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Recent Technological Progress for Advanced Tokamak Research in JT-60U and JFT-2M

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Outline of the talk

1. Introduction
2. Progress of JT-60U Facilities toward long pulse operation
    1) 65 s tokamak discharges
    2) Modification of the N-NBI ion source
    3) Anode voltage control for the EC system
    4) Carbon grill antenna for the LH system
3. Extension of advanced tokamak operation in JT-60U
4. Feasibility tests of ferritic steel with tokamak plasmas in JFT-2M
5. Summary

Toward a future reactor with economical and environmental attractiveness.

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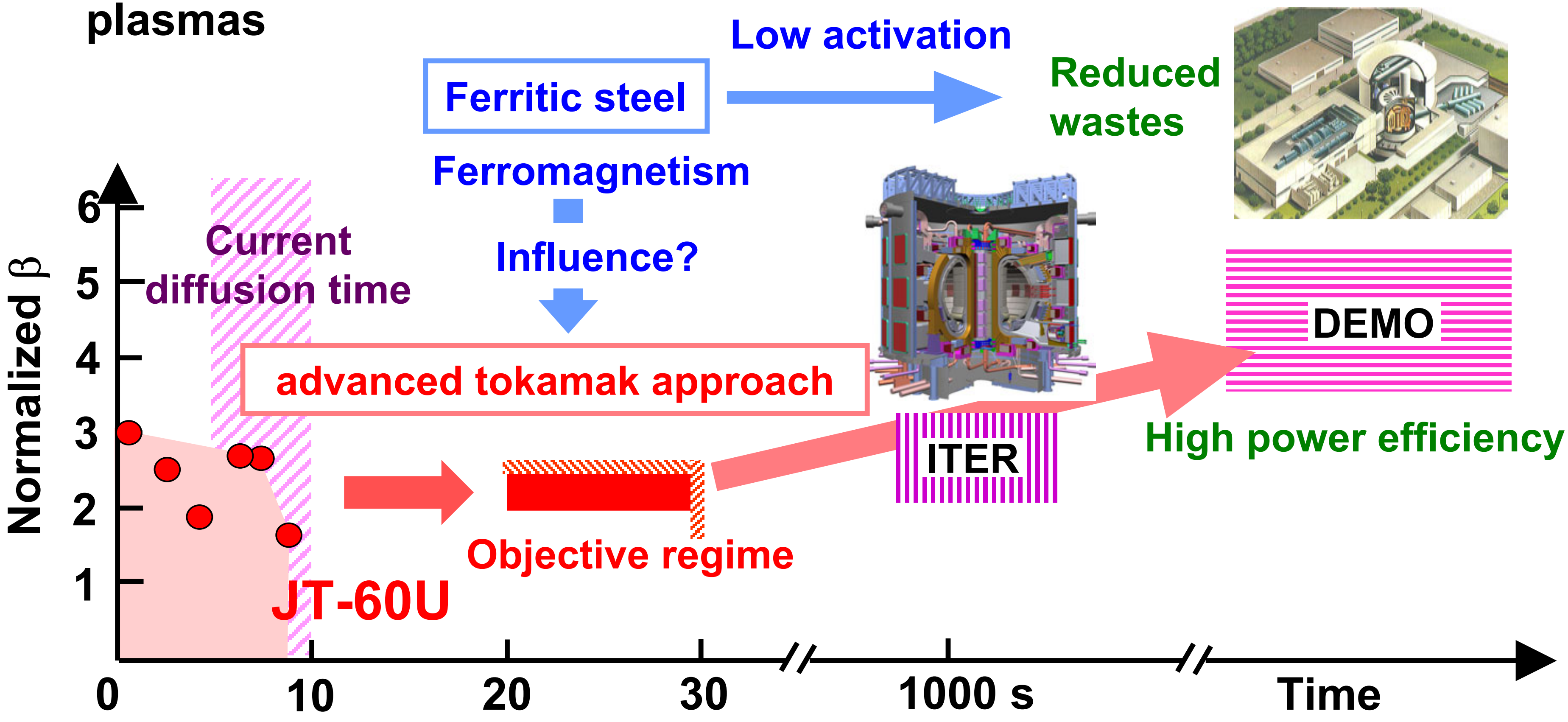
New objective regime of JT-60U

Steady state advanced tokamak research with discharges and heating much longer than current diffusion time.

Advanced Material Tokamak Experiment (AMTEX) in JFT-2M

Compatibility tests of ferritic steel walls with high performance plasmas



Modification of JT-60U to a long pulse device

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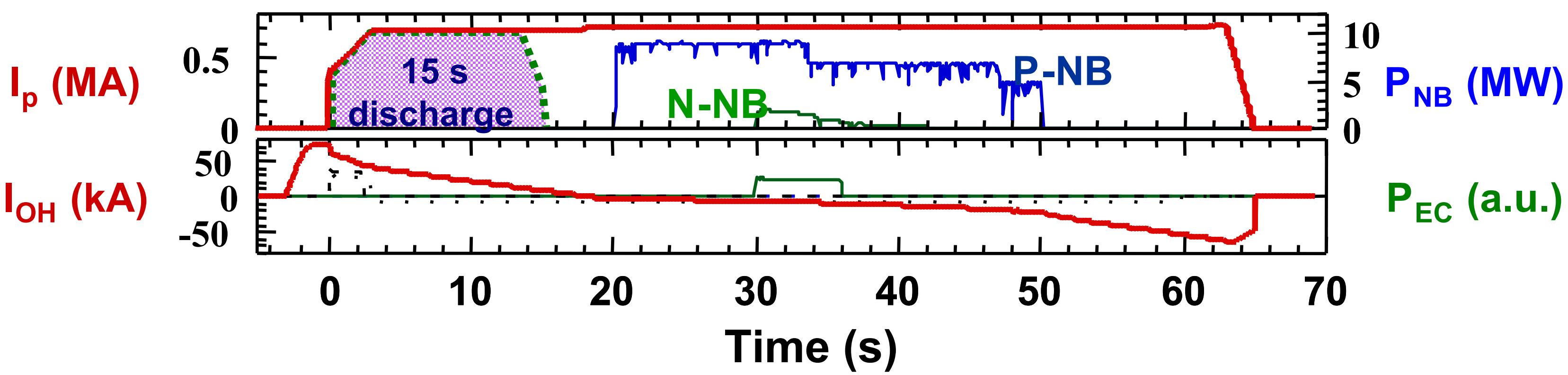
Tokamak discharge and heating durations were extended mainly by modifying the control systems within capacities of the systems.

Technological progress with components and operation was made for N-NBI, EC and LH.

Facilities		Duration	Modification / Improvement		
			Control system	Components	Operation
Coil P/S		15 s → 65 s	y	-	-
Gas			y	-	-
NBI	Positive	10 s → 30 s	y	Port limiters, P/S	-
	Negative		y	Ion source	-
RF	EC	5,10 s → 60 s	y	Cooling of window	Anode voltage control
	LH		y	Carbon antenna	-

4 T, 15 s → 2.7 T, 65 s



Progress and issues for long pulse injection of N-NBI

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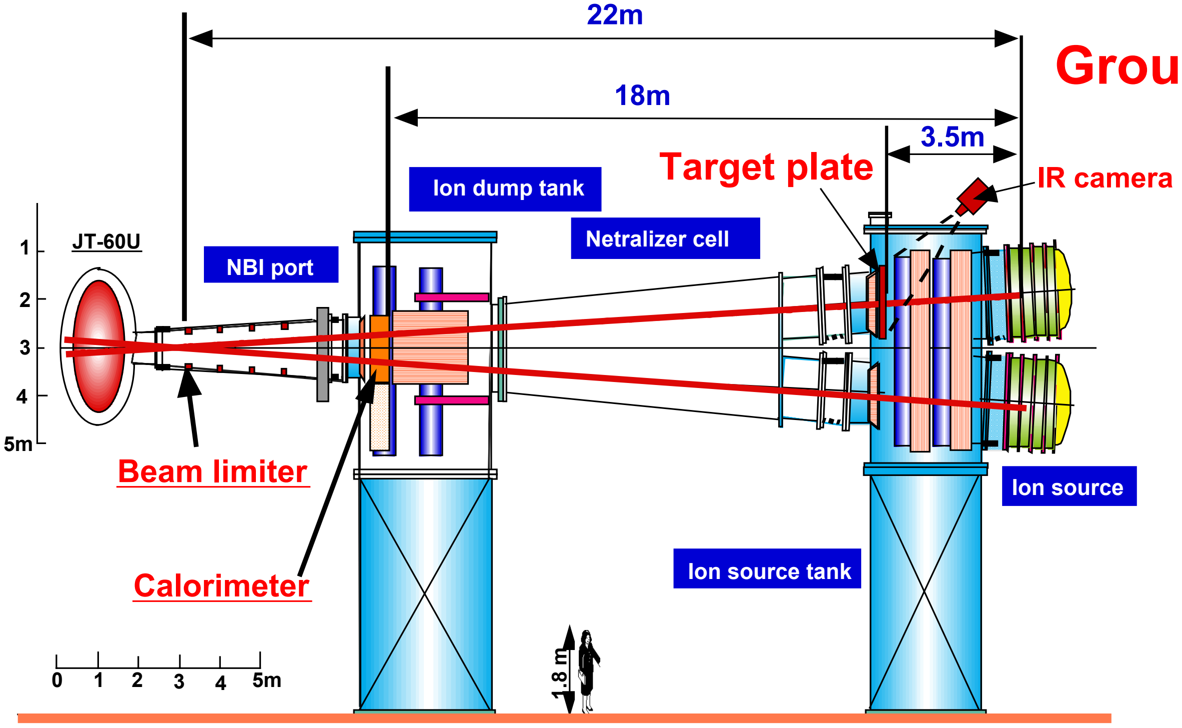
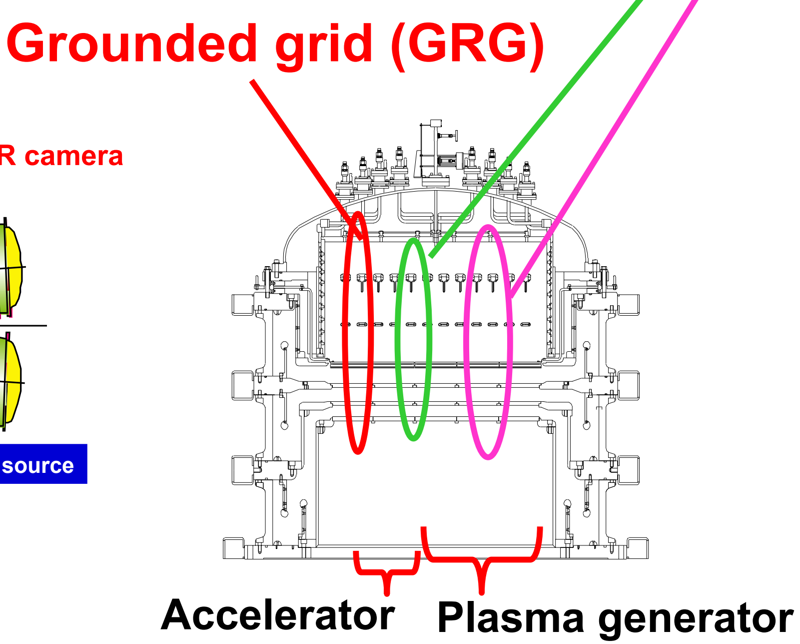
Measures done to date to improve beam divergence;

1) Programmatic control of **filament current** during beam injection
2) Collection of **irregular electric field** near the extracting apertures.

Required for 30 s injection: heat load reduction to the GRG.

Design :	10 MW	at 500 keV for 10 s	with 2 units	(D)
Achieved :	1.9 MW	at 400 keV for 5.4 s	with 1 unit	(D)
	2.6 MW	at 355 keV for 10 s	with 1 unit	(H)





Ion source of the N-NBI

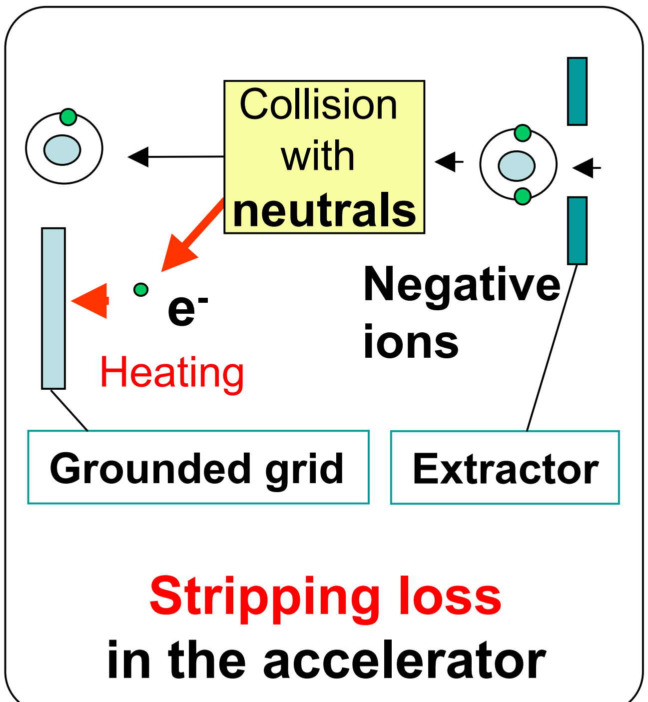
Modification of the ion source for heat load reduction

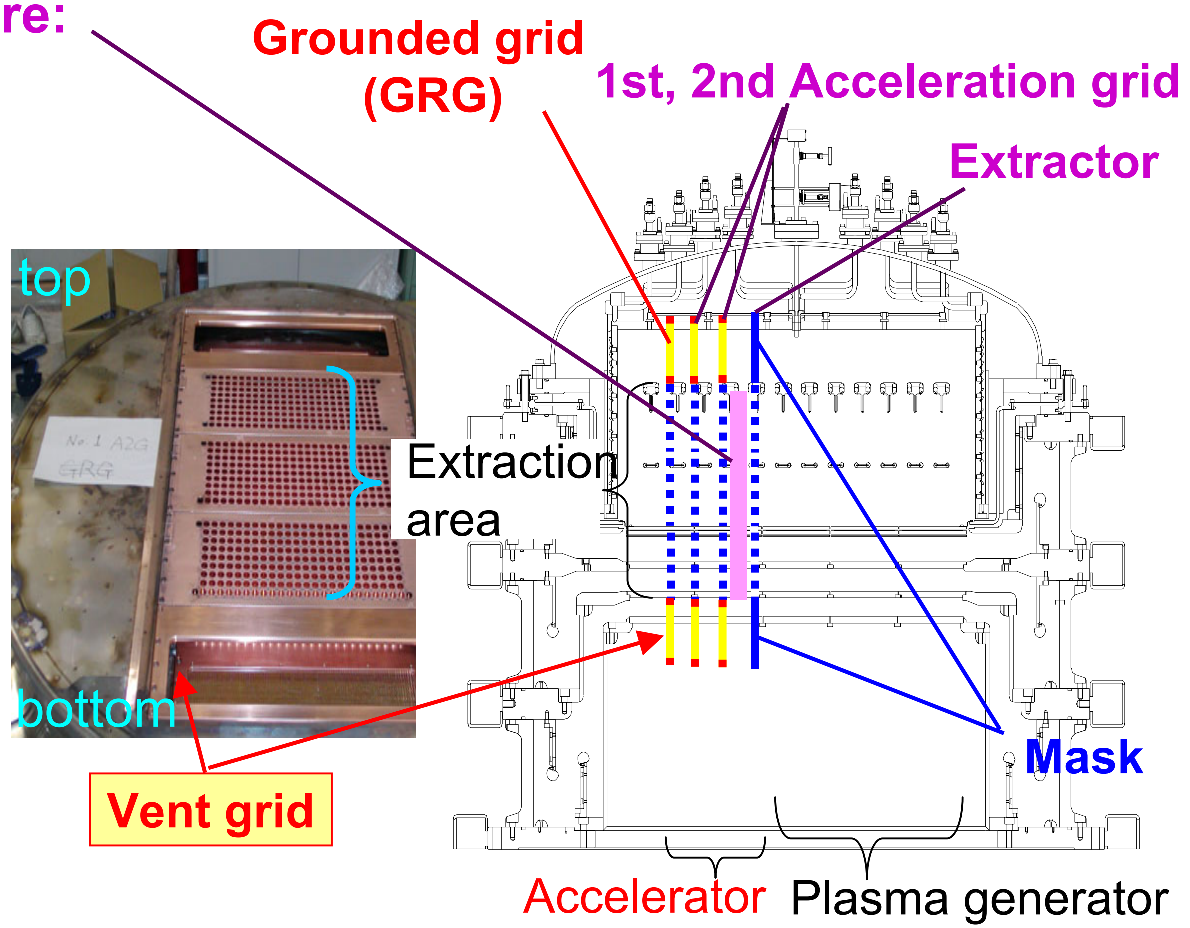
Cause for heat load to the GRG : Stripping loss

Measures : 1) Masking of the side grids of the extractor.

2) Making gas vents at the side grids of the accelerators and GRG.

Reduction in gas pressure:
0.16 Pa → 0.1 Pa





Heat load reduction and prospect to 30 s N-NB injection

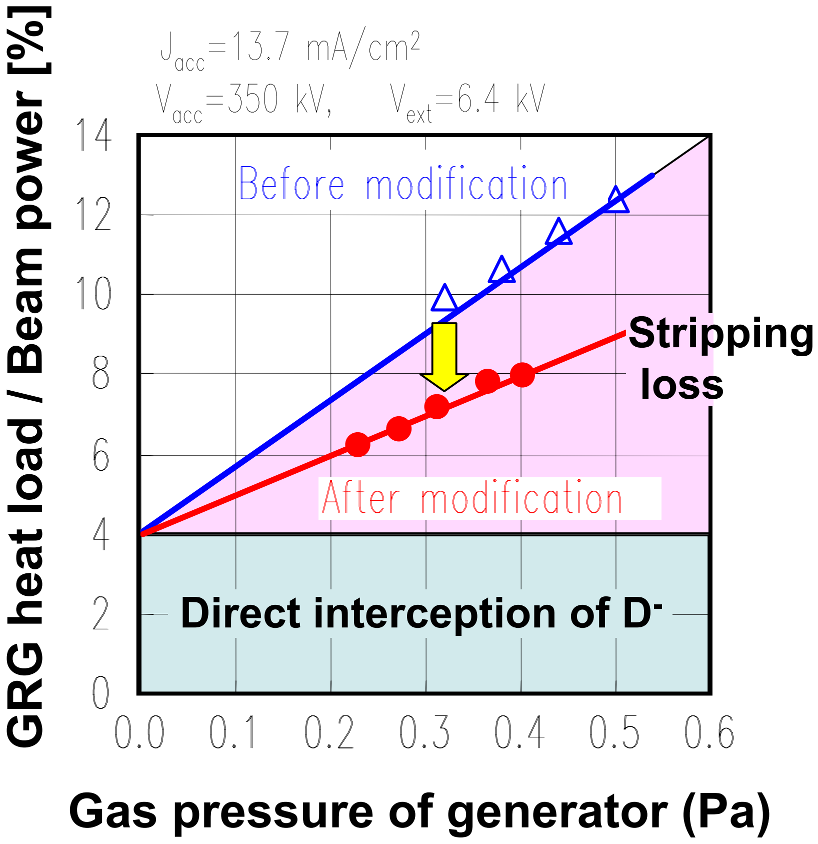
Result : 1) Two causes; Stripping loss and direct interception of D^-

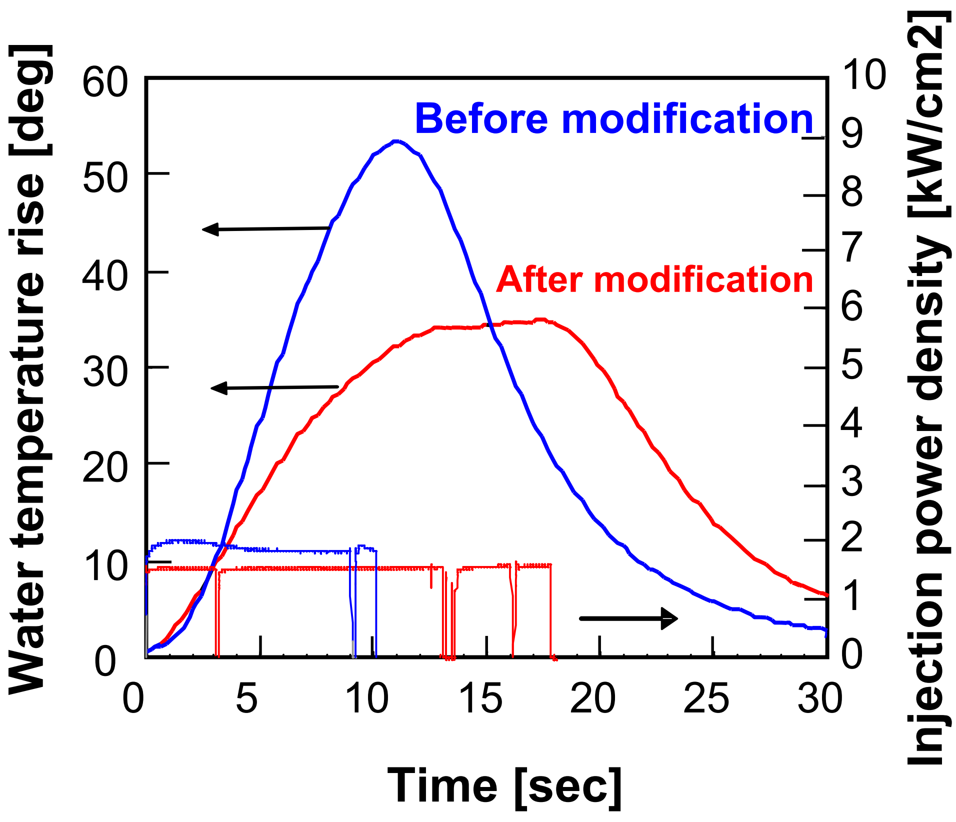
2) Reduction in stripping loss by 43% at 0.3 Pa

Operation and prospect :

1) Saturation of water temperature during 1.6 MW injection for 17 s.

2) 30 s injection is possible from the heat balance.





JT-60U EC system and objective operation

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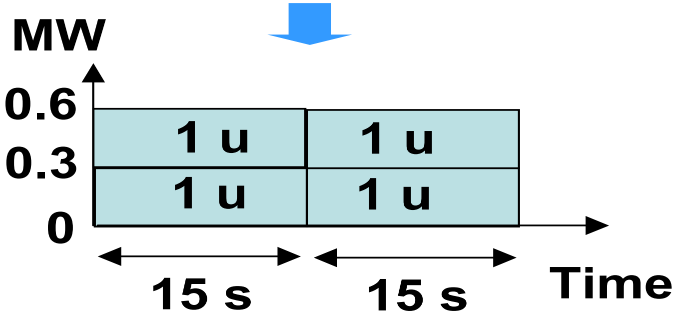
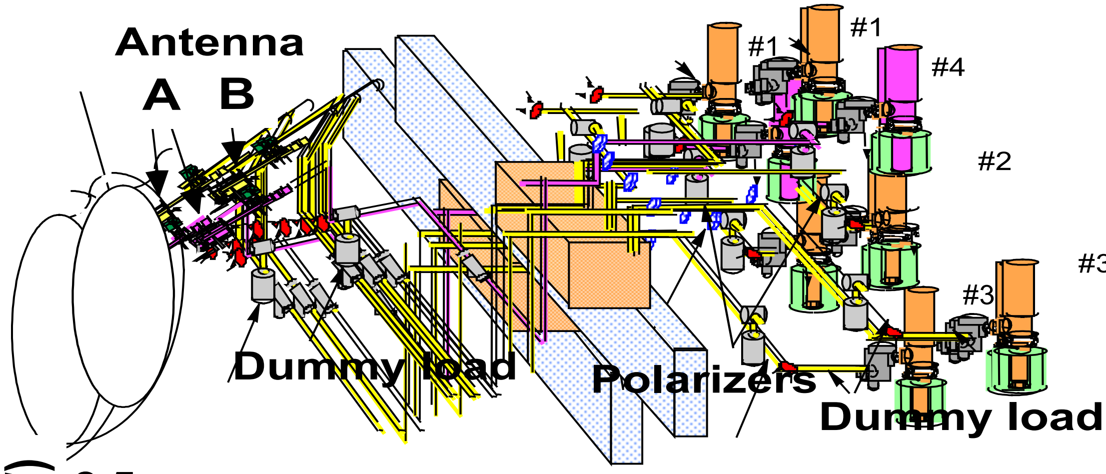
Gyrotron (Design) : 100 GHz, 1 MW/unit x 4, Oscillation duration

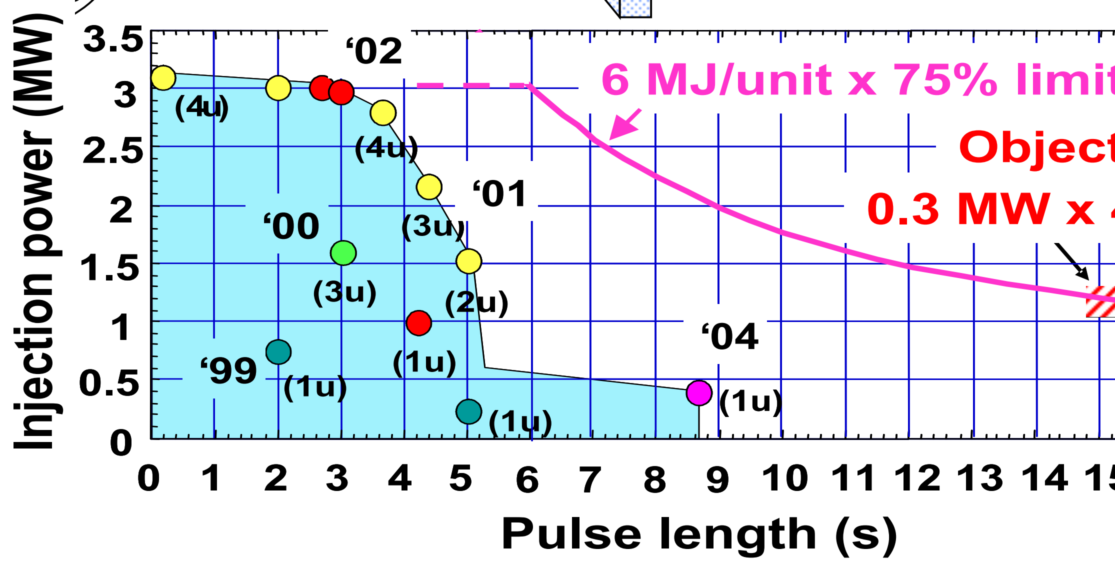
Plasma injection power and duration
→ 3 MW, 3 s.

Objective long pulse operation:

0.3 MW x 4 units, 15 s
→ 0.6 MW, 30 s
by series operation







Improvement for long pulse operation

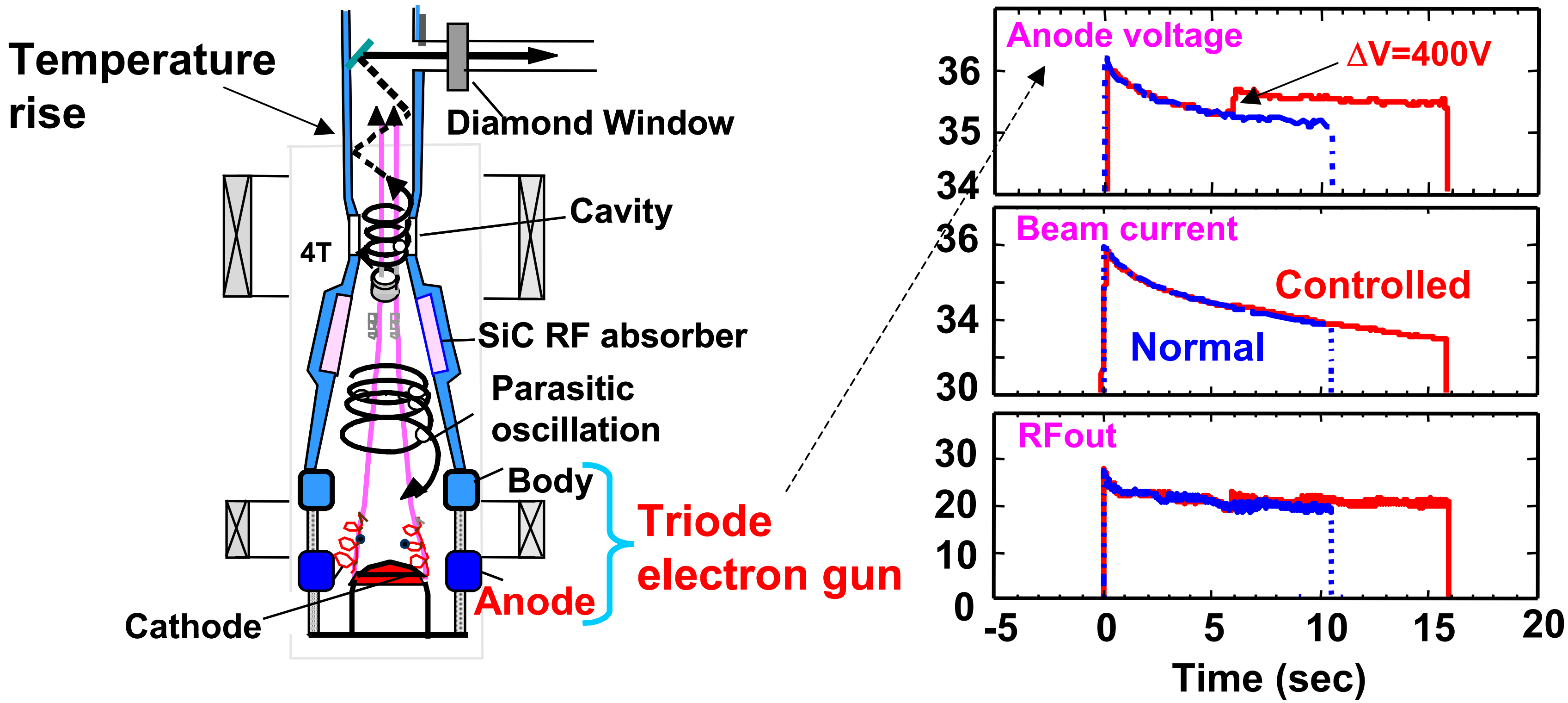
Problem: Decay of the beam current due to cathode cooling.

Operational improvement :

Anode voltage control (New) →possible only with JT-60U gyrotron.

Result: Oscillation continued for 16 s by ΔV_{anode}=400 V.
Limited to T<16 s by temperature rise at the mode converter.

Prospect: 0.6 MW injection for 30 s→ok



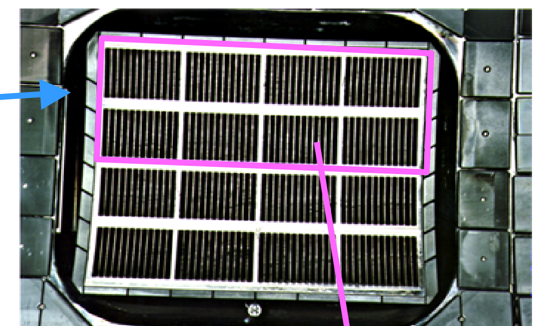
Development of a carbon LH grill antenna

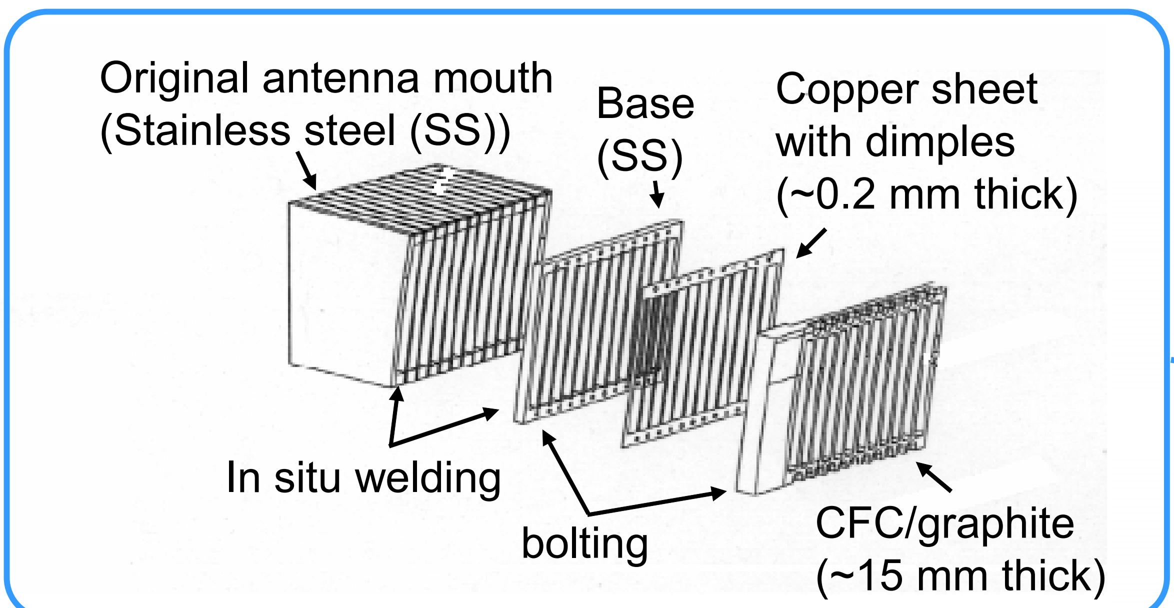
Necessity: Heat resistant antenna to avoid damage by plasmas and RF discharge

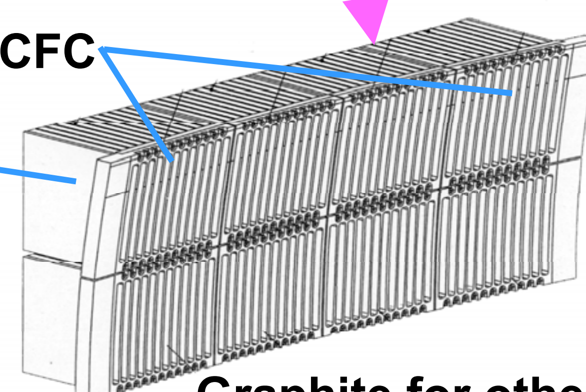
Key techniques: 1) Carbon grill mouth, 2) Bolt joint,
3) Copper sheet with emboss processing

Results and prospect: 1) LH injection ~ 1 MW, 7 s , ~5 MJ (duty 70%)
2) Similar level of current drive efficiency
3) Copper impurities are decreasing.

The original multi-junction stainless steel antenna



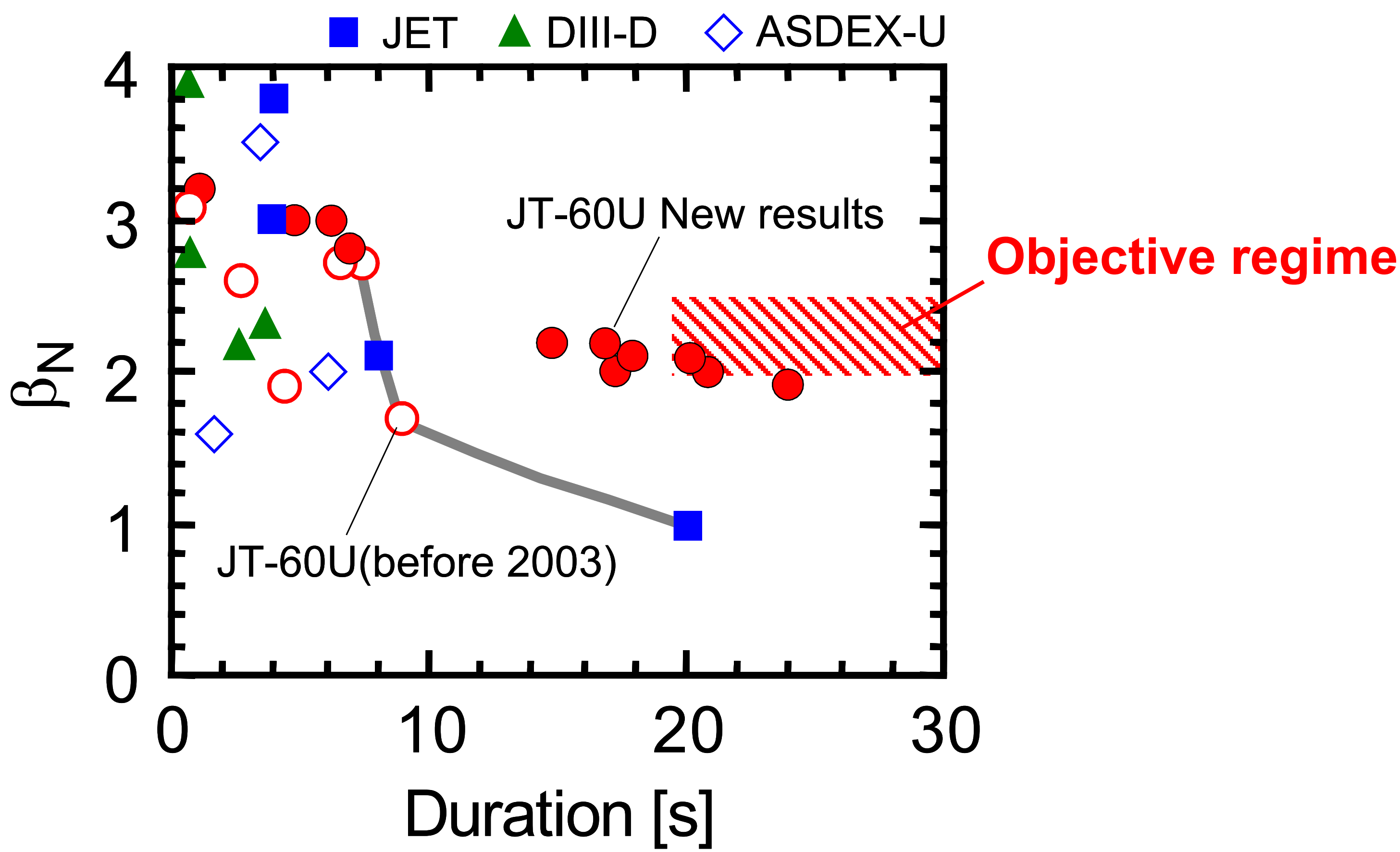




Extension to steady state high β_N plasma operations

The duration of advanced tokamaks with β_N~2 have been extended to 15-24 s mainly by P-NBI heating.

Plasma current profile control by the modified N-NBI and/or RF will be used to further sustain β_N plasmas in steady state.



Feasibility tests of ferritic steel to a tokamak in JFT-2M

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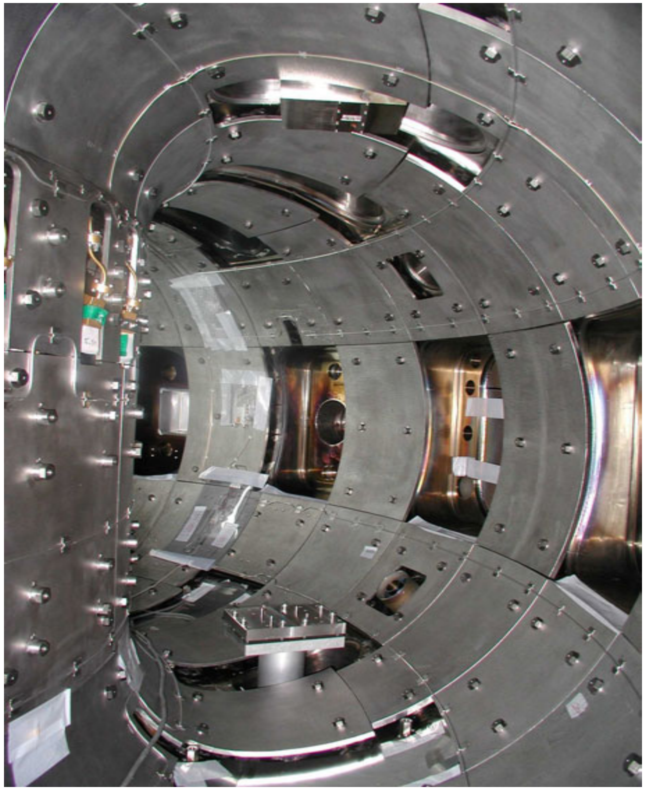
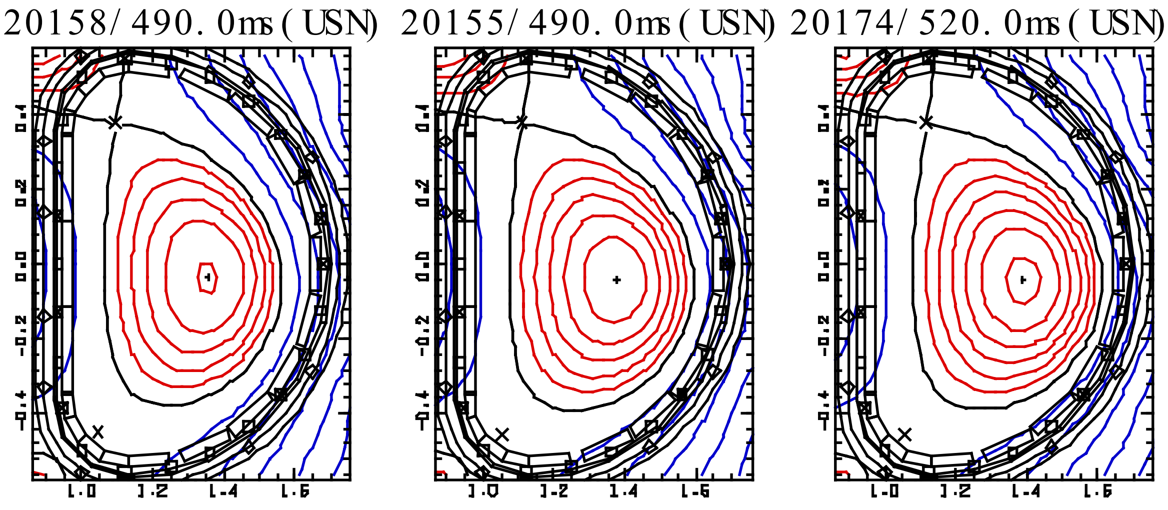
Condition: 1) First wall fully covered with ferritic steels.
2) Ripple field rate : 2.2%→0.4%
3) No large low-n mode error field triggering locked mode.

Results: 1) H-mode characteristics similar to the previous ones.
2) No serious influence on generation of high β_N plasma

Prospect: Favorable for usage of ferritic steel in future reactors.



β_N~3.5 has been obtained at r_{wall}/a=1.3~1.6



r_{wall}/a=1.6 r_{wall}/a=1.4 r_{wall}/a=1.3

Summary

1) For steady state advanced tokamak research, JT-60U has been modified to a device with a potential of long pulse tokamak operation up to 65 s and heating operation up to 30 s.

2) For this purpose, technological progress has been made with the N-NBI, EC and LH systems;
   - Ion source of the N-NBI
   - Anode voltage control method
   - Heat resistive carbon grill LH antenna.

3) Compatibility of ferritic steel walls with high performance tokamak plasmas has been confirmed in JFT-2M, which encourages the use of this steels in future tokamak reactors.