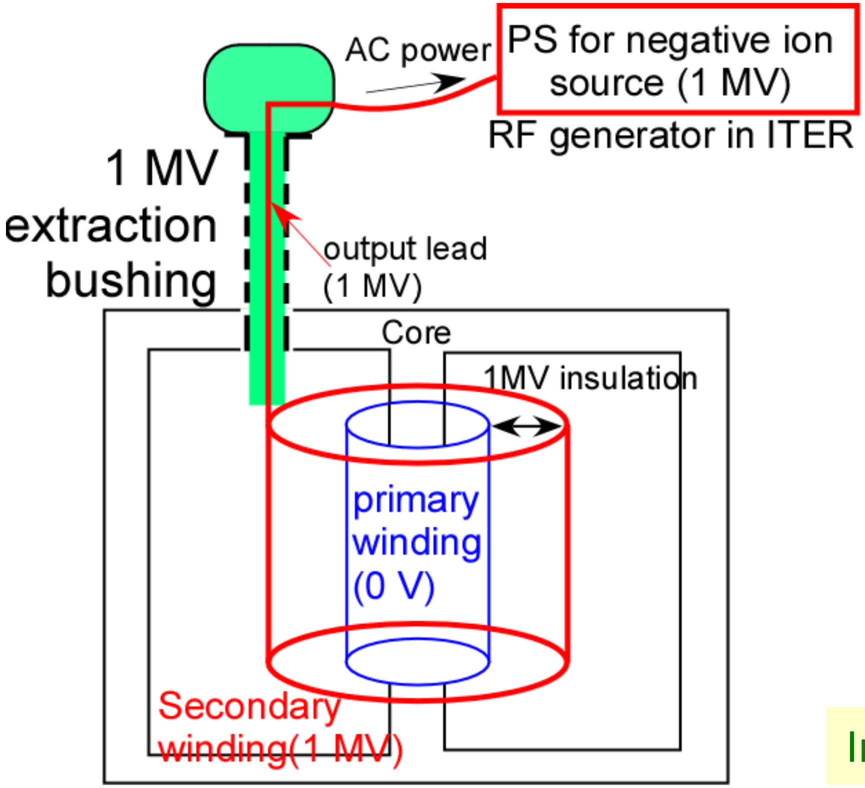
Negative ion beam	(ITER NB) 1 MeV, 40 A, 3600 s	(JT-60SA) 500 keV, 22 A, 100 s

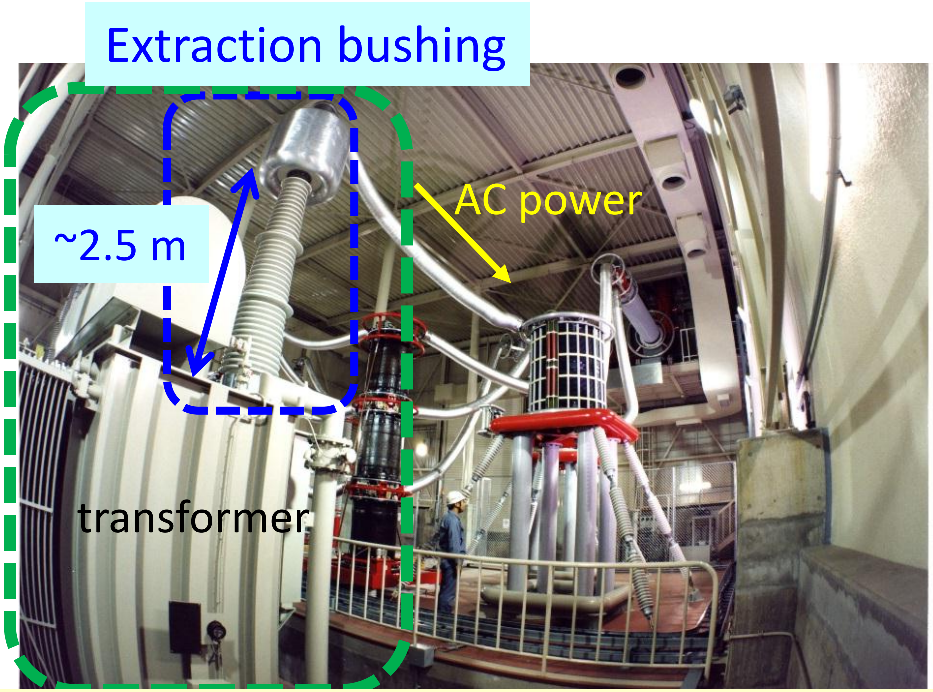
	on or before FEC 2012	**on FEC 2014**
Items	*High voltage insulation*	
Insulating transformer	DC 500 kV, 10 s ⇨	**DC 1 MV, 3600 s**
HV bushing	Part test ⇨	1MV vacuum insulation design
	Long pule beam production & acceleration	
High current beam	13 A, 30 s ⇨	15 A, **100 S**
High energy beam	980 keV, 0.4 s ⇨	680 keV, **60 s**

1 MV insulating transformer

【Function of the insulating transformer】

To feed AC power to the PS for negative ion source at DC 1 MV potential.





Insulating transformer for JT-60U (DC 500 kV, 10 s)

A bushing extracting output lead at 1 MV from the transformer to the air is needed.

(Issue) ϕ=2 m, **H=10 m** insulator is required for 1 MV in ITER.

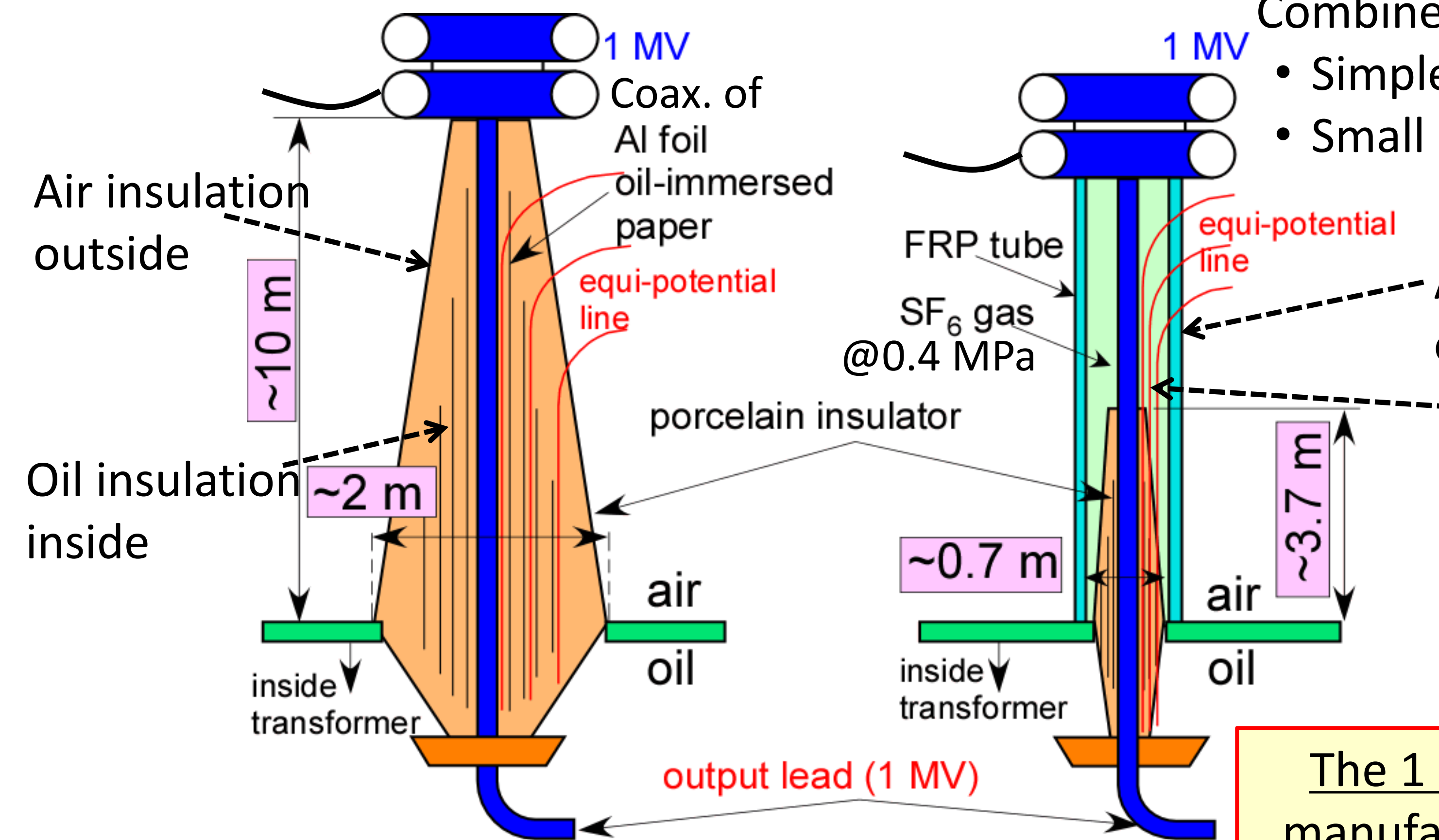
No existing manufacturing facility.

New 1 MV bushing

Condenser bushing(porcelain + aluminum foil + oil-immersed paper)

【New device】Composite bushing

Combined with
- Simple FRP tube
- Small condenser bushing



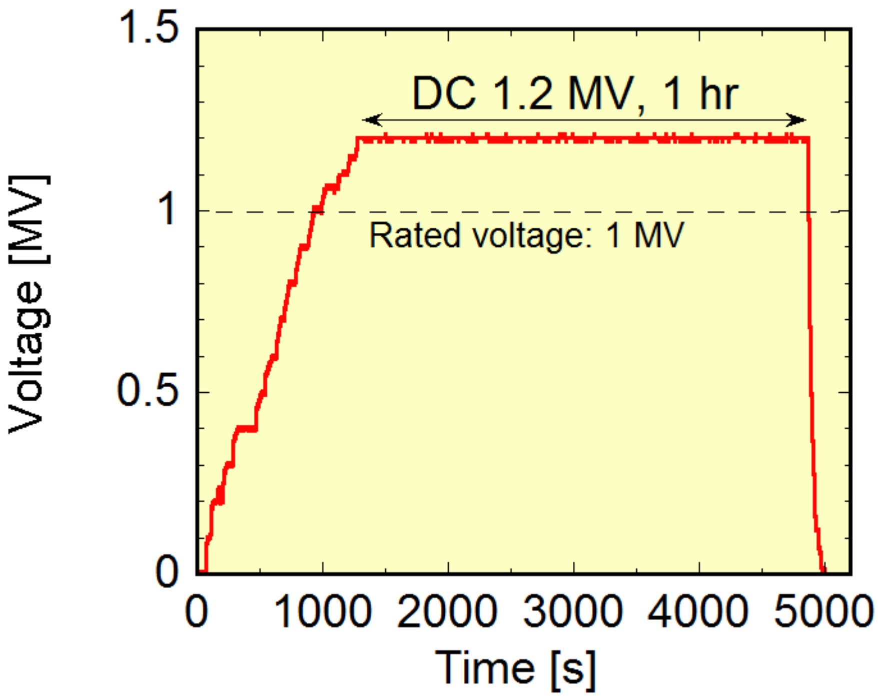
Not manufacturable

with manufacturable parts

The 1 MV bushing with manufacturable parts has been newly devised.

1 MV insulating transformer mockup

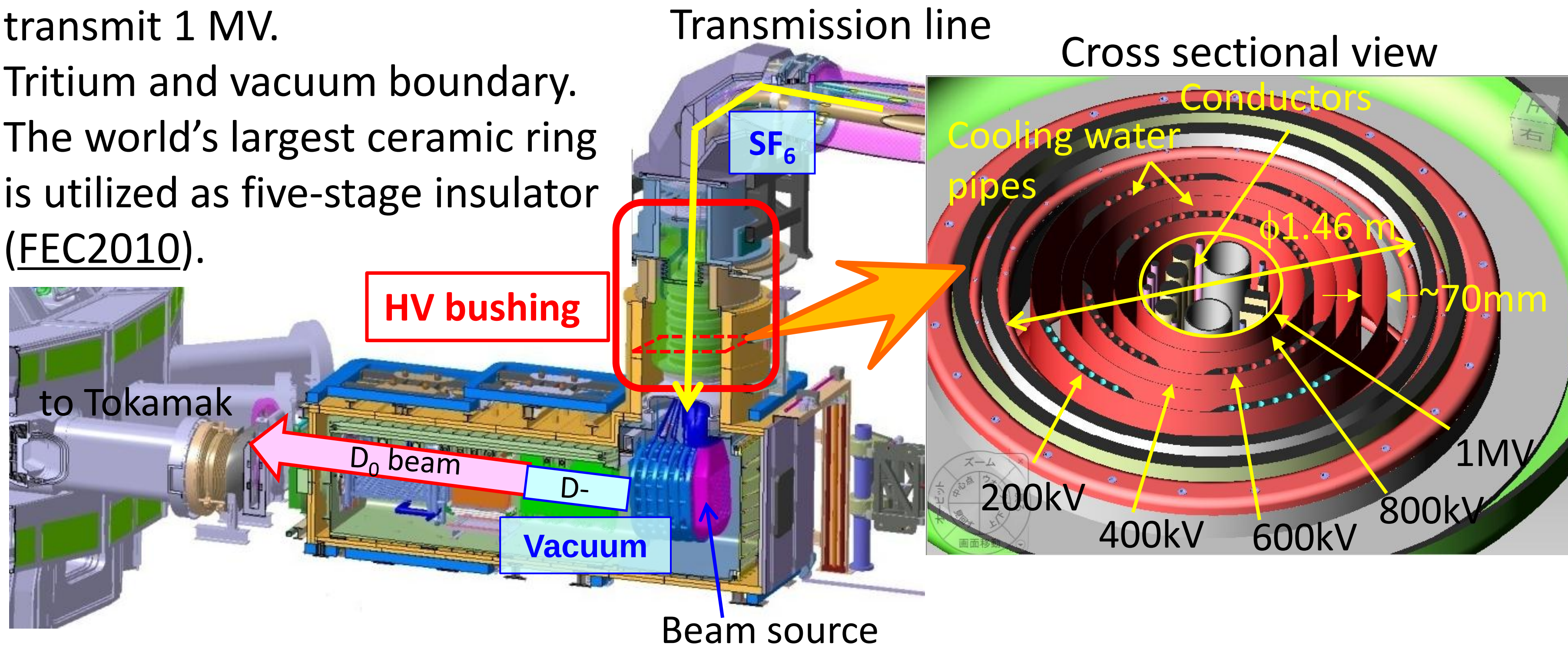
- The 1 MV insulating transformer mockup has demonstrated stable insulation of 1.2 MV for 1 hr (including 20 % margin of rated voltage).
- **The ITER requirement was achieved.**



The 1 MV insulating transformer has been successfully developed for ITER.

HV bushing

- An insulating feedthrough to transmit 1 MV.
- Tritium and vacuum boundary.
- The world's largest ceramic ring is utilized as five-stage insulator (FEC2010).

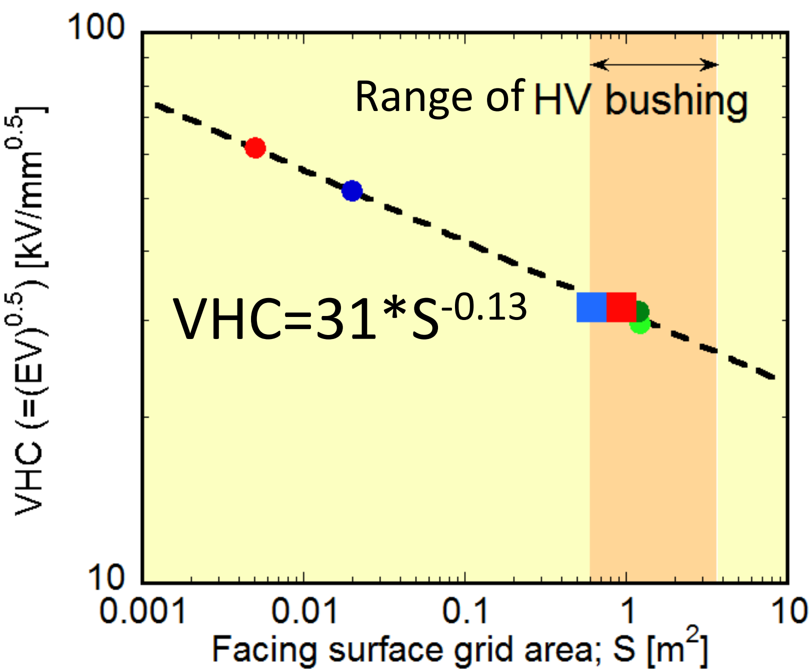


- All conductors and pipes at five different potentials (200 kV~1 MV), electrically shielded by five coaxial cylindrical screen (e.g. ϕ=500 mm, H=3.6 m), in a single vacuum space in order to minimize the tritium boundary.

- Even with the world's largest ceramic ring (ϕ1.46 m I.D.), insulation distance of each gap is no more than around 70 mm.

(Issue) Voltage holding in large coaxial electrodes is not clarified in the field of vacuum insulation.

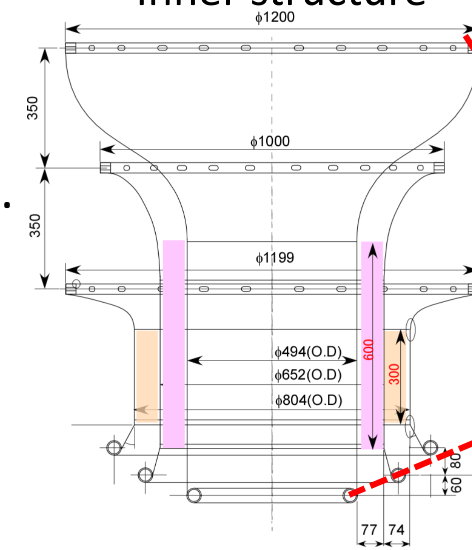
- The dependence of voltage holding capability on surface area was investigated in wide range of surface area.

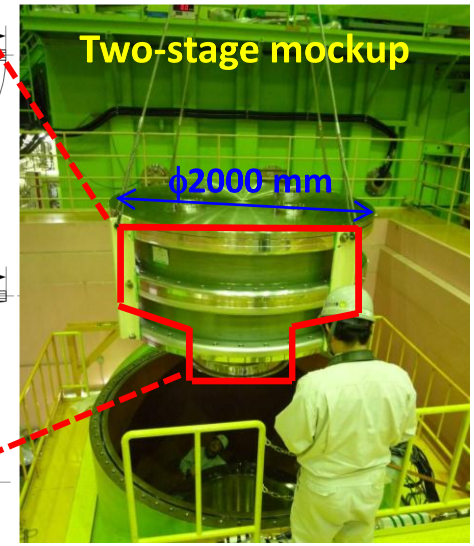


- The empirical scaling for large electrode has been obtained.

Using this scaling, two-stage mockup was designed and and tested.

Inner structure





Stable insulation of 480 kV for 1 hr.
(including 20 % margin of rated voltage for ITER)
→**vacuum insulation design for 1 MV is validated.**

Vacuum insulation of the HV bushing for ITER has been ensured.

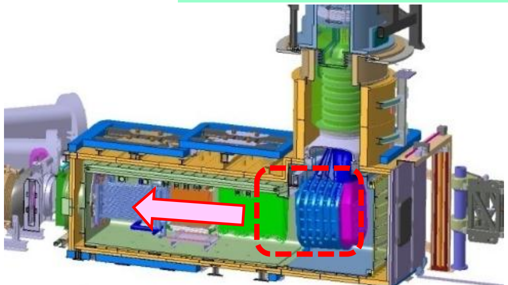
NBIs on ITER and JT-60SA

Cs-seeded negative ion source & Multi-Aperture Multi-Gap (**MAMuG**) accelerator

(Issue) Long pulse production

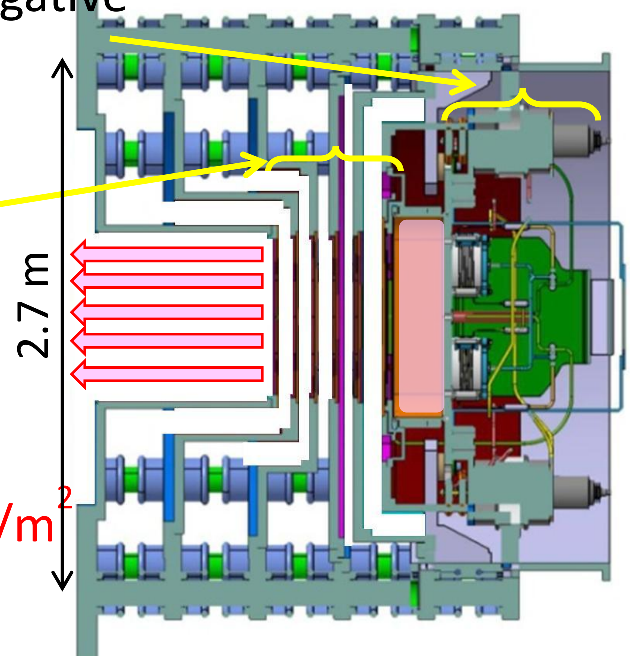
(Issue) Long pulse acceleration

ITER NBI



RF-driven negative ion source

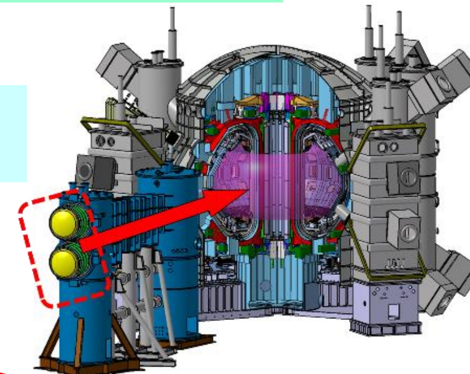
Five-stage accelerator



D⁻ beam

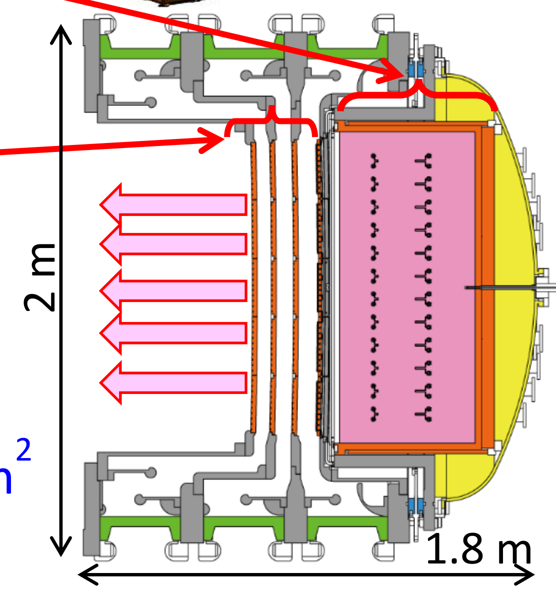
- 1 MeV
- 40A, 200 A/m^2
- 3600 s

JT-60SA N-NBI



Arc-driven negative ion source

Three-stage accelerator

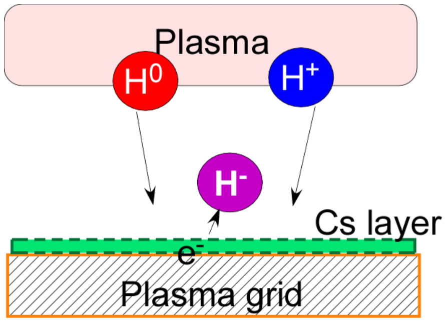


D⁻ beam

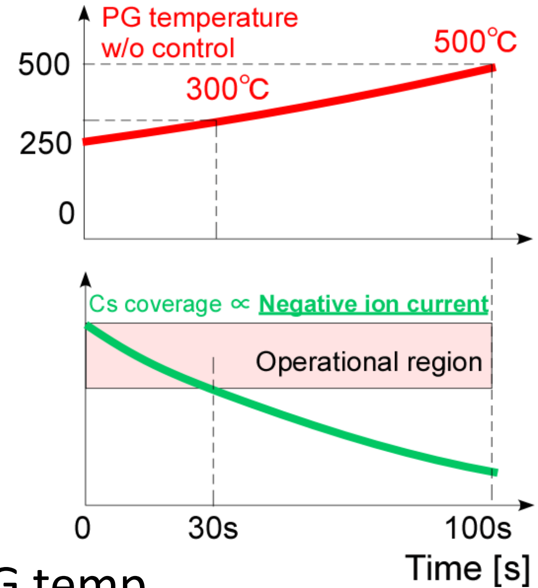
- 500 keV
- 22 A, 130 A/m^2
- 100 s

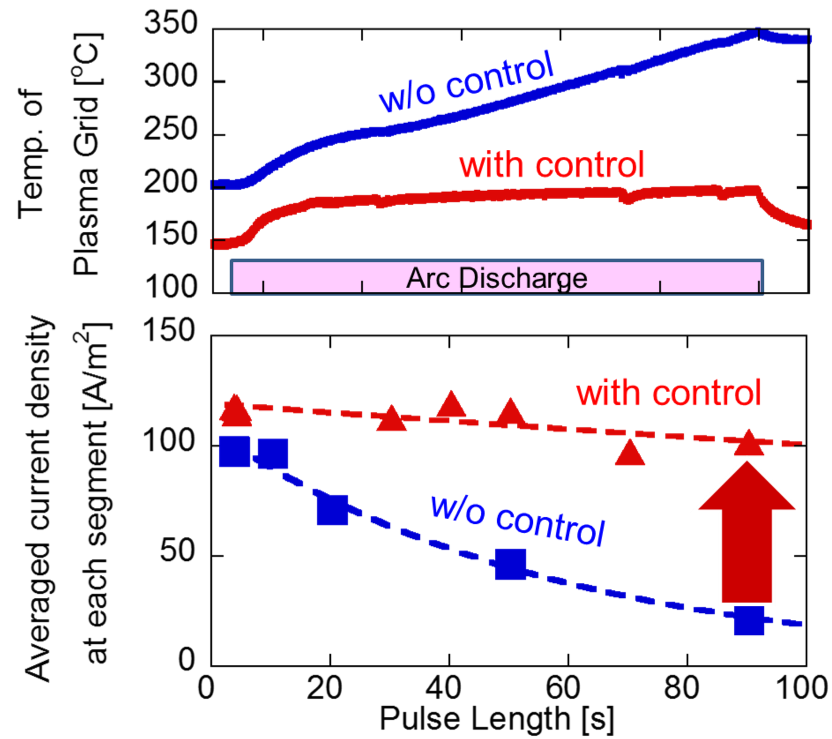
Long pulse production in Cs-seeded source

Plasma grid (PG) temperature control is issued for long pulse production.

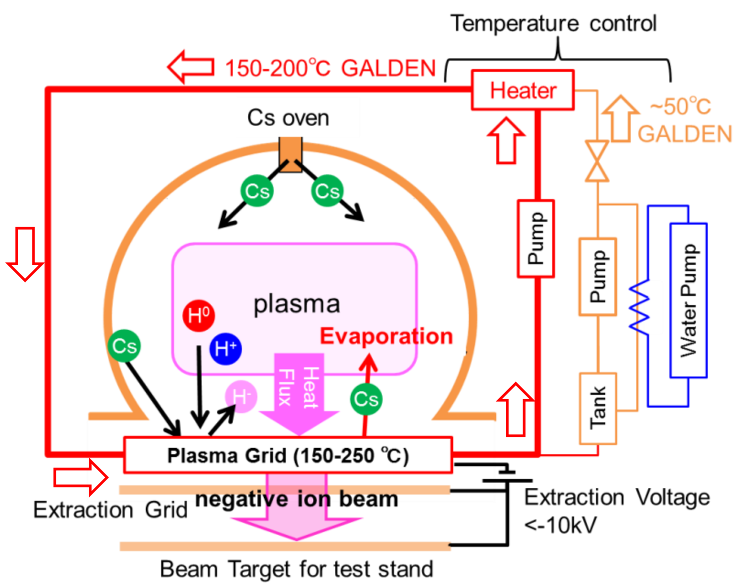


Low work function





Active control of PG temp.

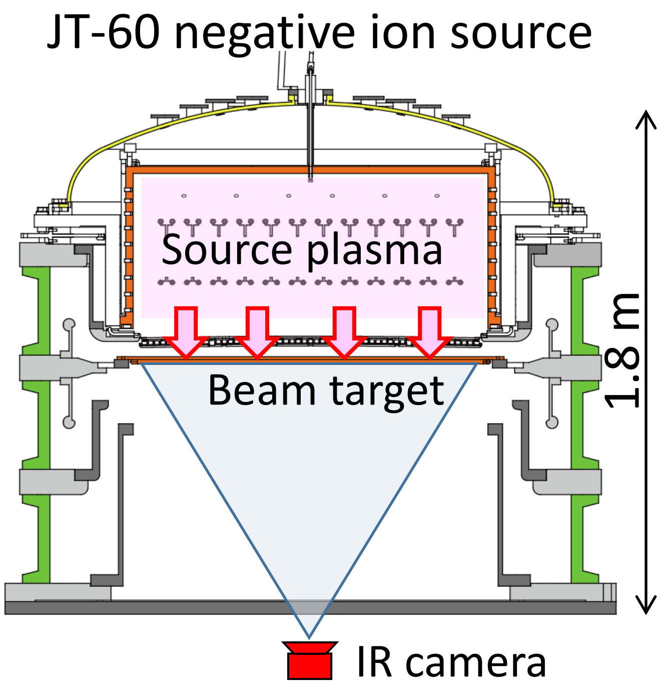


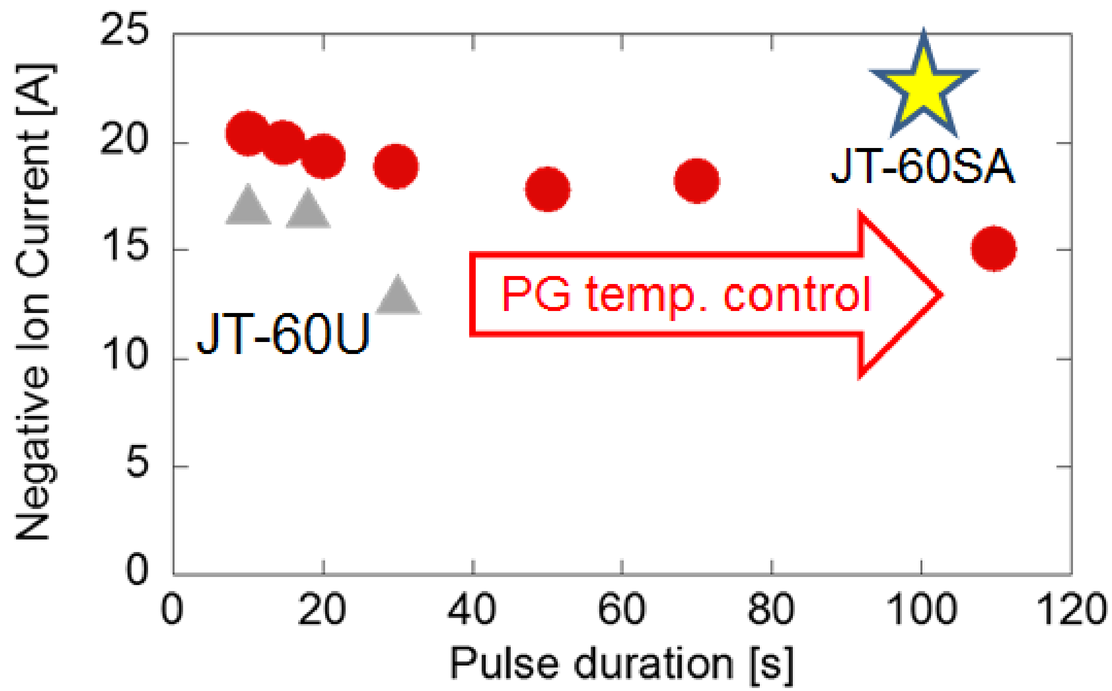
A 120-130 A/m^2 beams have successfully produced for 100 s (JT-60SA requirement).

Active temperature control of plasma grid has demonstrated the long-pulse beam production.

Achievement of long-pulse high-current production

Active PG temperature control has been applied to produce high current and long pulse negative ion beam in JT-60 negative ion source.



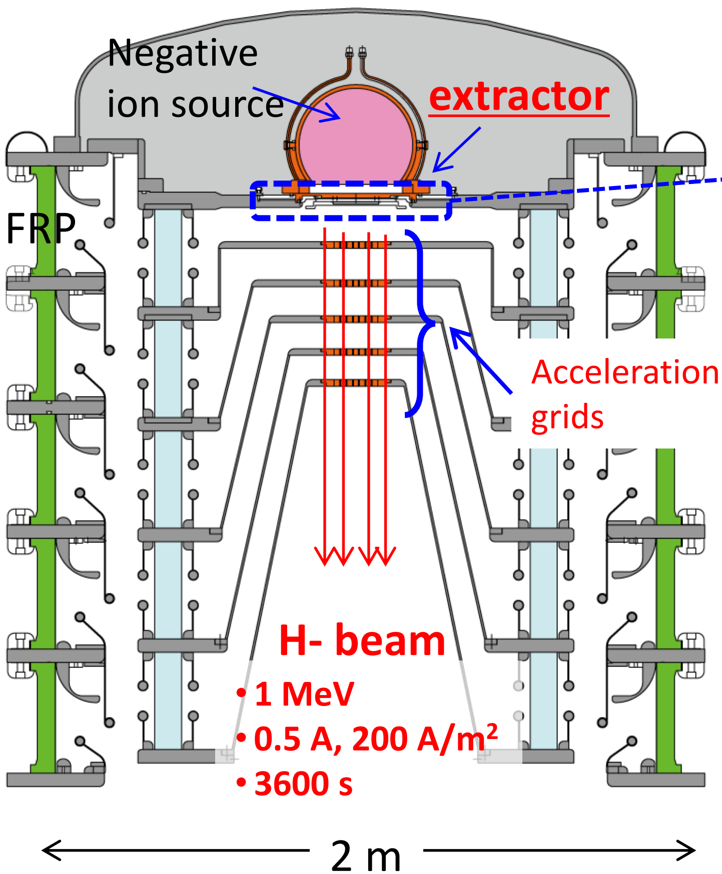


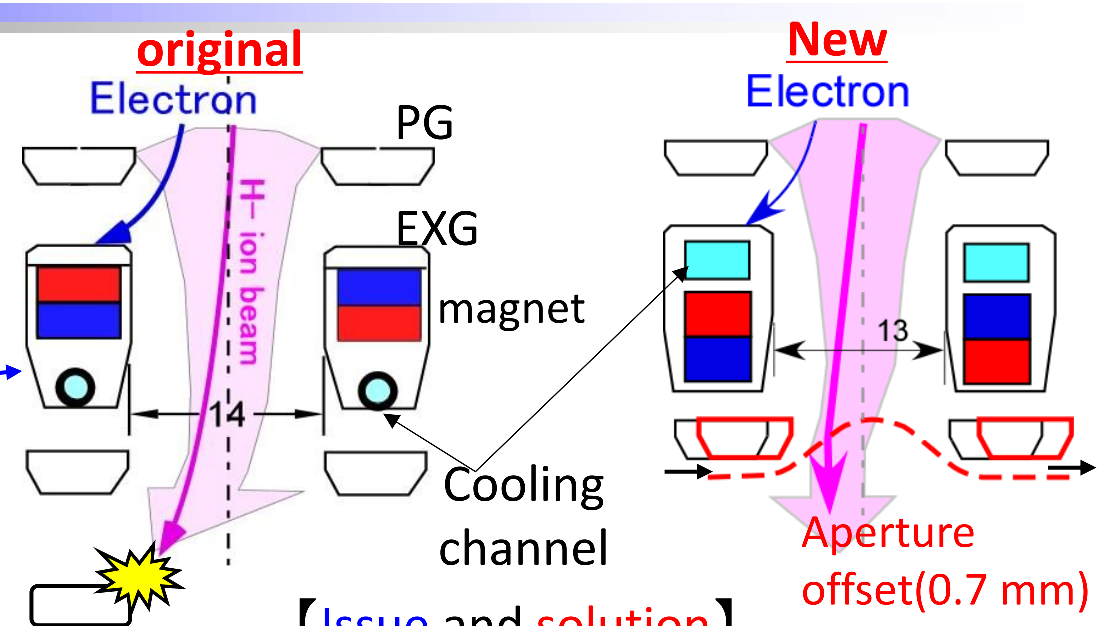
Long pulse production of 15 A negative ion beam, equivalent to 70 % of the beam current (22 A) for JT-60SA, has been achieved for 100 s.

The reduction of beam current on the pulse duration time will be recovered by the feedback control of arc discharge power to produce the higher-current beam.

Long pulse acceleration in MAMuG accelerator

MeV accelerator in JAEA





【Issue and solution】

■ Heat load on EXG

➔cooling channel close to heat receiving surface

310➔150℃ around magnet (<allowable temp. (200 ℃))

■ Grid heat load by beam deflection

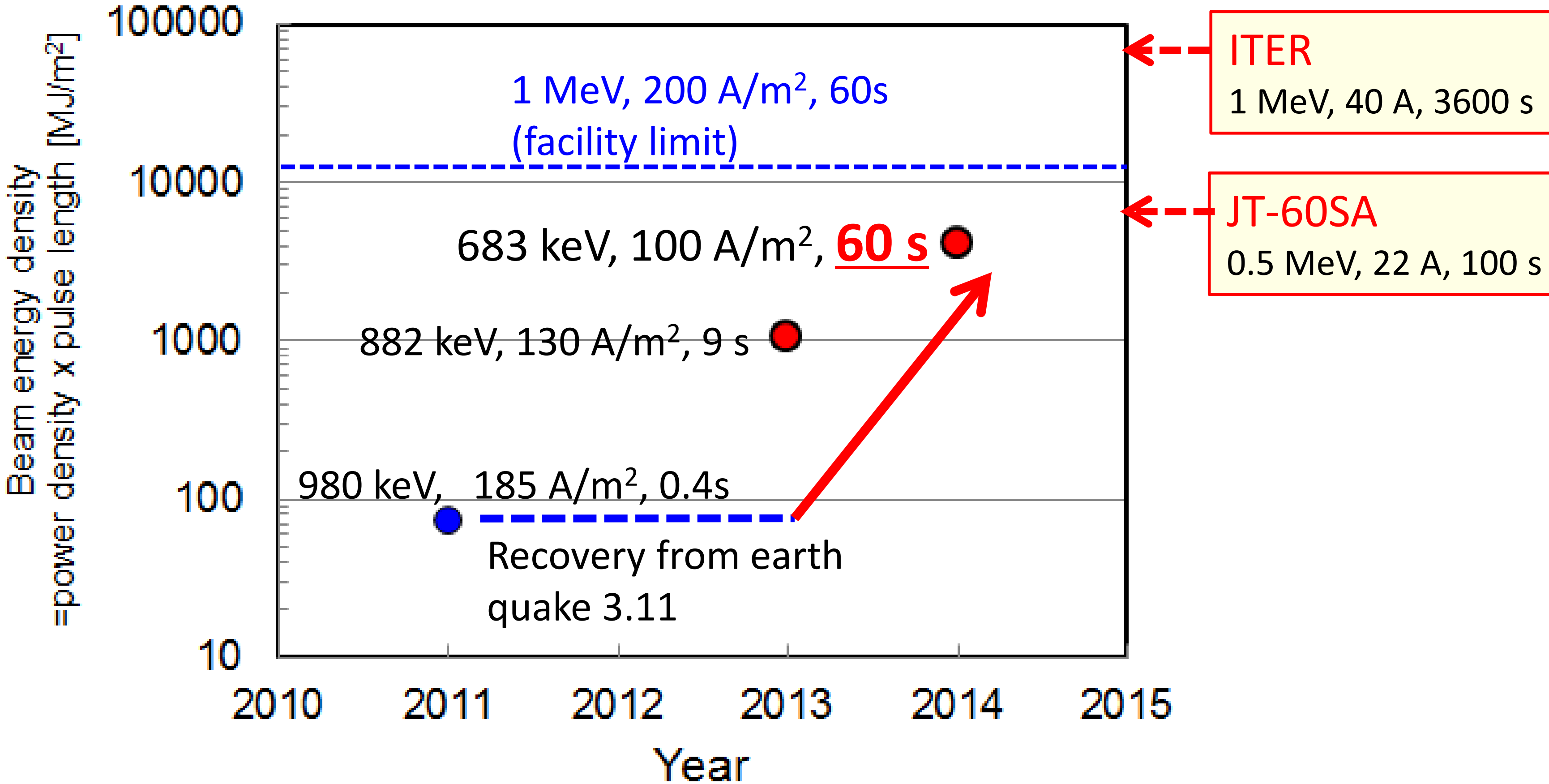
➔controlling the beam steering by aperture offset

Grid heat load: 10 % of input power

Low grid heat load enables steady state operation.

The modification enabled the long pulse beam acceleration.

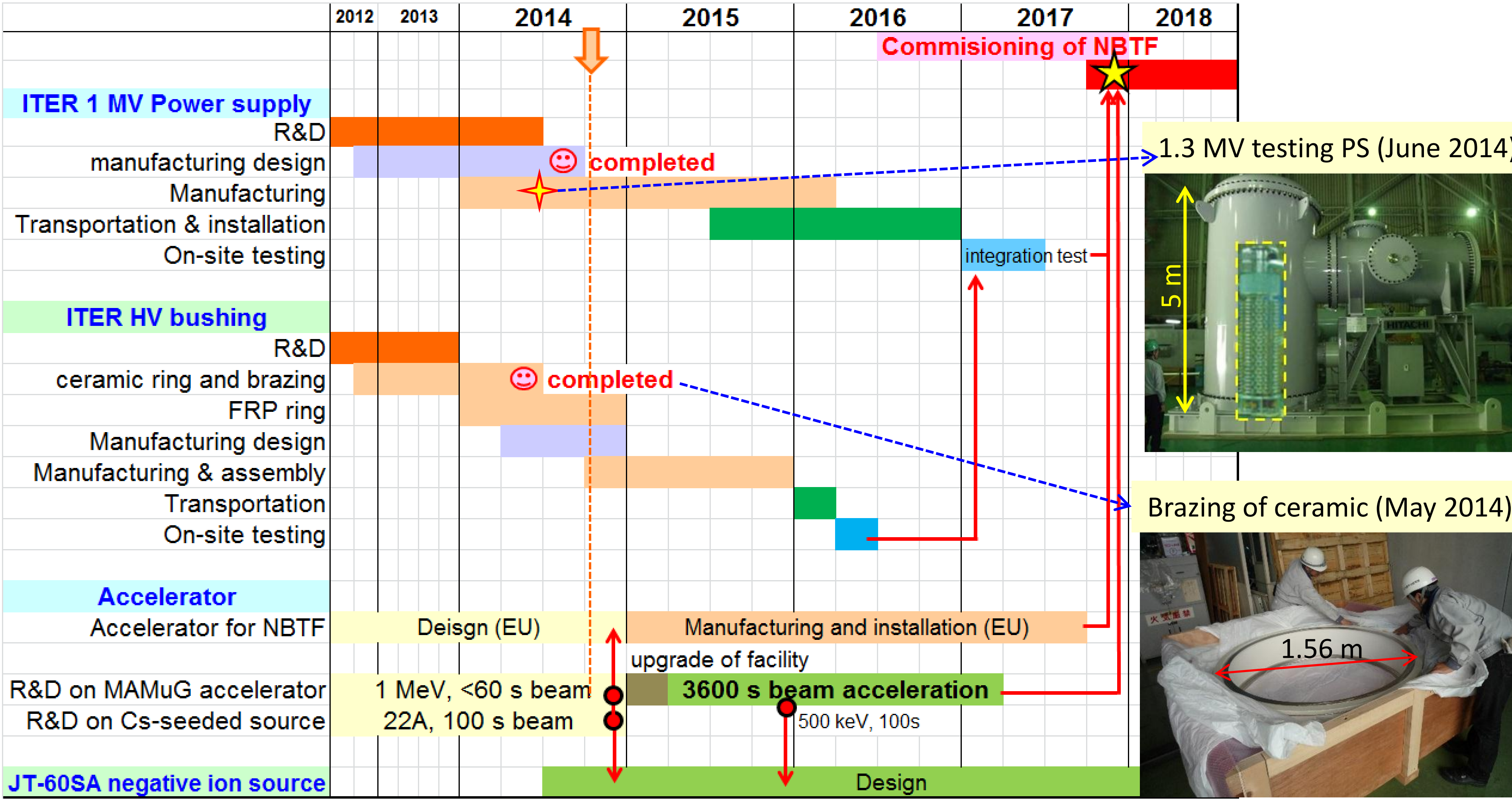
Achievement of long pulse acceleration



- Beam energy density has been increased two orders of magnitude in the last two years.
- No degradations of voltage holding and beam optics during long pulse acceleration.
- Increases of beam energy and pulse length are in progress with further conditionings for ITER and JT-60 SA.

Present status and schedule

The procurement activities on ITER NBTF are in progress as scheduled in Japan.



Summary

In order to realize NB system for ITER and JT-60SA, key technologies have been developed in the past two years.

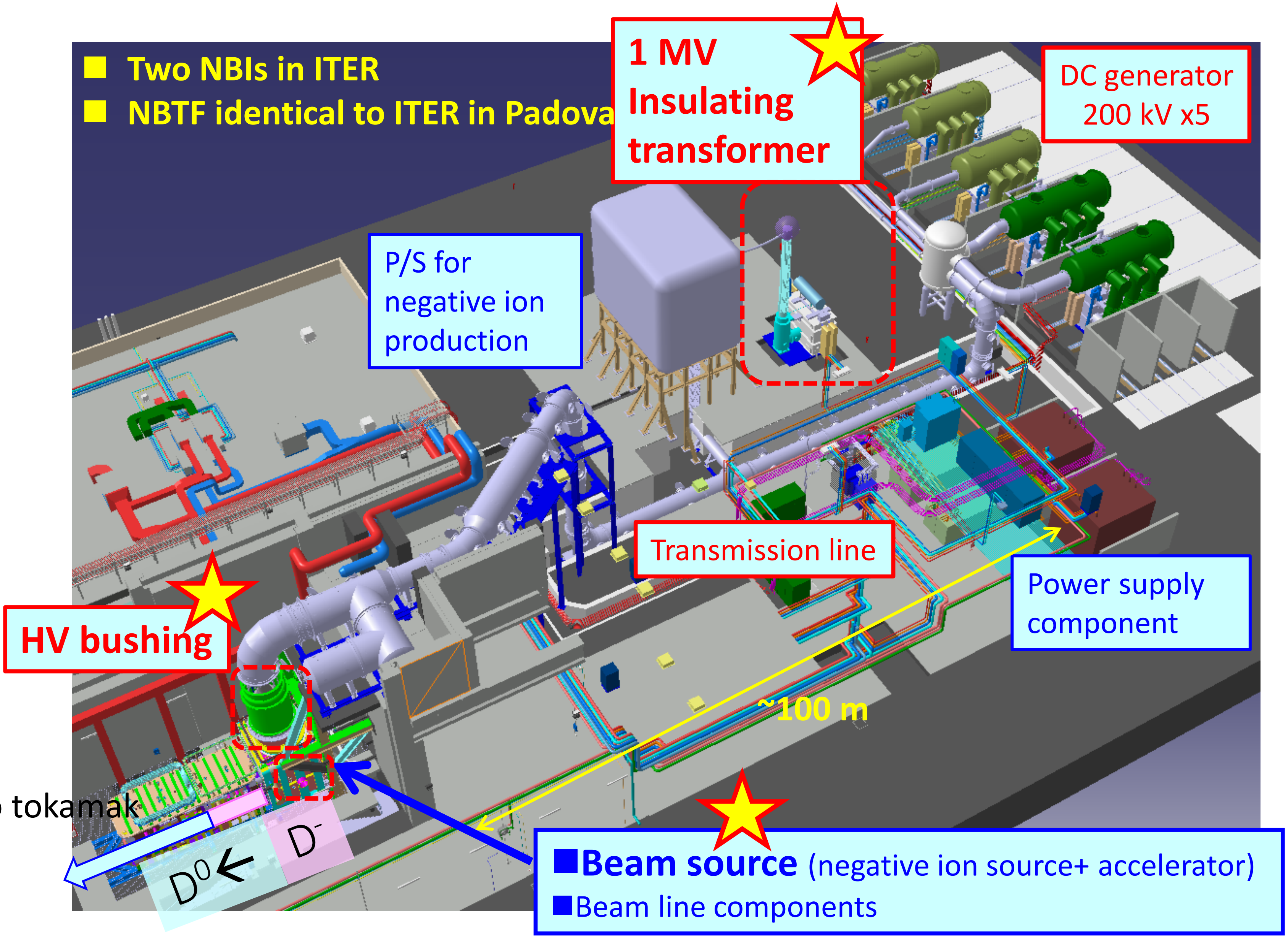
■ DC high voltage technology;

- The new composite bushing with manufacturable parts,
  → The 1 MV insulating transformer has been realized.
- 1MV vacuum insulation scaling of large electrodes to be scalable to ITER
  → The design of the HV busing has been ensured.

■ Beam production & acceleration;

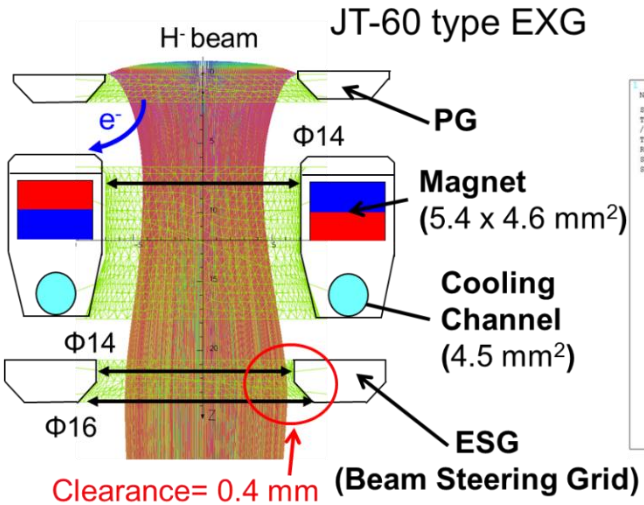
- Active temperature control technology of plasma grid in Cs-seeded negative ion source
  → A 100 s negative ion beam production at 15 A.
- Beam steering and heat removal technology on MAMuG accelerator
  → A 60 s beam acceleration at 683 keV, 100 A/m^2, that is two orders of magnitude longer than the previous achievement.

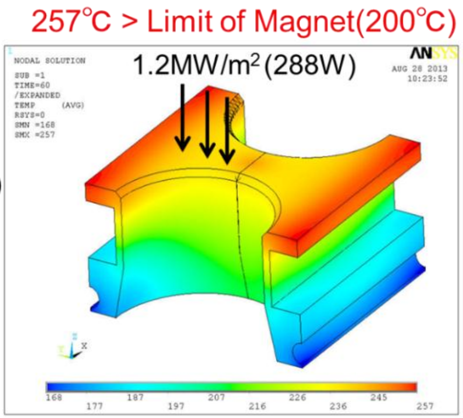
Neutral Beam Injector (NBI) System



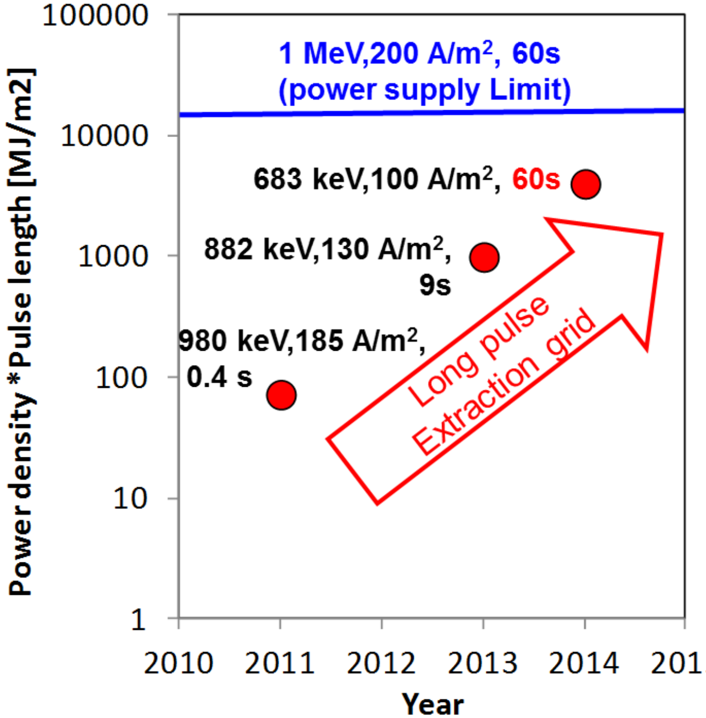
Long pulse acceleration of high power density beam

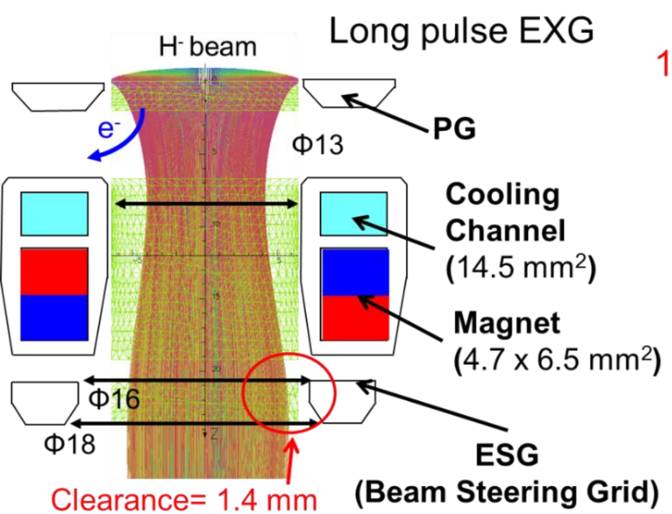
Heat load on the extraction grid is issued for long pulse beam acceleration.

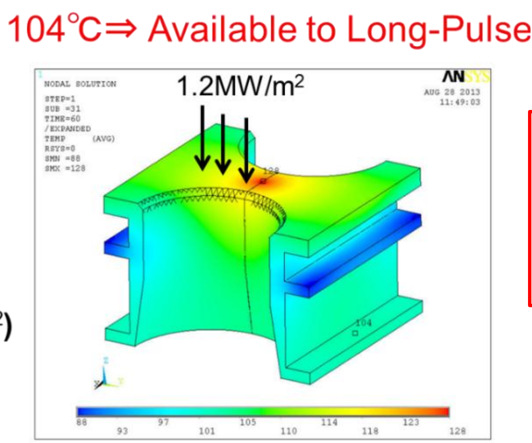




【issue】Limited less than 1 MW/m².

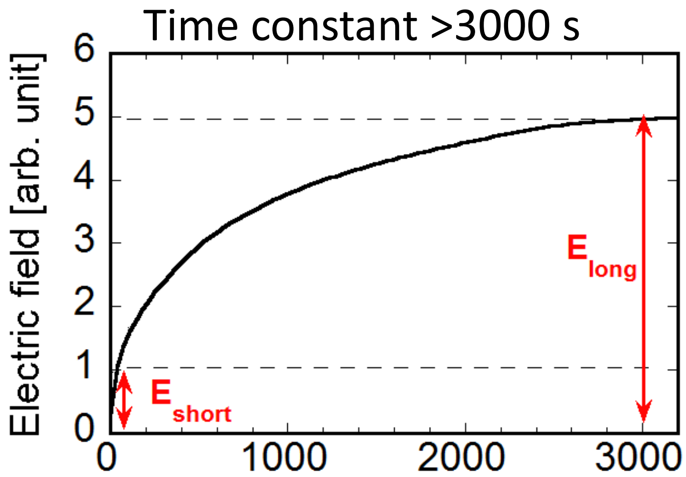






High-power and long-pulse beam acceleration of 70 MW/m² for 60 s was achieved.

Insulation structure between windings for DC 1 MV



By applying existing insulation structure(DC 500 kV, 10 s) to DC long-pulse operation;

→Five times higher electric field ($E_{long}/E_{short} = 5$)

→Ten times higher in ITER (1 MV)

【Issue】

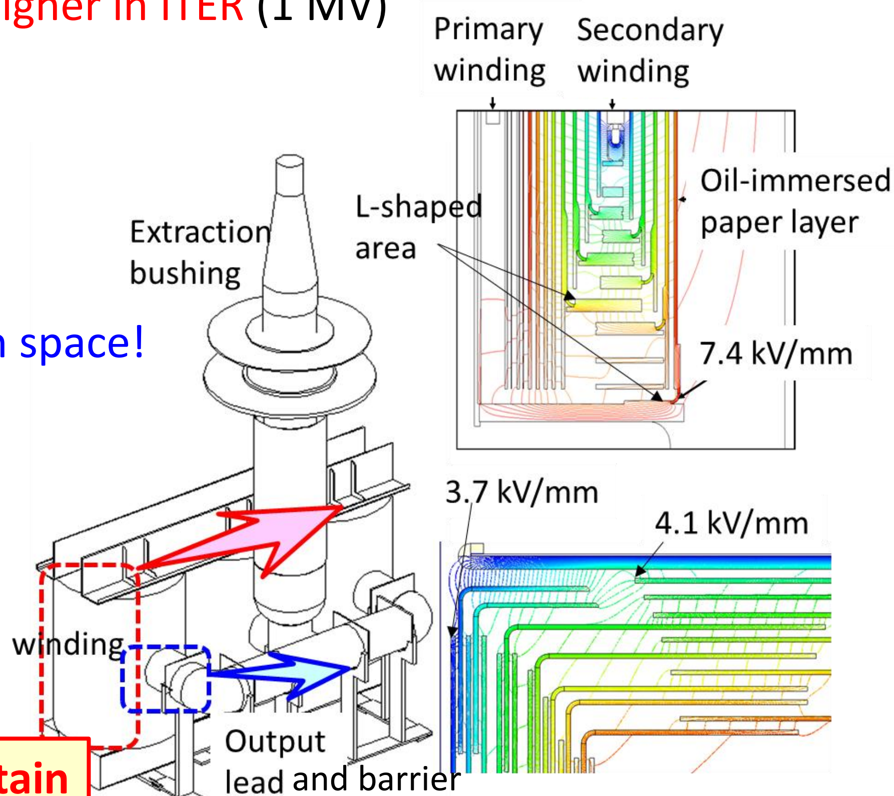
Dimension drastically increases.

Ten times larger transformer? Too large installation space!

Not acceptable in ITER.

【New device】

Insulation structure with insulation oil and oil-immersed paper layer to realize a feasible transformer

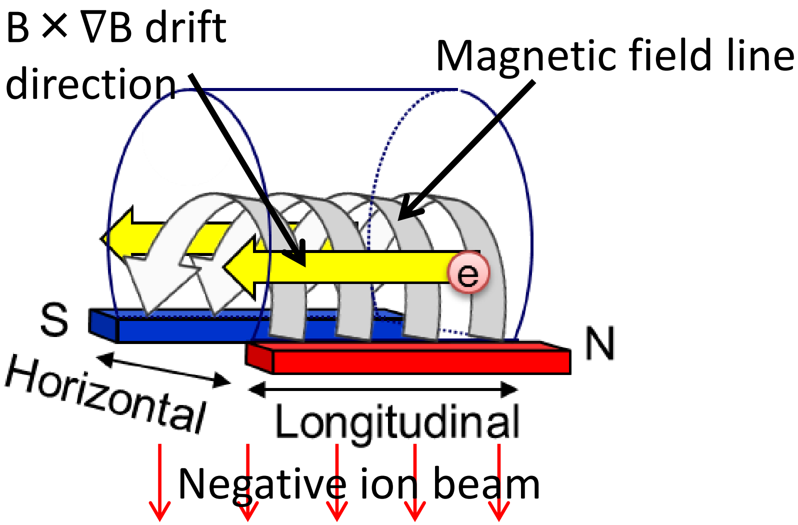


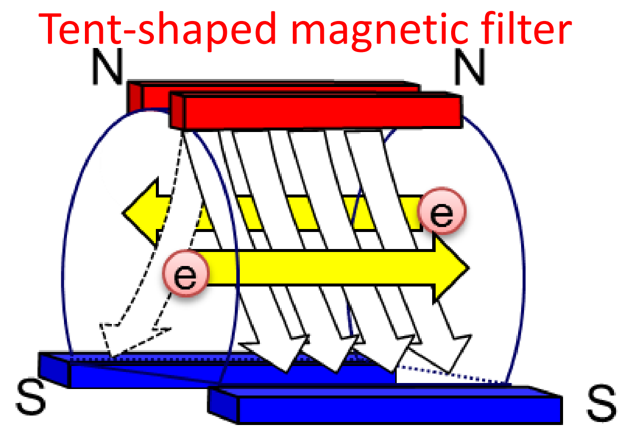
Allowable electric field: 16 kV/mm

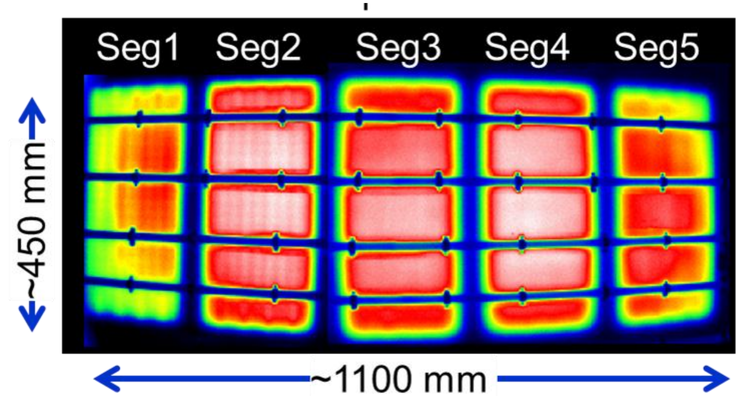
Insulation structure inside the transformer to sustain 1 MV for long pulse operation was established.

Improvement of spatial uniformity of negative ion beam

Non uniform negative ion beams causes local grid heat load that prevents long pulse operation.







Due to magnetic (B × ∇B) drift, primary electron drifts in one direction. Non-uniform negative ion production occurs in the source.

- Beam Uniformity : 69 % ⇒ 83 %
- 32 A negative ion beam from total extraction area
- 22 A from segment 2~4.
- Requirement on JT-60 SA was satisfied.