Status and Programmes on Negative Ion Beams at JAERI

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Fourth IAEA Technical Meeting on
"Negative Ion Based Neutral Beam Injectors"

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Summary: Progress at JAERI

1.Uniformity issue

- Key is local penetration of fast electrons through magnetic filter, followed by local destruction of ions in pure volume, whilst enhancement of surface production in Cesiated source.

2.MeV accelerator R&D

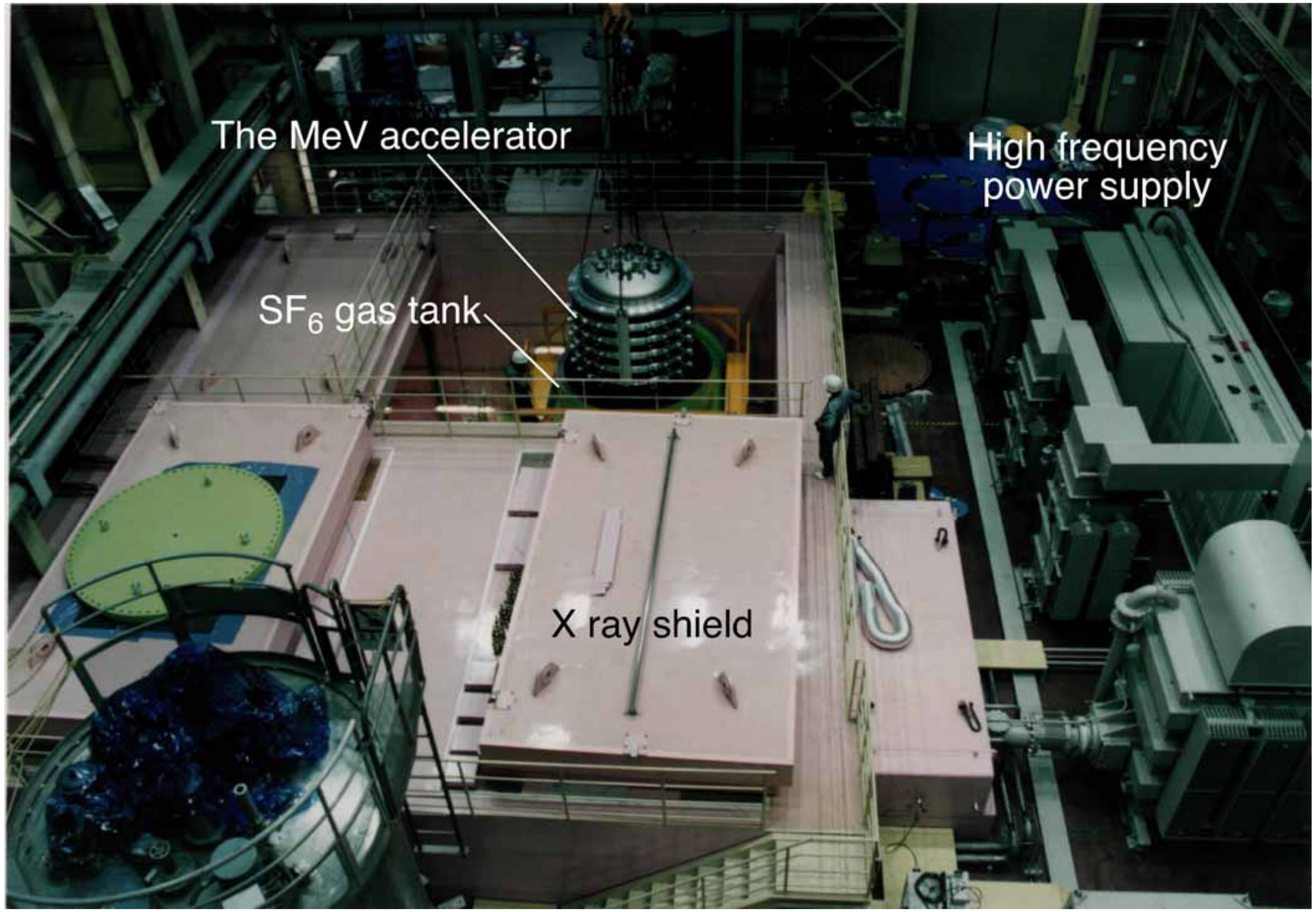
- 1 MV vacuum insulation for 8,500 s by large stress ring to lower the electric field concentration at triple junction.
- 836 keV, 146 A/m^2 H^- ion beams (total ion current: 206 mA) achieved.
- The MeV level H^- ion beams attained $\approx$ 5 mrad beamlet divergence.
- Estimation of photoelectrons in insulation materials.

3.R&D for future NB systems to be used in DEMO

- Cs free source with low work function materials.
- Laser neutralizer.

MeV test facility

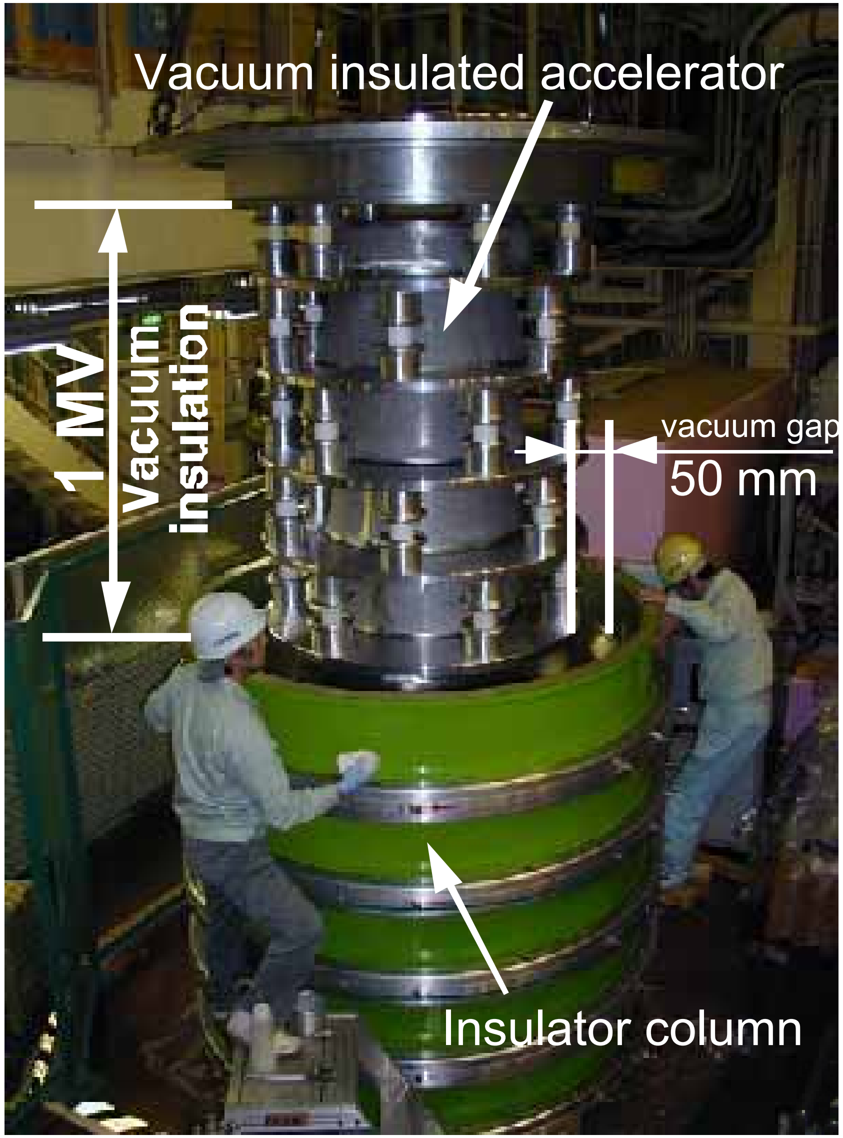
T. Inoue et al., JAERI-Tech 94-007 (1994).



- Constructed in 1994 at JAERI for R&D of the 1 MeV, 1 A class H^- ion accelerator.
- The Cockcrot Walton power supply and the accelerator are contained in gas tanks, for high voltage insulation by SF_6 gas of 6 bar.

JAERI MeV accelerator

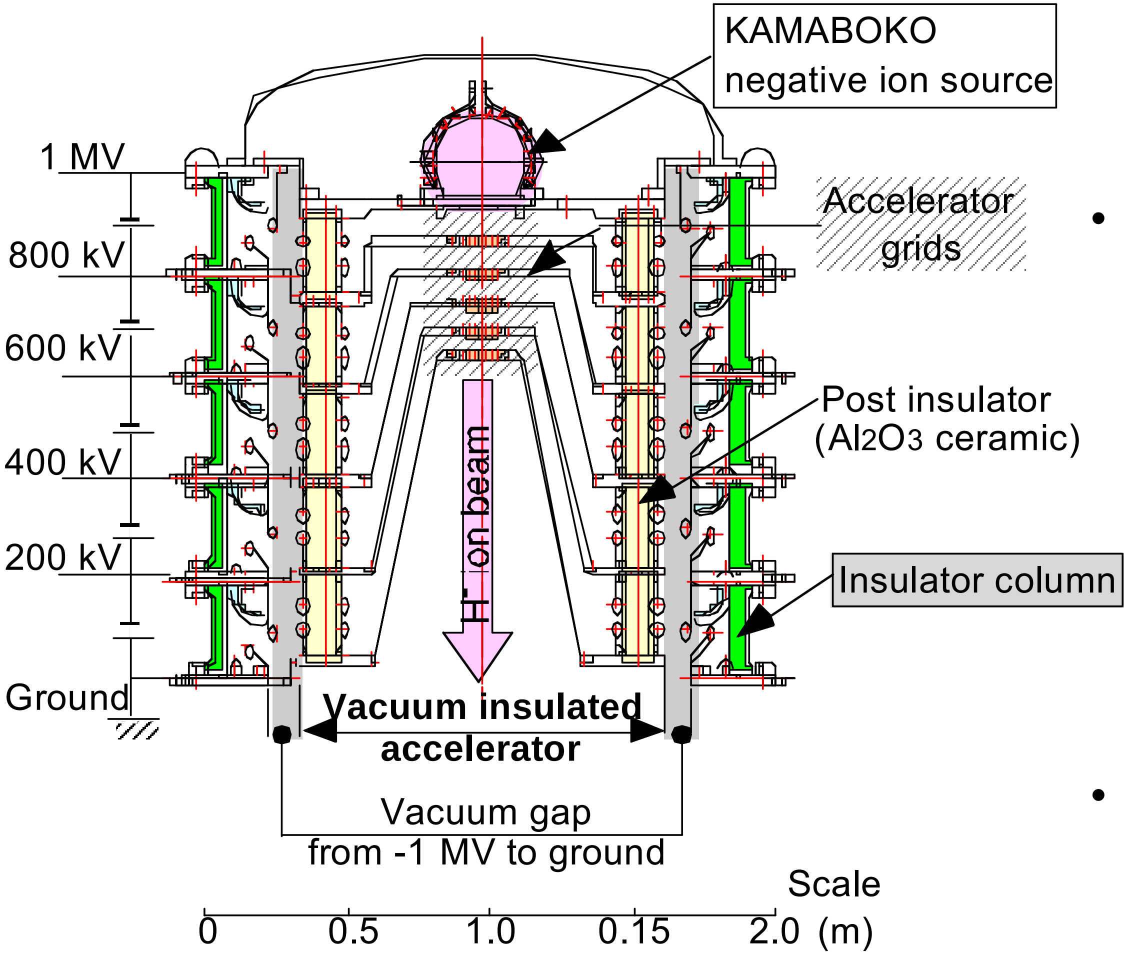
K. Watanabe et al., Rev. Sci. Instrum. 73/2 1090-1092 (2002).



- Insulator column:
  - a stack of 5 FRP rings made of fiber-reinforced epoxy,
  - each 1.8 m dia. and 0.33 m in height,
  - 1.9 m high in total for 1 MV.
- Insulator column as vacuum boundary:
  - against the SF_6 insulation gas,
  - like the HV bushing of ITER.
- The vacuum insulated accelerator:
  - inserted in the insulator column,
  - 50 mm wide gap all around between the insulator column and the accelerator.

JAERI MeV accelerator

The JAERI MeV accelerator
- Vacuum insulated,
- Multiaperture, Multegrid accelerator.



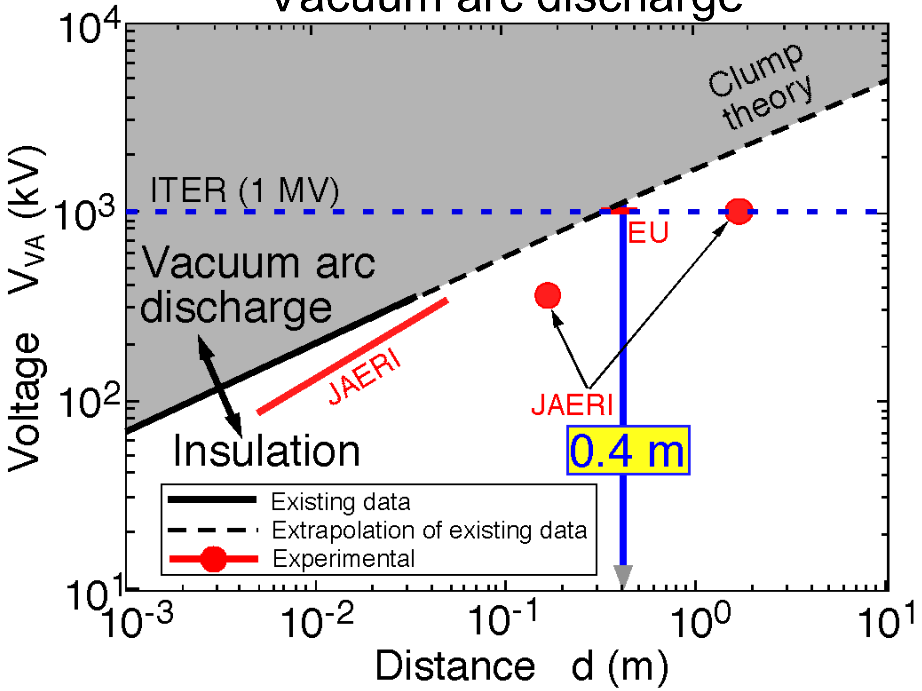
- KAMABOKO negative ion source:
  - directly mounted on accelerator.
- Extractor:
  - 3 x 3 apertures in PLG,
  - 7 x 7 apertures in EXG.
- Accelerator:
  - 4 grids at intermediate potentials (every 200 kV, Multi-grid),
  - 7 x 7 apertures in all grids (Multi-aperture),
  - The grid spacing progressively shorter at each downstream.
  - No water cooling.
- Pressure in the accelerator:
  - 0.02 ~ 0.1 Pa.

1 MV vacuum insulation data

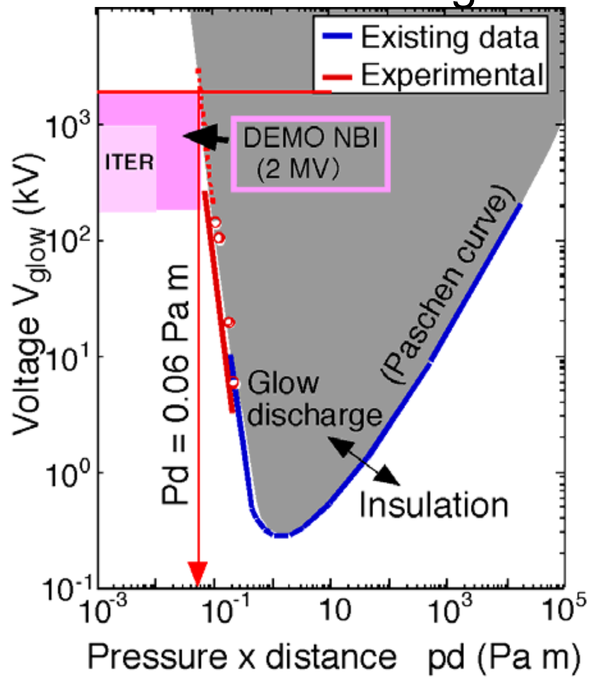
T. Inoue et al., Rev. Sci. Instrum. 71 (2), 744-746 (2000).

issue: Possibility of both vacuum arc and glow (gas) discharges,
The clump theory and Paschen law extrapolated in MV range.

Vacuum arc discharge



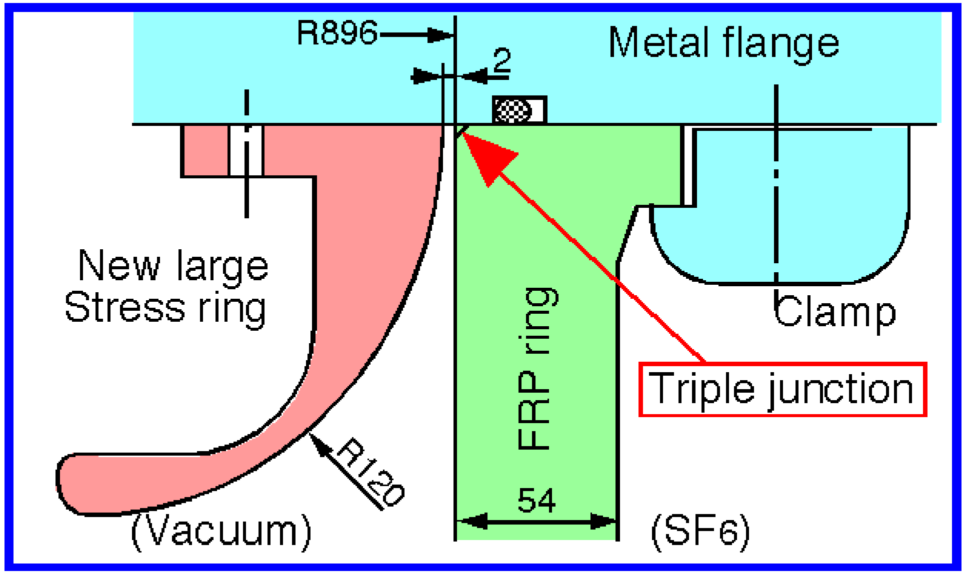
Glow discharge

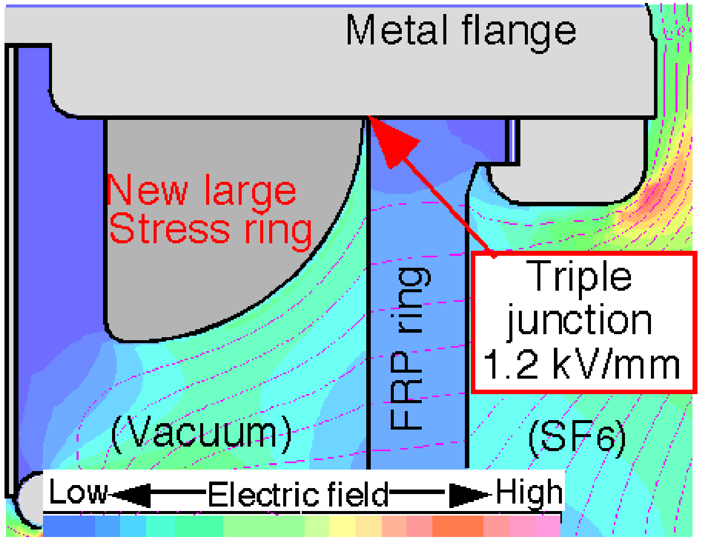


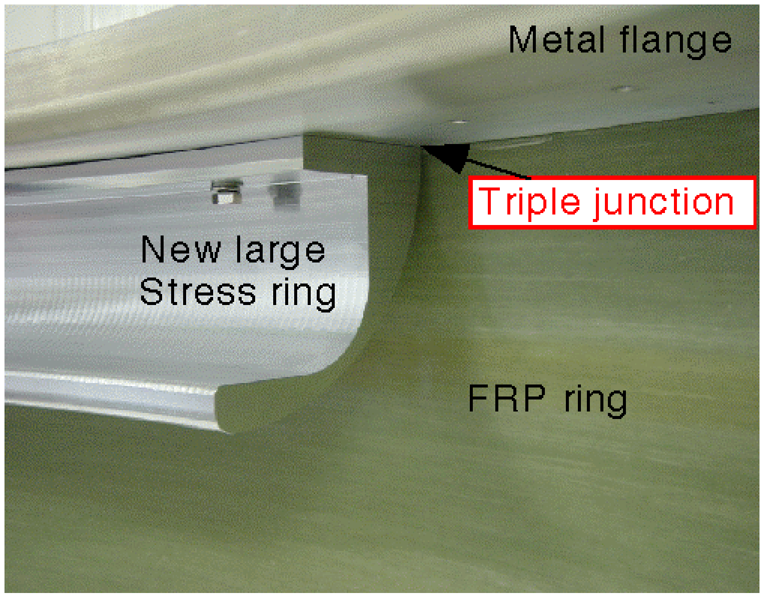
Done: The vacuum insulation design guideline:
extrapolated to high voltage, long gap and low pressure region for both vacuum arc and glow discharges.

Stress ring to prevent surface flashover

T. Inoue et al., Fusion Eng. and Design 66-68, 597-602 (2003).







- New large stress ring is effective to prevent surface flashover,

  by lowering stress at triple junction to:
  - 1.2 kV/mm (1/3 of the original)

1 MV sustained for 8,500 s cw,

Beam acceleration test started in Dec. 2001.

KAMABOKO high power operation

The objective of the present R&D is to accelerate H^- ion beams of MeV level energy with the current density of ITER required level (200 A/m^2).

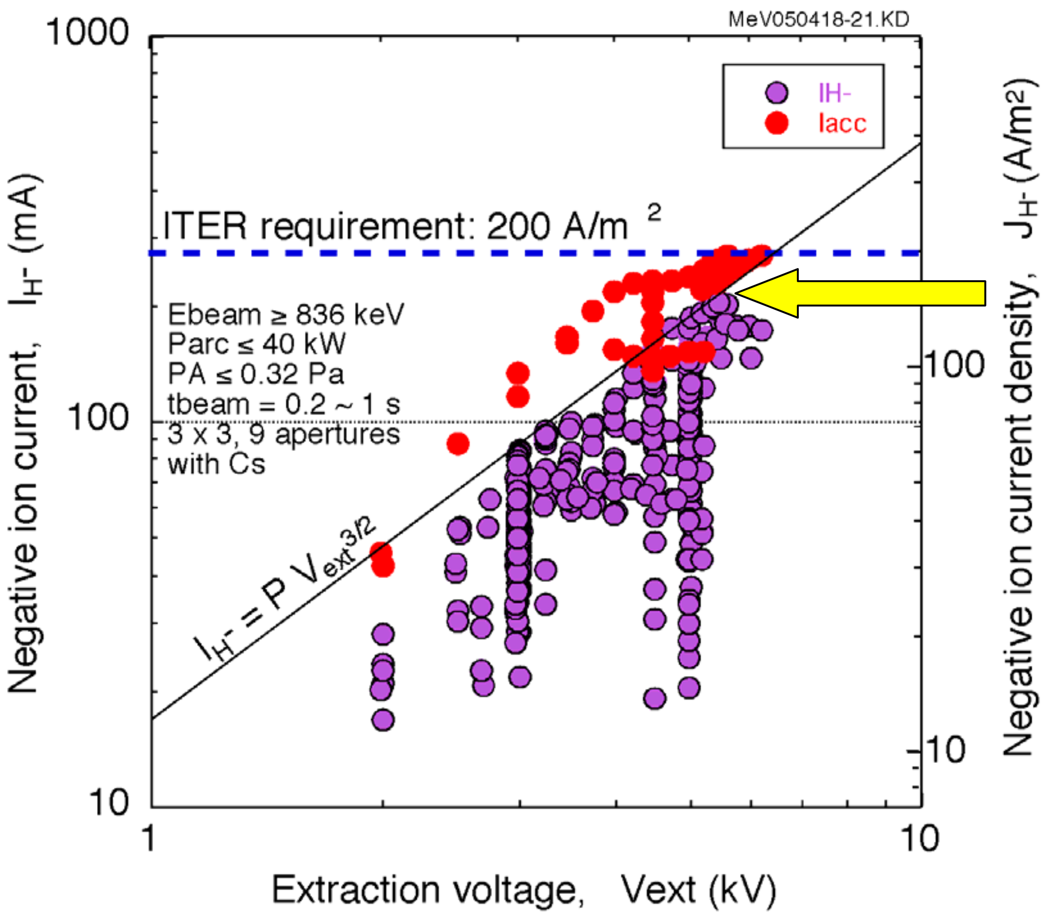
- KAMABOKO source tuning:
  - Cs seeded,
  - Filaments: from 5 to 7, each 110 mm long (Arc power available: 40 kW),
  - Magnetic filter strength: from 460 to 745 Gauss cm.

Air/SF_6 leaks degraded H^- ion production and accelerator voltage holding capabilities.

- O-ring damage due to backstream ions
  As was reported by Cadarache, we also had melt damage on port plug (located top of the source on the beam axis), with air leak due to O-ring damage.

- SF_6 permeation through Viton O-rings
  Some Viton O-ring allows permeation of SF_6 gas, in particular at high temp. Those in solenoid valves in gas feed line were removed and welded, though still leaking through those in the insulator column.

836 keV, 146 A/m² H^- ion beams



- All beam shots in April 18-21, 2005.
- Wide operation window at under perveance conditions.
- 836 keV, 146 A/m² H^- ion beams achieved (I_{H^-} = 206 mA).
- The accelerated beam current does not show clear saturation tendency, suggesting that enough amount of H^- ions are produced in the source.
- Since the KAMABOKO source itself has already achieved 300 A/m² H^-, further increase of the current /current density is expected toward the ITER required current density.

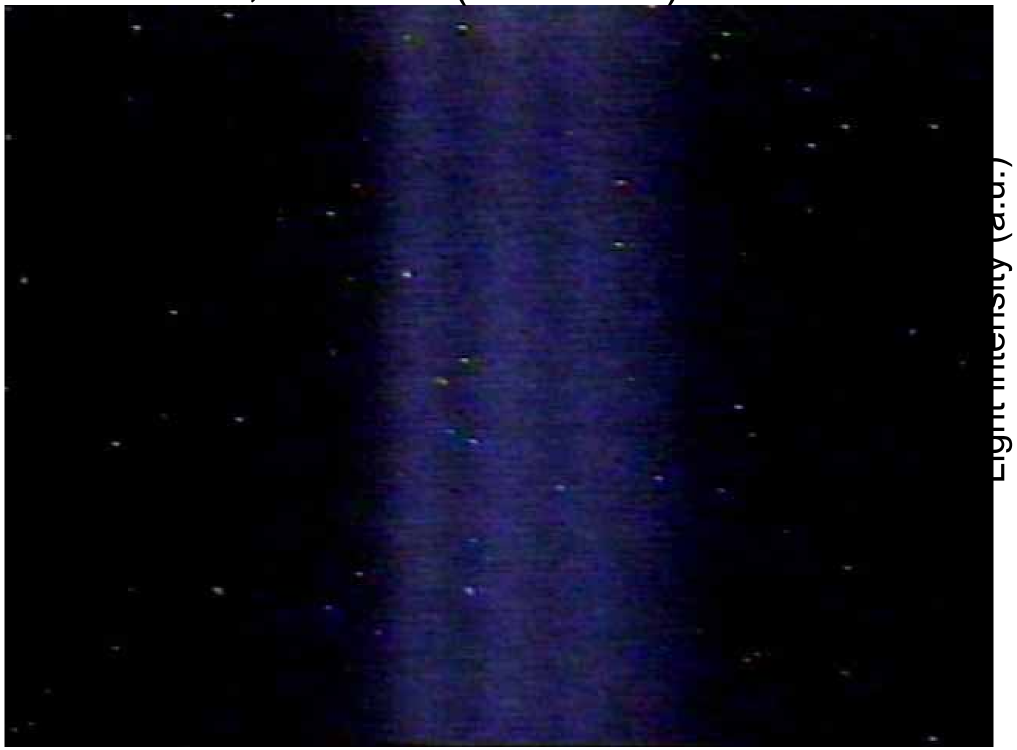
Beam optics of MeV level H^- ion beams

By M. Kashiwagi

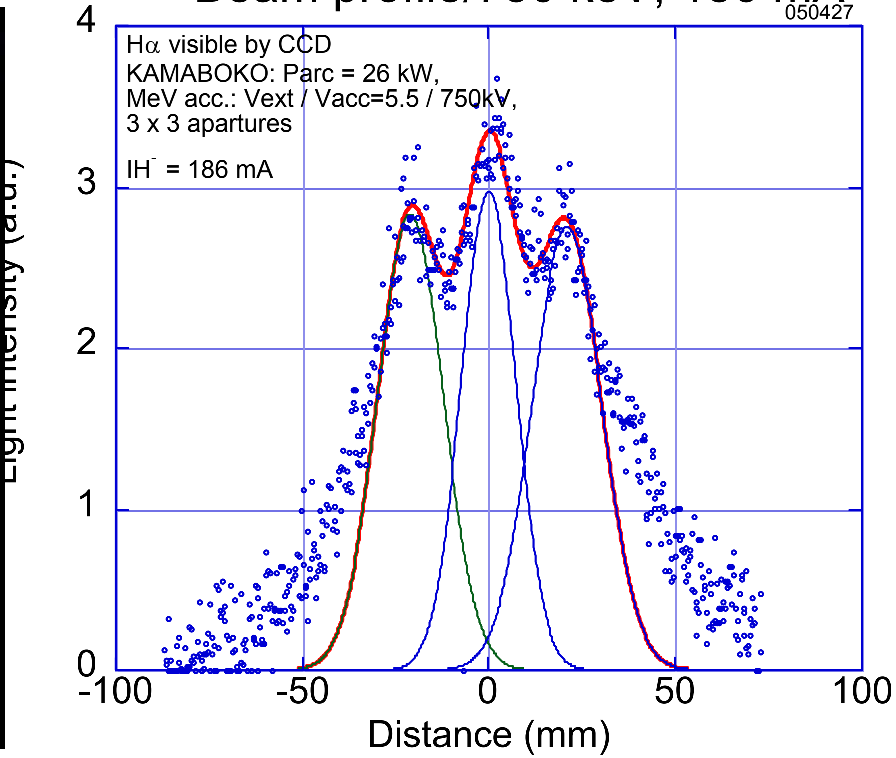
Beam optics measurement by linear CCD

(SONY XC-ST30, electric output proportional to photon input)

800 keV, 140 mA (100 A/m²) H^- ion beam



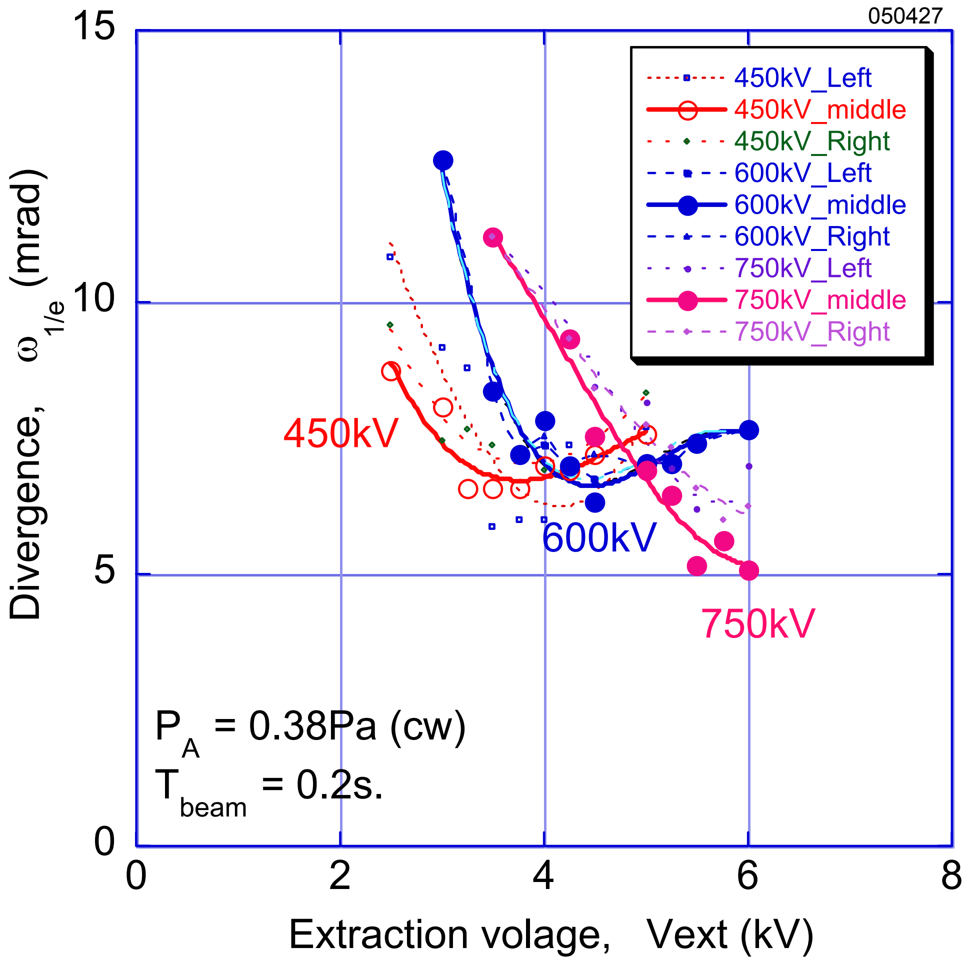
Beam profile/750 keV, 186 mA



Beamlets extracted from 3 x 3 = 9apertures are accelerated to high energy with small divergence angle.

Divergence of MeV class H^- ion beams

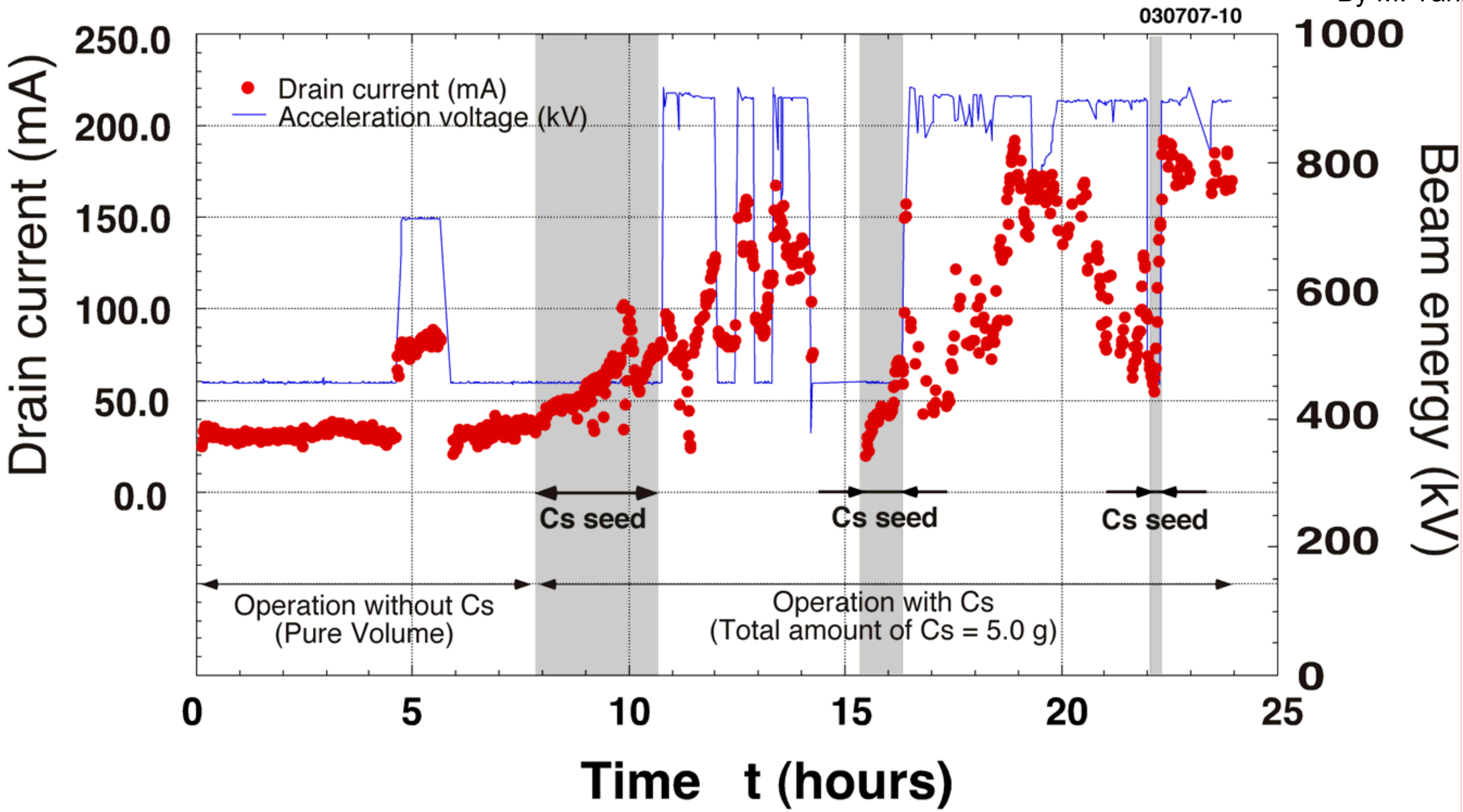
By M. Kashiwagi



Beamlet divergence ≈ 5 mrad was achieved in 750 keV, 140 A/m² H^- ion beams.

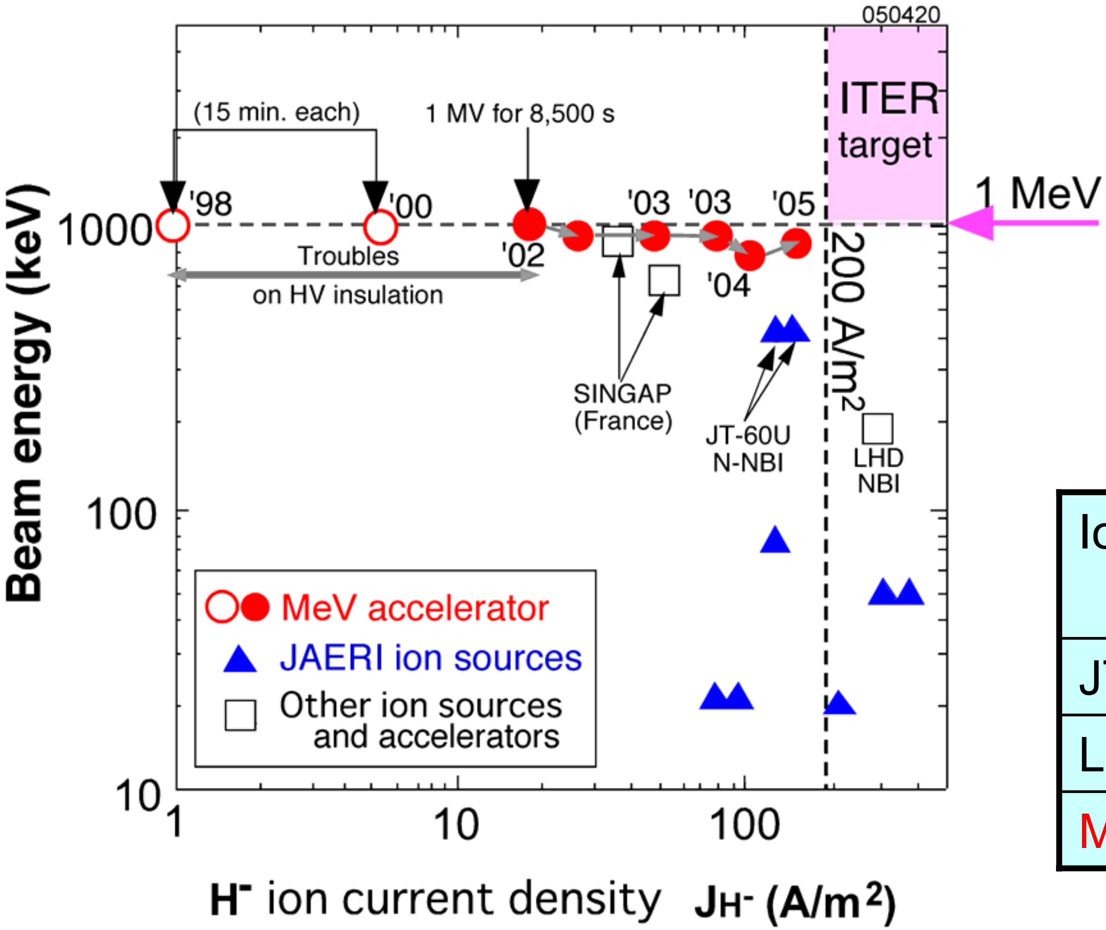
Stability of 900 keV H^- ion beams

By M. Taniguchi



900 keV H^- ion beams of 100 〜200 mA (drain current) were accelerated stably for 175 shots, even under Cs seeded condition.

Progress of MeV accelerator R&D



1 MeV accelerator R&D in progress.

- 836 keV, 146 A/m^2 H$^-$ ion beam (206 mA) achieved.

Beam pulse length: ≥ 0.2 s

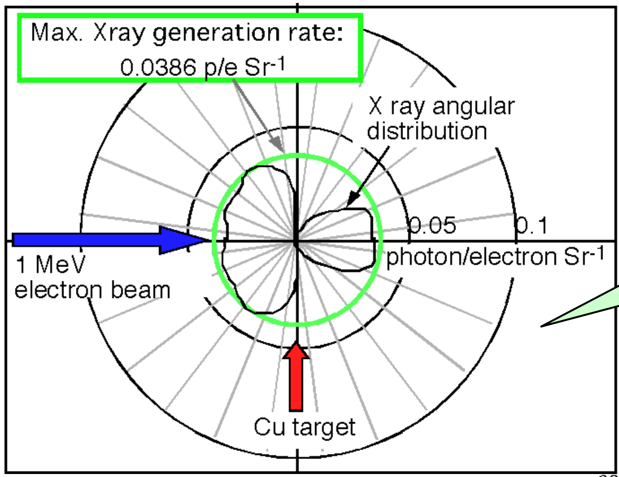
limited by the beam dump (swirl tubes, 30° to beam axis).

Defining:
(power density)
= (energy) x (current density)

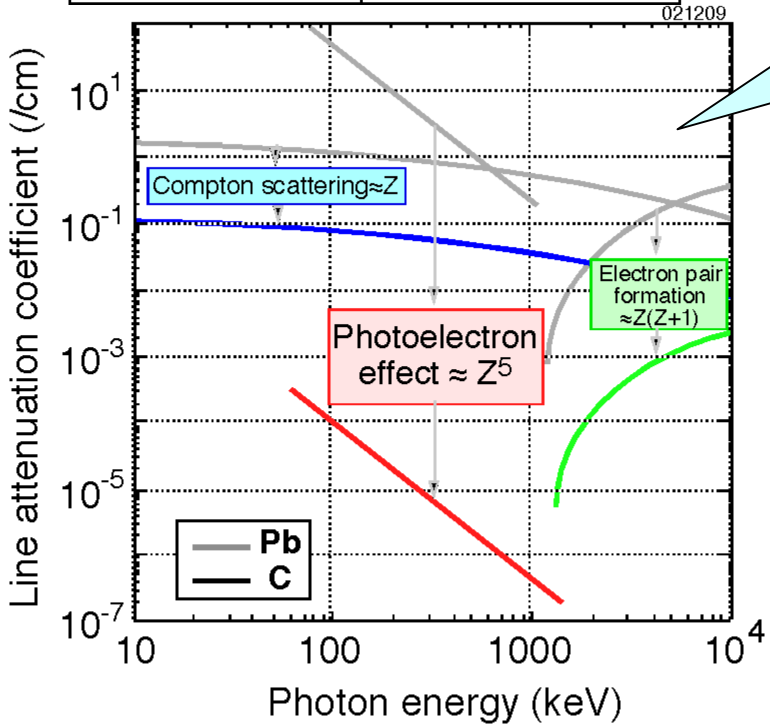
Ion source	Power density (MW/m^2)
JT-60 N-NBI	52
LHD NBI	59
MeV accelerator	122

The beam dump to be replaced to a new one (14.5°) in May ‘05.

Estimate of photoelectron effect



Angular distribution of photons by EGS4
- –Photon generation: 0.0386 photon/electron Sr^{-1}
- –Typical photon energy: 100 keV



Line attenuation coefficient in light element
- •Photoelectron effect ≈ Z^5
  - –Attenuation by photoelectron effect is small even for low energy photons.
  - –Line attenuation coefficient: 10^{-4} /cm

•Absorbed photons in 0.1 A electron acceleration
＝Primary electrons generated in FRP:
0.38 μA

•Dark current by inherent conductance of FRP:
~ 200 μA

Estimate

Acceptable up to 10^3 of secondary electron multiplication,
Breakdown by photoelectron would not occur in 0.1 A electron acc.

Assumption of DEMO requirement

	Requirement	Comment
Beam power	~ 100 MW	• Higher energy = higher power density. • Beam power/injector to be limited by heart removal capability of beamline components.
Accelerator (Energy) (focusing)	1.0 ~ 1.5 MeV	• **Max. energy for electrostaticaccelerator?** **= vacuum insulation or RFQ?** • Sinethrough at plasma ramp up. • Wall loading: 5 MW/m^2. Beam focusing and shielding around beam path.
Negative ion source	~ 200 A/m^2 D$^-$ $\leq$ 40 A	• Max. reliable/reasonable current/current density. • Reliability,at least year long maintenance free. • **Filamentless, Cs free simultaneously.**
System efficiency (Neutralizer)	$\geq$ 50%	• Gas neutralizer not applicable due to gas consumption. • **Need plasma/laser neutralizer.**

Comparison of acceleration types

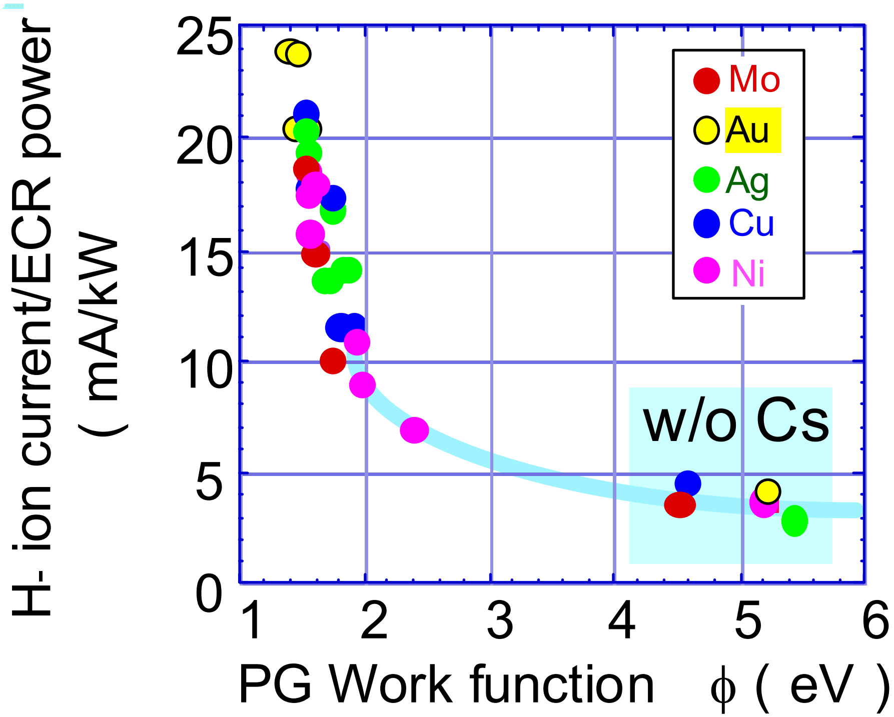
	Electrostatic accelerator	RFQ accelerator
Technology basis	Extrapolation of existing tech.	New R&D required
Acc. efficiency	> 90%	~25%
Size	ϕ 3 m x 3 m^{l}	ϕ 3 m x 10 m^{l}
Structure	Simple	Assembly accuracy required
Beam energy	Depend on vacuum insulation	> 2 MeV possible
Beam current	Multiaperture	1 A/channel x bundle?

Recent design analyses at JAERI shows beam energy of 1~ 1.5 MeV is preferred from the first wall / shinethrough aspects.

Electrostatic accelerator could be still valid for DEMO NB systems.

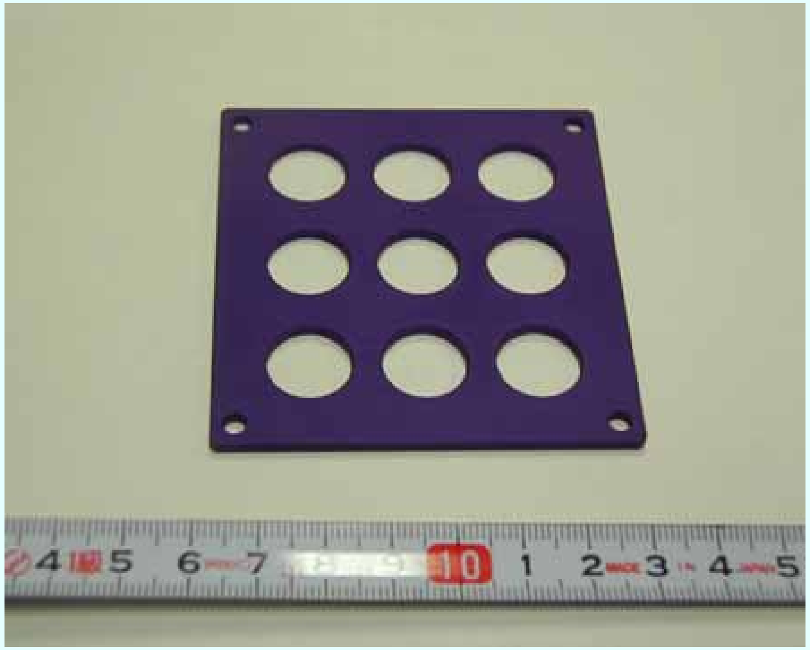
Toward Cs free negative ion source

H^- ion current
as a function of work function on PG



Negative ion production is dependent on work function.

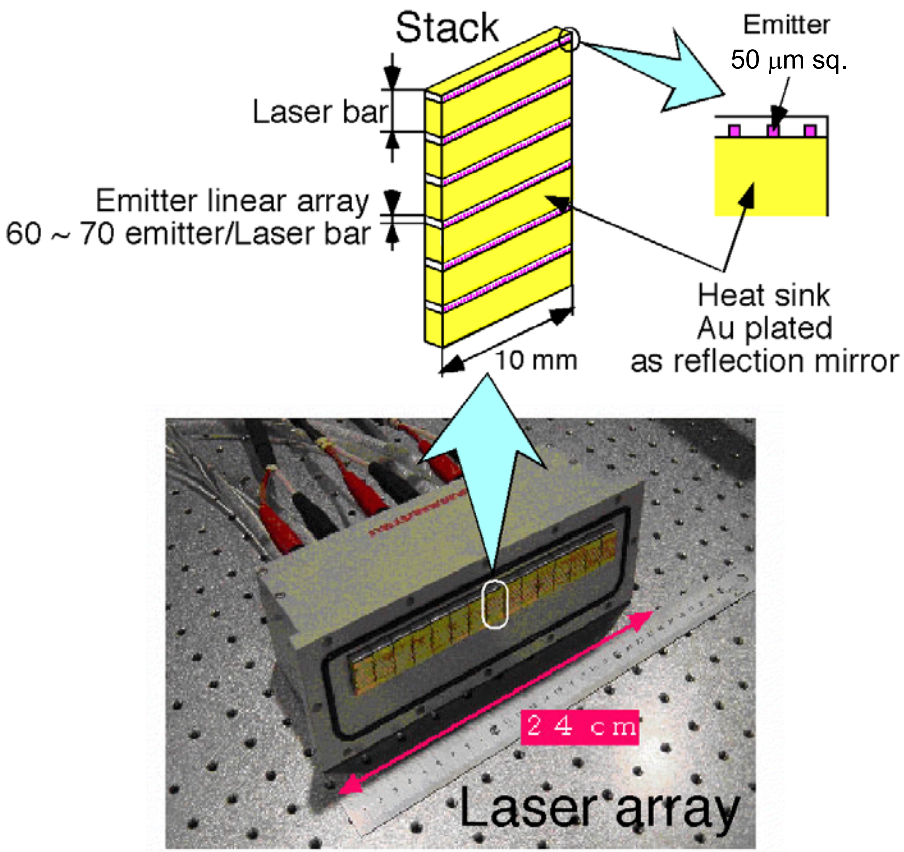
Low work function material with Cs?



- LaB_6
- Cs inplanted Mo

To be tested in 2005.

Laser neutralizer

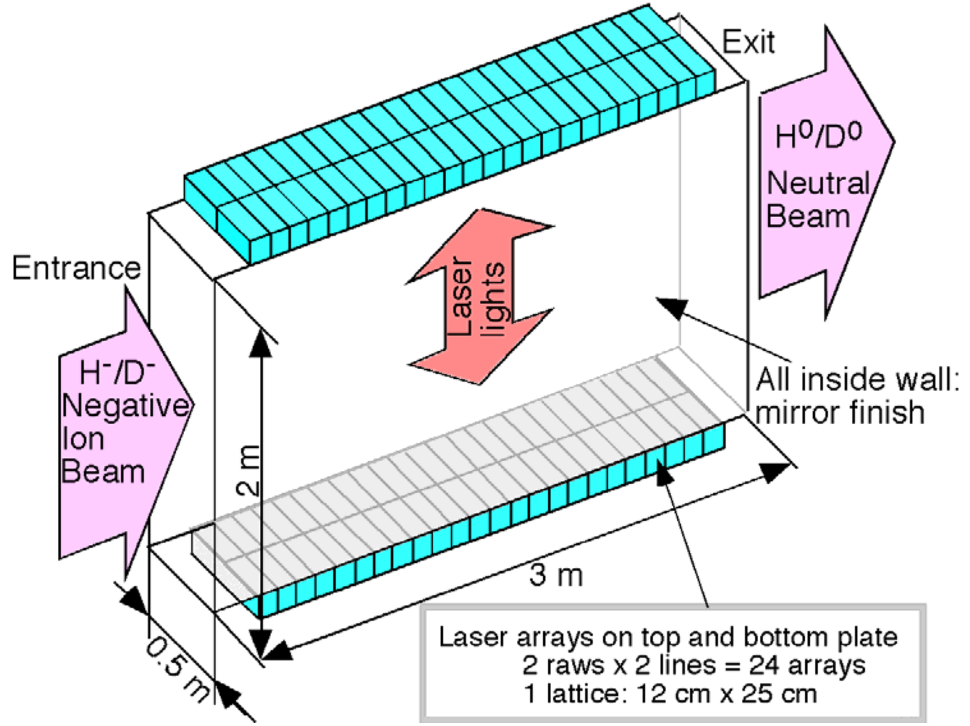


2.7 kW cw Semiconductor laser array

- Light emission efficiency: 40%
- Au plated, reflection rate: 99.95 %
- HAMAMATSU Photonics Co. Ltd.

Application to neutralizer of ITER NBI size

- 96 arrays on top and bottom,
- Power required to drive laser: 620 kW
- Reflection more than 2000 times necessary,
- Optics to minimize the light leakage from the beam entrance exit opening to be designed.



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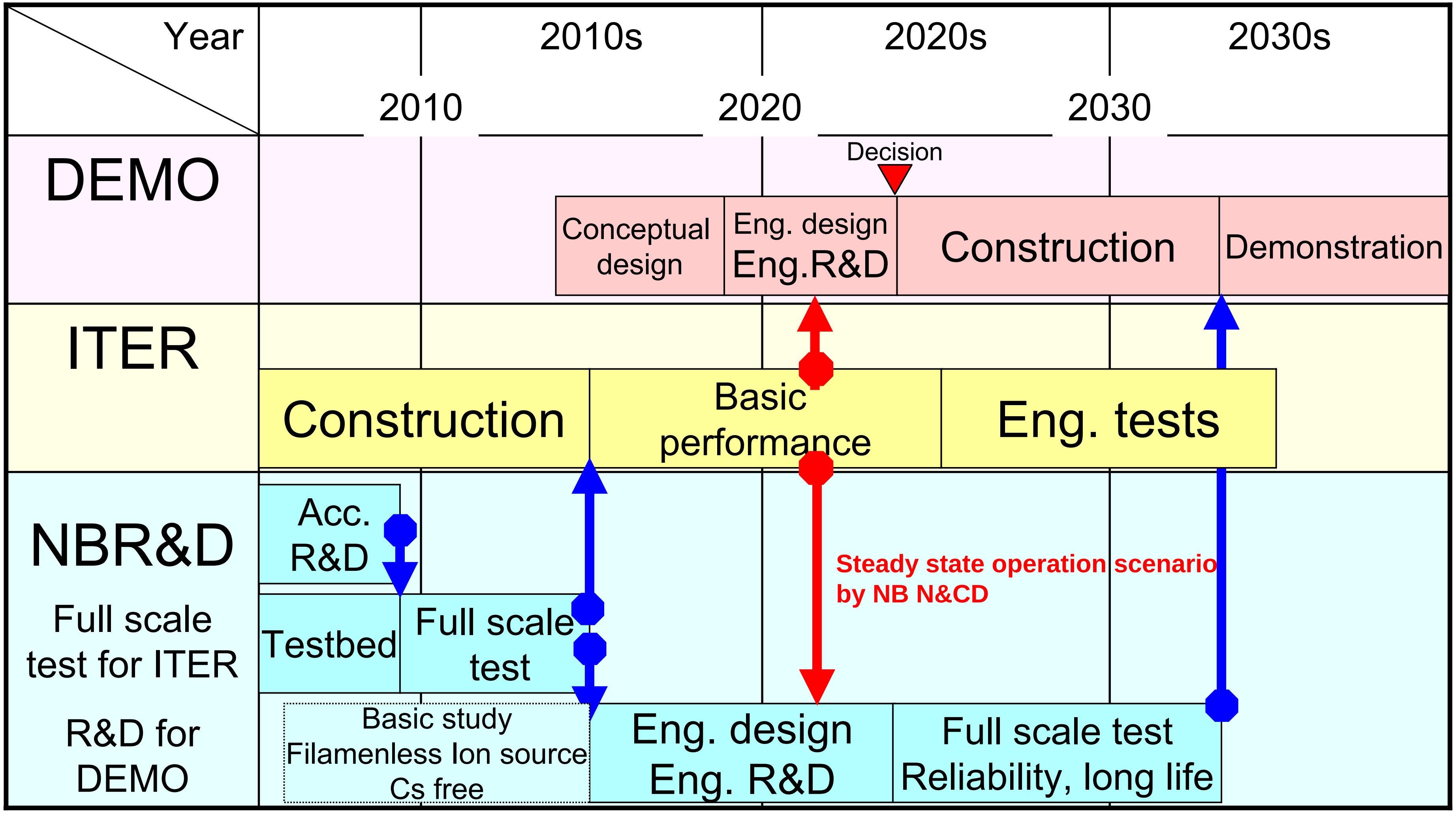
Roadmap for long term NB R&D

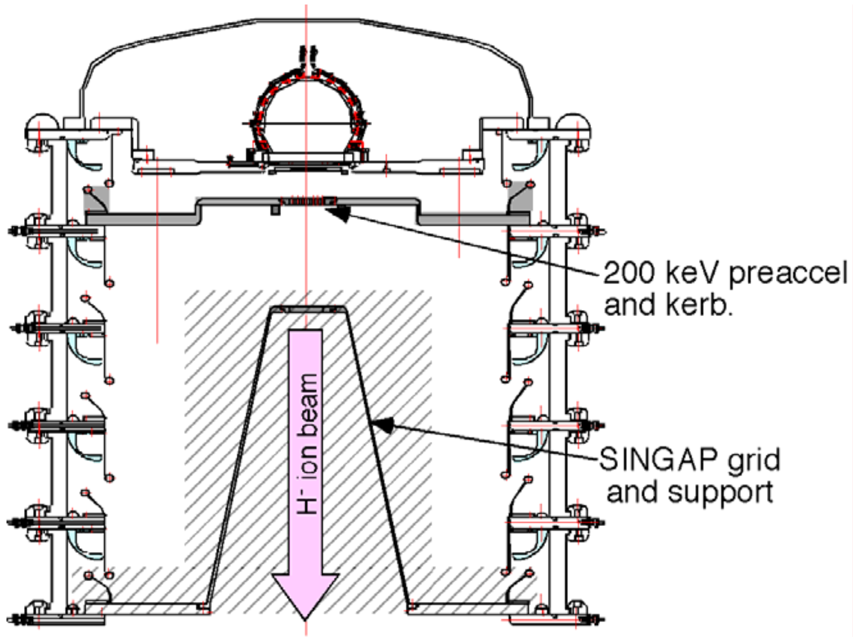


R&D plan for FY2005

MeV accelerator	•Demonstration of 1 MeV 200 A/m^2 H^- ion beam. •Beam optics study and MAMuG optimization. •Pulse length extension up to 2 s x 100 shots. •Modification to SINGAP like structure.
Uniformity	•Uniform H^- ion production ($\leq$ 10%) in 10 A negative ion source at $\geq$ 100 A/m^2 with Cs, and reasonably low electron current.
Cs free source	•Sample fabrication by new low work function materials. •Work function measurement for LaB6 and Cs implanted Mo. •Initial test of negative ion production by new grids.
Filament free source	•Analyses of rf/ECR matching with plasma, under support of rf experts of JT-60 and ITER.
Testbed	•Power supply design. •Radiation shielding analysis. •Large bore Al_2O_3 ceramic manufacturing technology R&D.

SINGAP test at JAERI

Modification of JAERI MeV accelerator with SINGAP like structure



- 200 keV preaccel. by available power supply
- Water cooled grids, which were not possible for MAMuG with budget limitation.

All parts necessary for the SINGAP test were delivered in JAERI Naka.