Some lessons from long pulse operation of negative ion sources and accelerators

R S Hemsworth

(with help from D Boilson, H P L de Esch, L Svensson, A Krylov, C Grand and P Massmann)

Euratom cea — TORE SUPRA

The KAMABOKO III negative ion source

Designed and built by JAERI, Naka, Japan

Model of the ITER reference design of ion source

- ☺ First tested in Japan: 280 A/m^2 of H$^-$

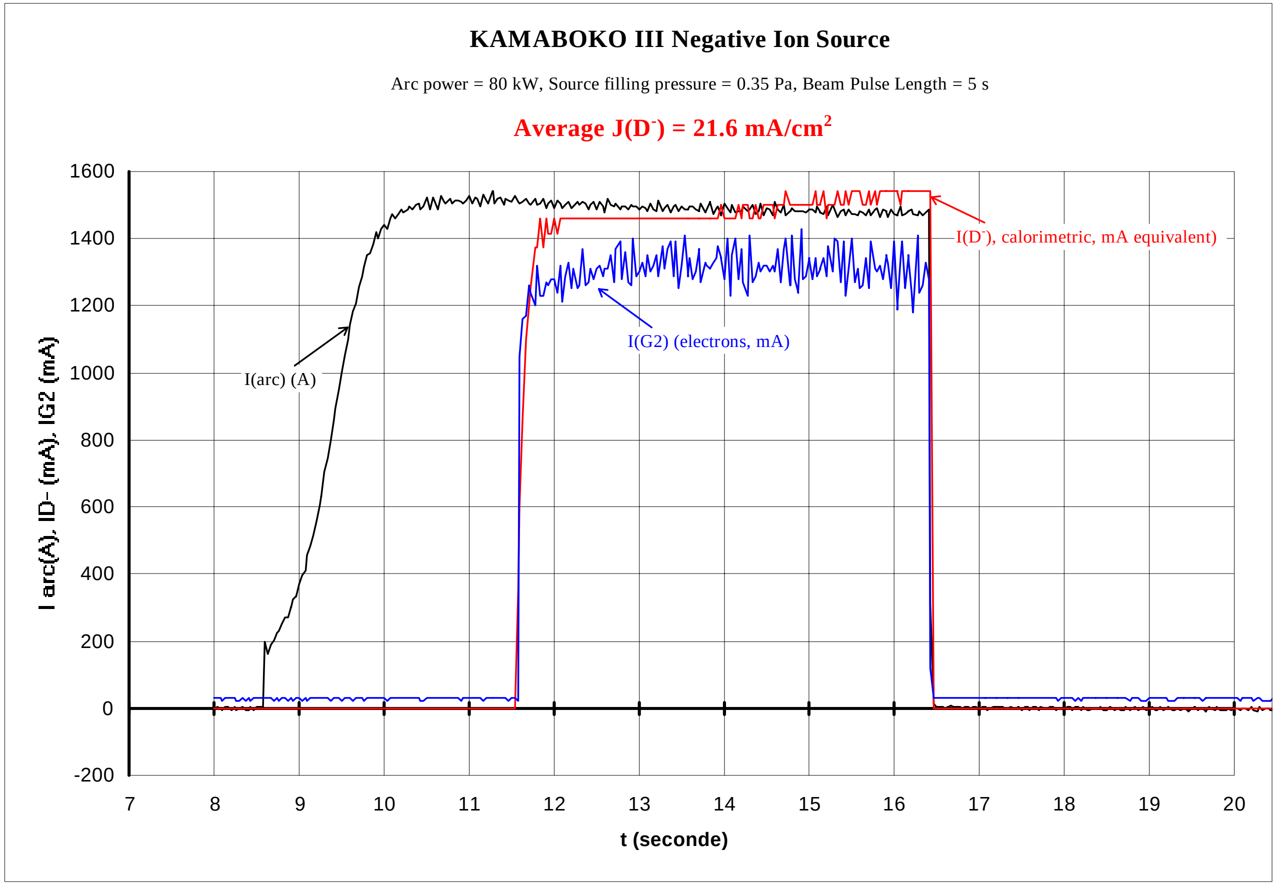
Sent to the DRFC, CEA, Cadarache, France for testing in deuterium.

Short pulse, 5 s operation

- ☺ Reproduced the 280 A/m^2 of H$^-$ but:
- ☹ with deuterium: $\frac{\text{Ie extracted}}{\text{ID}^-} > 10$!!

Increased magnetic filter strength from 450 Gauss.cm to 900 Gauss.cm:

- ☺ 220 A/m^2 of D$^-$, with $\frac{\text{Ie extracted}}{\text{ID}^-} \approx 1$

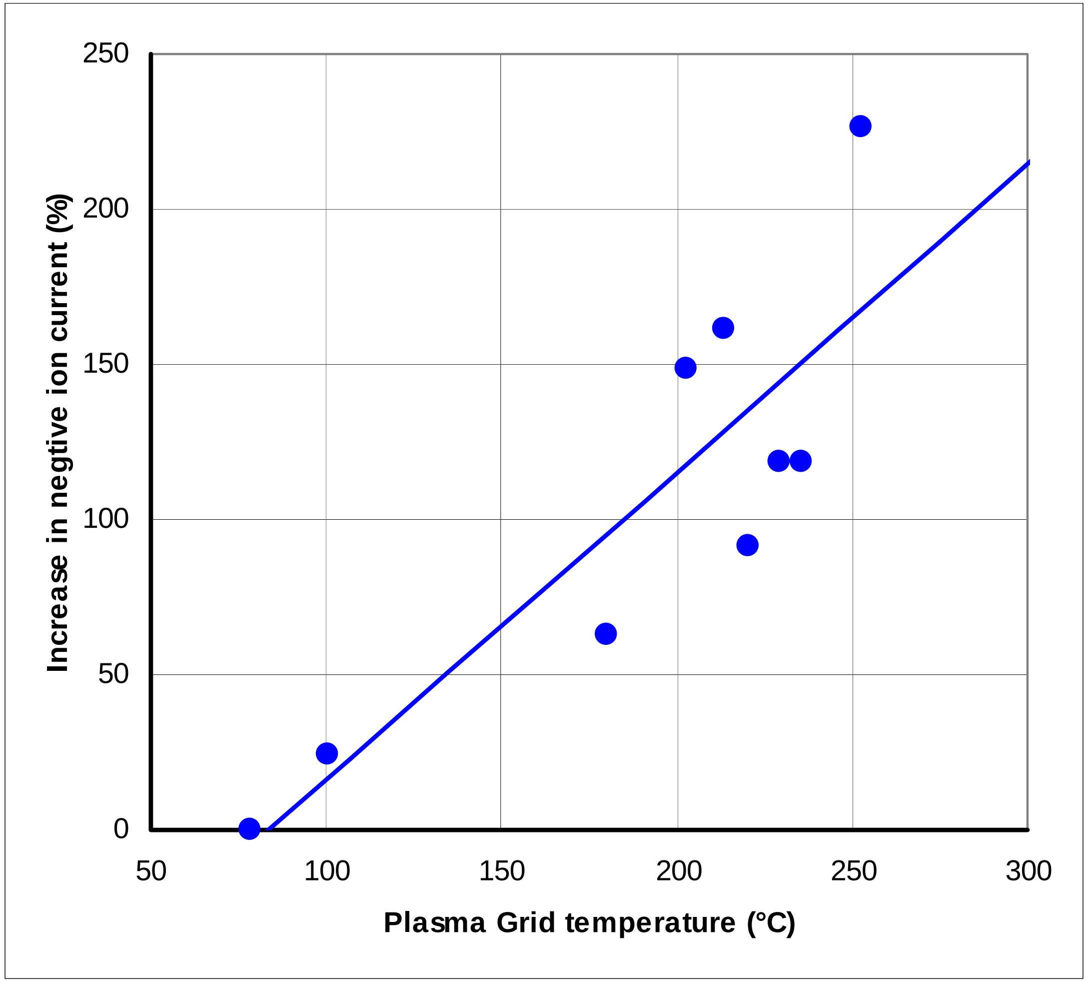

KAMABOKO III Negative Ion Source
Arc power = 80 kW, Source filling pressure = 0.35 Pa, Beam Pulse Length = 5 s
Average J(D-) = 21.6 mA/cm2
I(arc) (A)
I(D-), calorimetric, mA equivalent)
I(G2) (electrons, mA)
I arc(A), ID- (mA), IG2 (mA)
t (seconde)
1600
1400
1200
1000
800
600
400
200
0
-200
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Long pulse operation

- **operational advantages & difficulties**
- **reduced negative ion yield**
- **reduced plasma grid temperature effect**
- **increased caesium consumption**
- **caution in the future operations**

Planned changes to the system

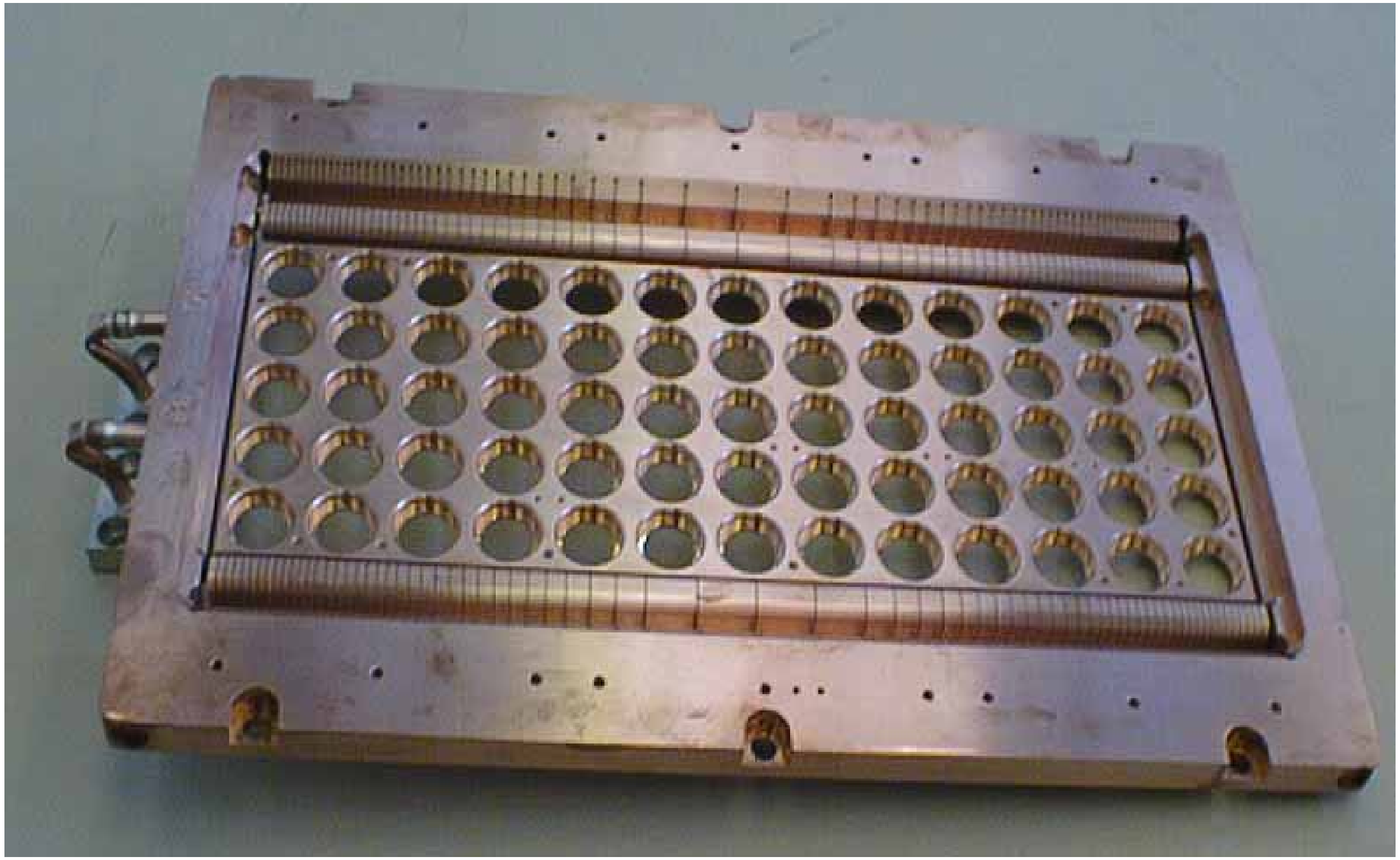
- ☺ New data acquisition system
- ☺ New timing system
- ☺ Water cooled arc series resistances
- ☺ Change cooling water circuit to ensure adequate flows
- ☺ Remote operation to allow D^- operation for long pulses (neutron dose)
- ☺ New long pulse plasma grid capable of operation at ≈300 °C



Effect of plasma grid temperature on the accelerated negative ion current with the KAMABOKO III ion source.

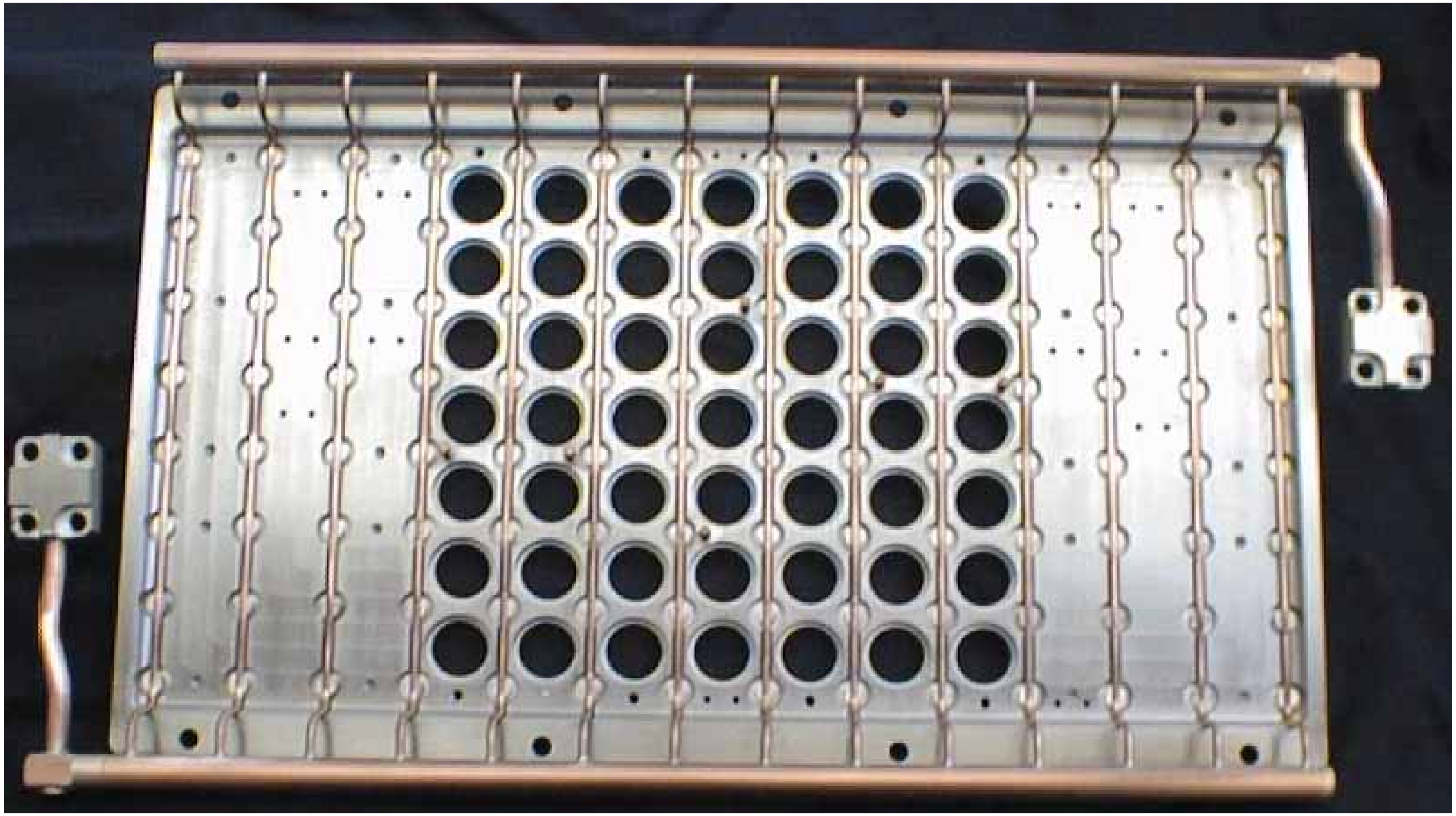
Parc ≈ 40 kW, Psrc ≈ 0.3 Pa, Bias ≈ 5 V, with Cs **Short (<5 s) pulses, Mo grid**

Long Pulse Grids Provided by JAERI



Cu/Cr/Zr long pulse grid (6 mm thick).

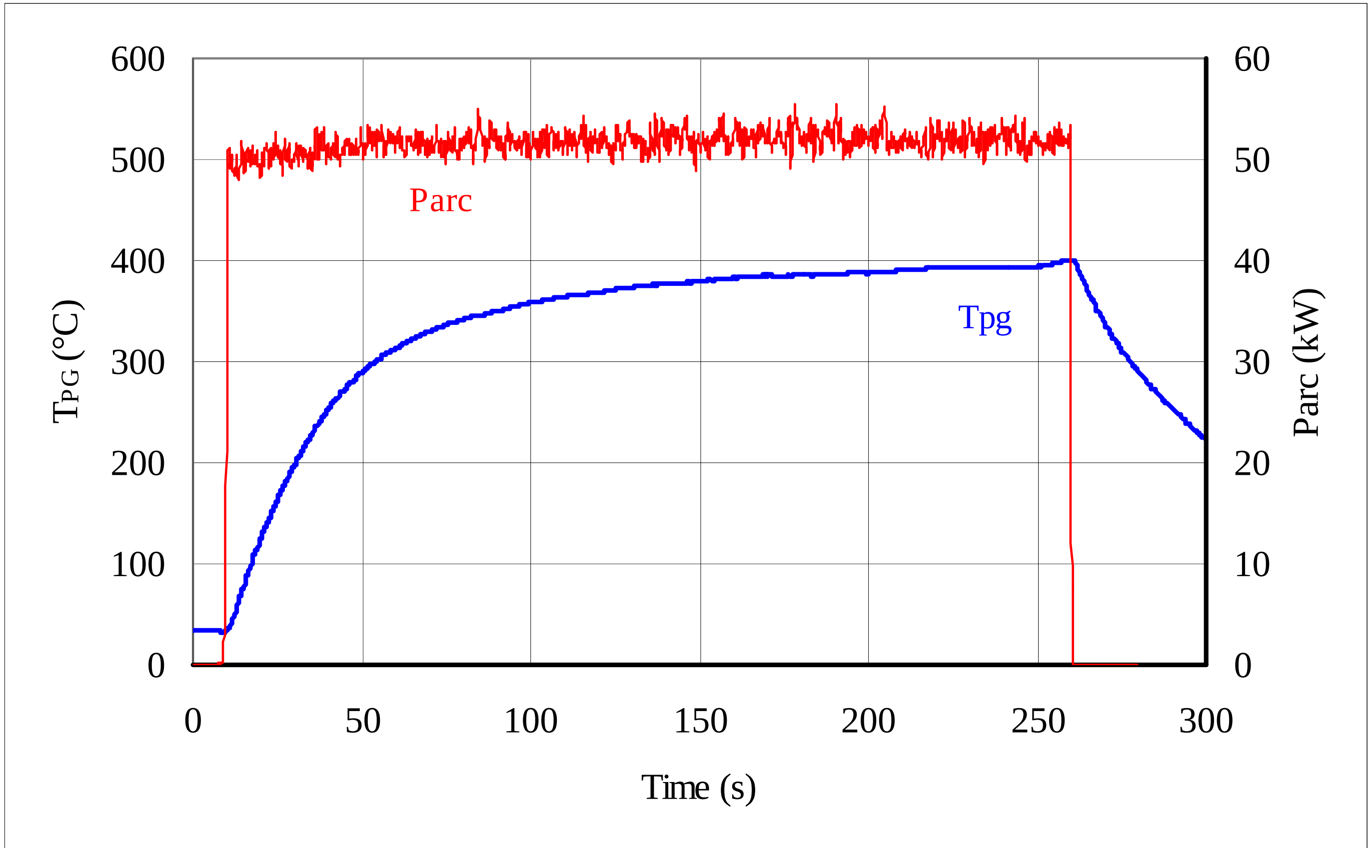
A thermal bridge limits the heat flow to the cooling channels along each edge



Molybdenum long pulse grid (6 mm thick).

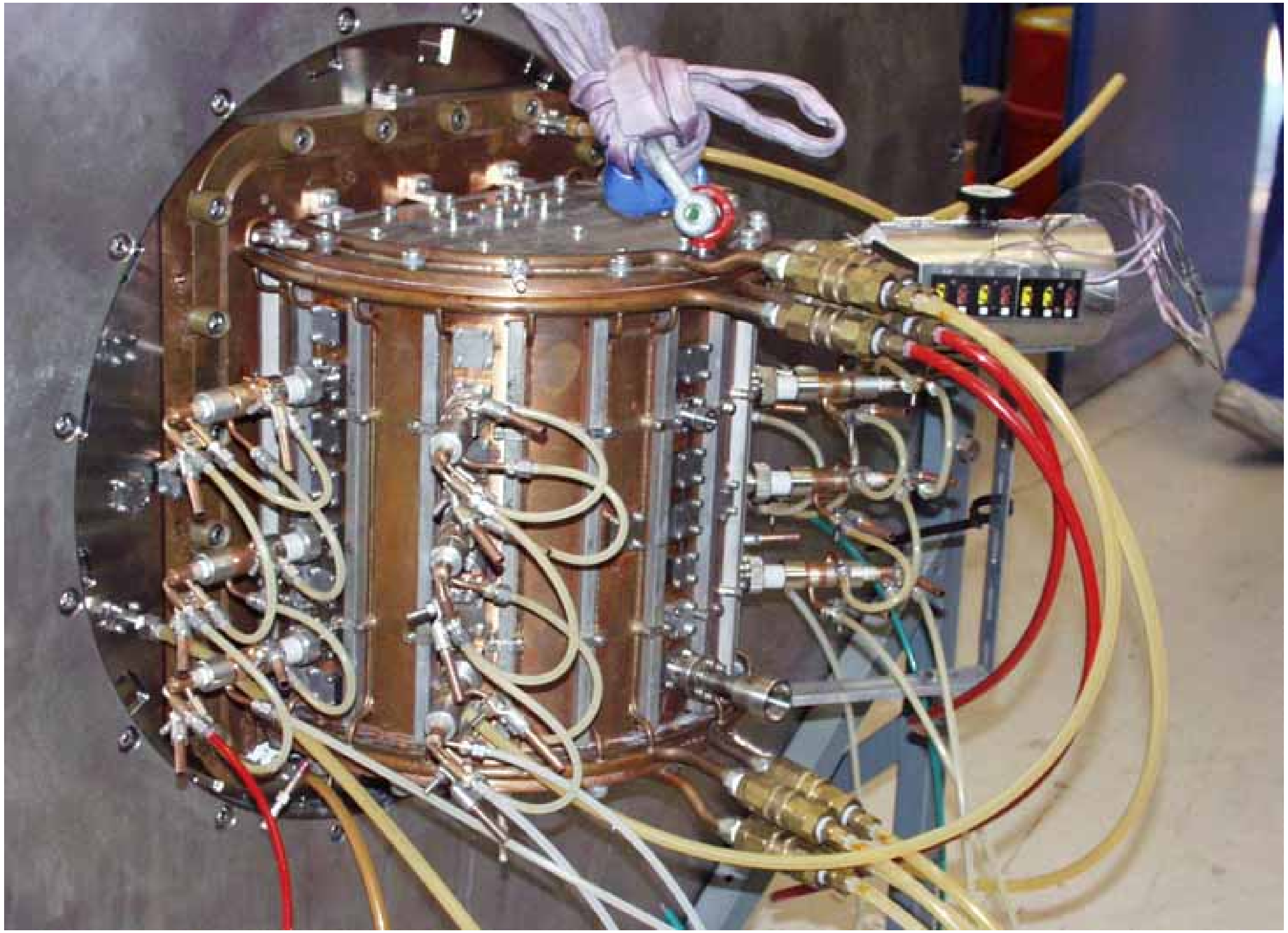
A set of stainless steel disks act as thermal bridges between the grid and copper cooling tubes traversing the grid.

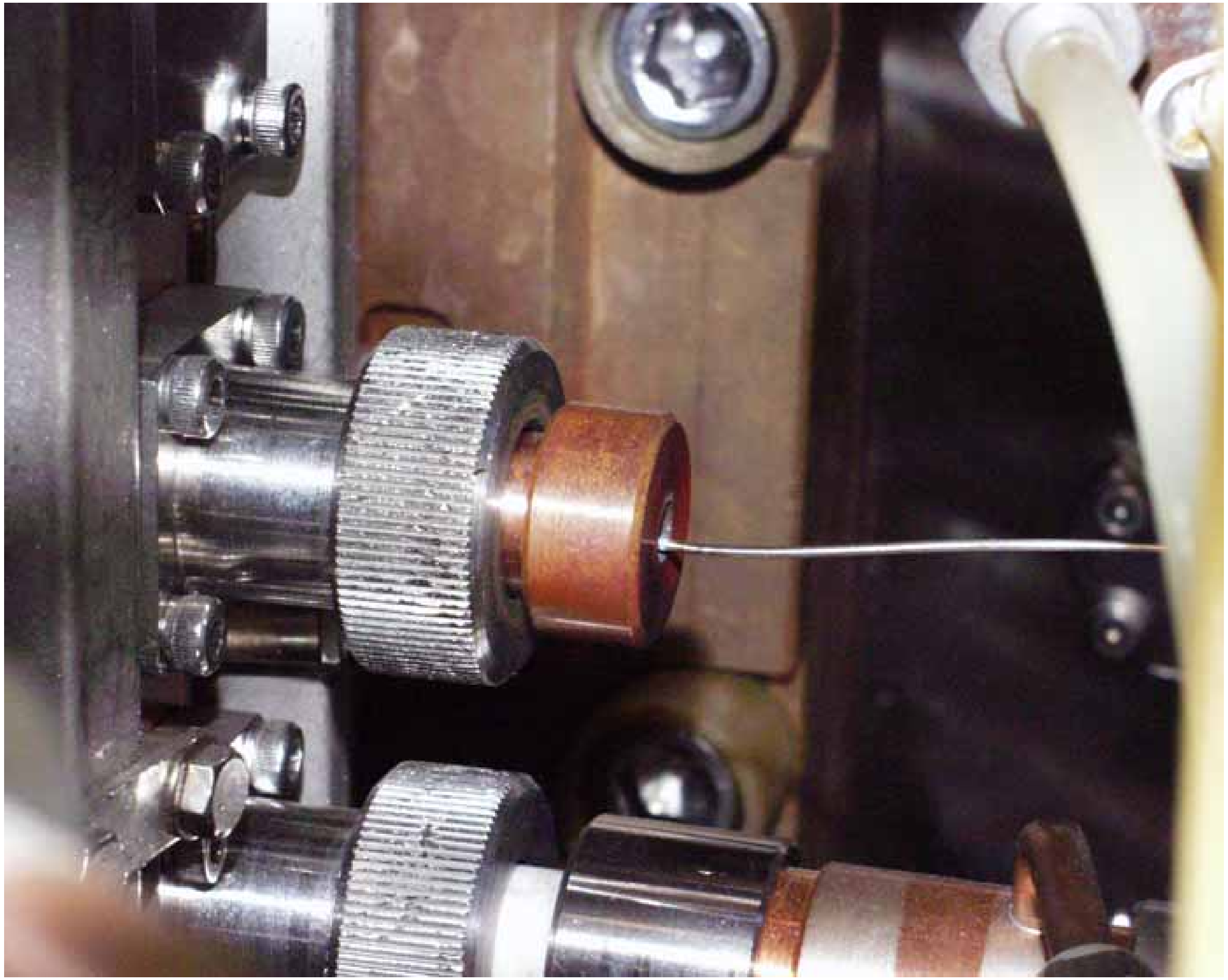
Euratom cea TORE SUPRA



Frame cooled grid

Unplanned changes: ☹ Remove/change source flanges





☹ **Extraction grid supports**

Originally the extraction grid supported off the plasma grid by small ceramic insulators

These became metallised due to increased number of breakdowns

Replaced by shielded supports mounted on the acceleration grid

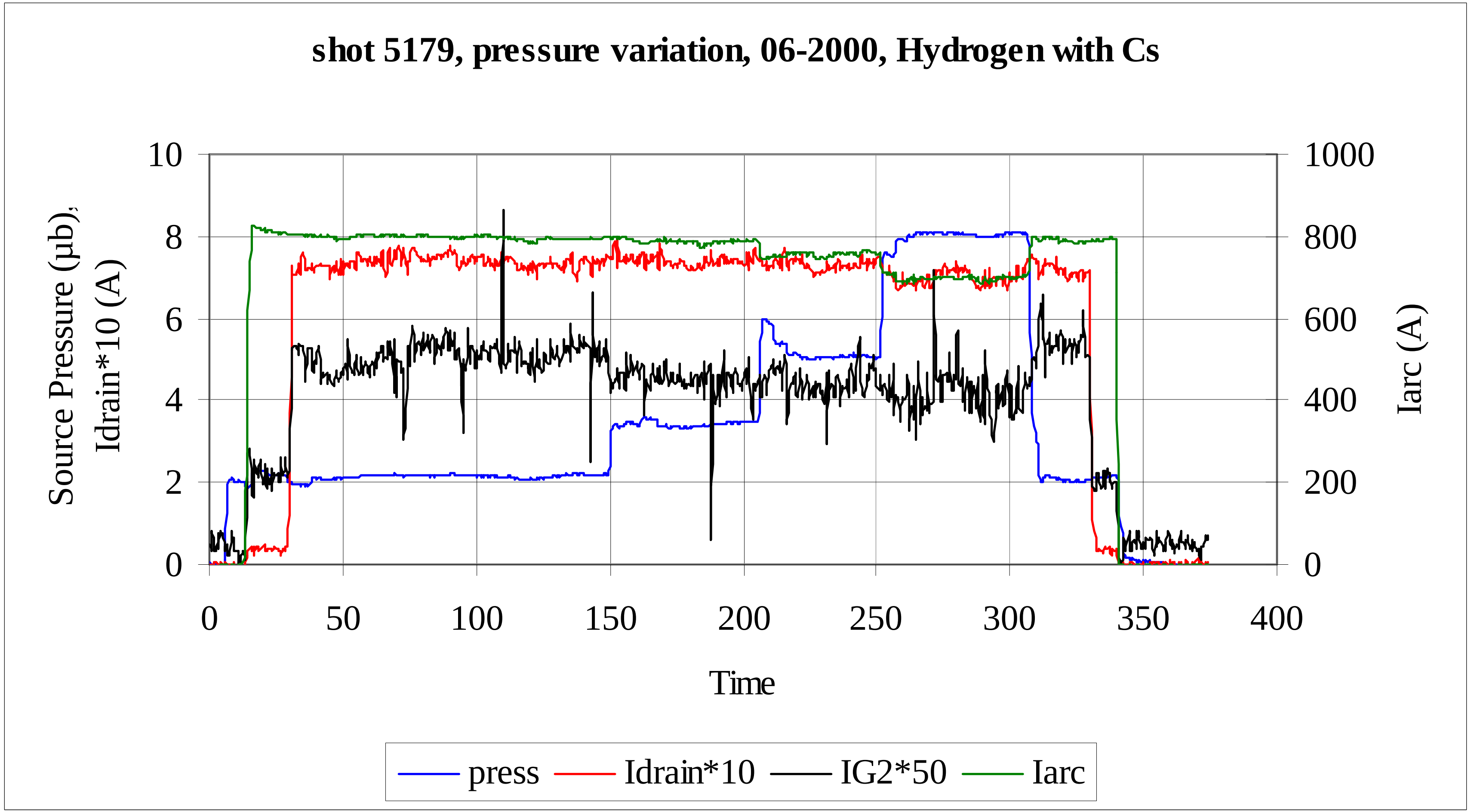
☹ Breakdown protection system

☹ Extraction grid feedthrough

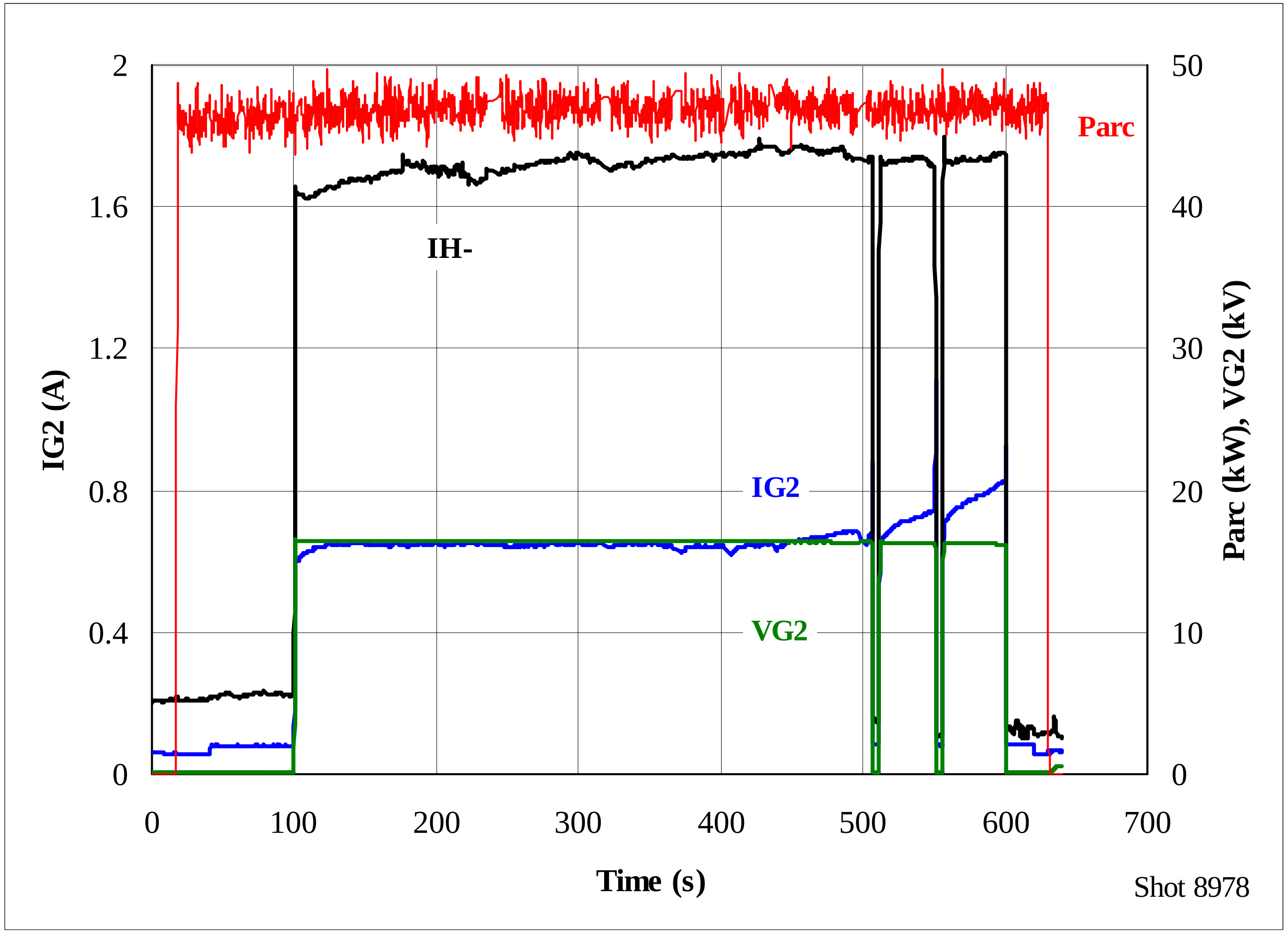
☹ ……

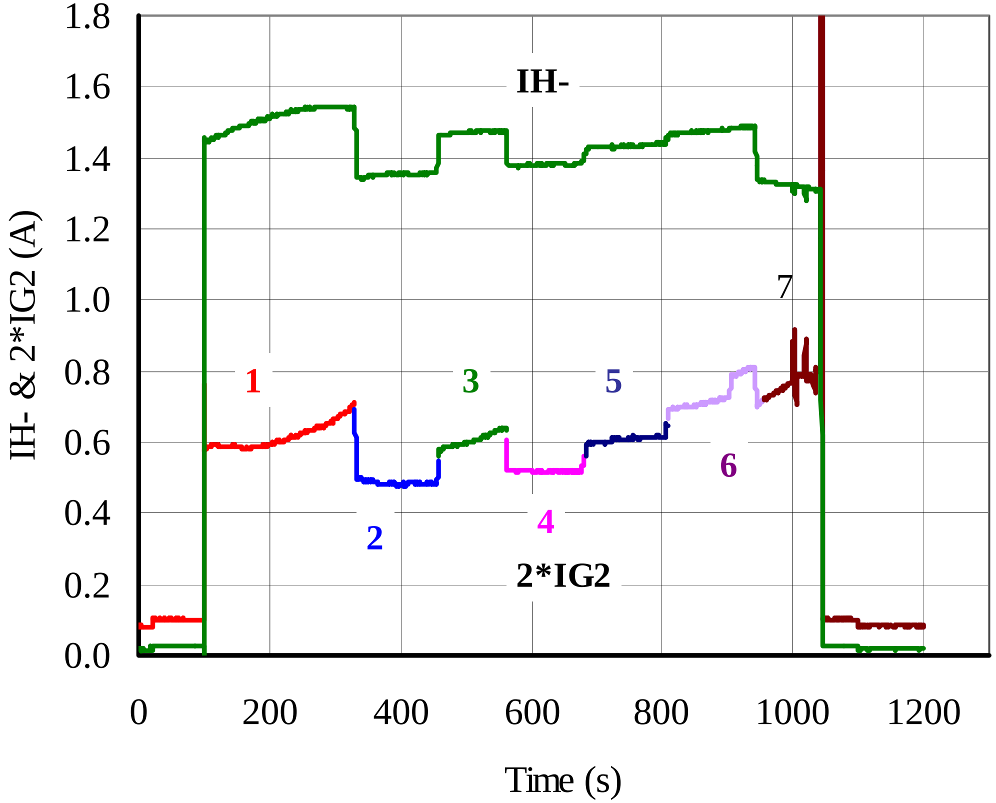
Advantages

☺ **Ability to change parameters during a single shot**



☹ **Unexpected long time constant effects**

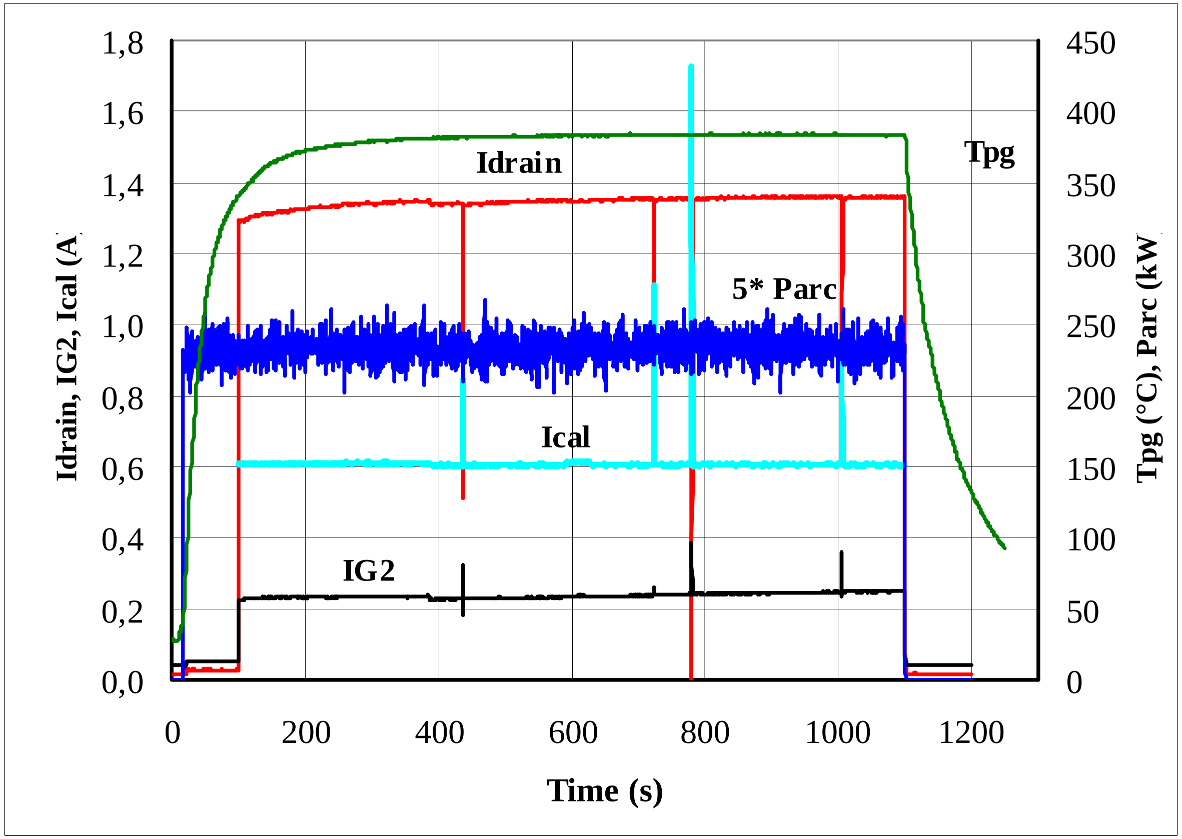




1. VG2 ~8 kV
2. Decreased VG2 by 2 kV to 6 kV
3. Increased VG2 by 1 kV to 7 kV
4. Decreased VG2 by 1 kV to 6 kV
5. Reduced filament voltage
6. Reduced filament voltage
7. Decreased VG2 by 1 kV to 5 kV

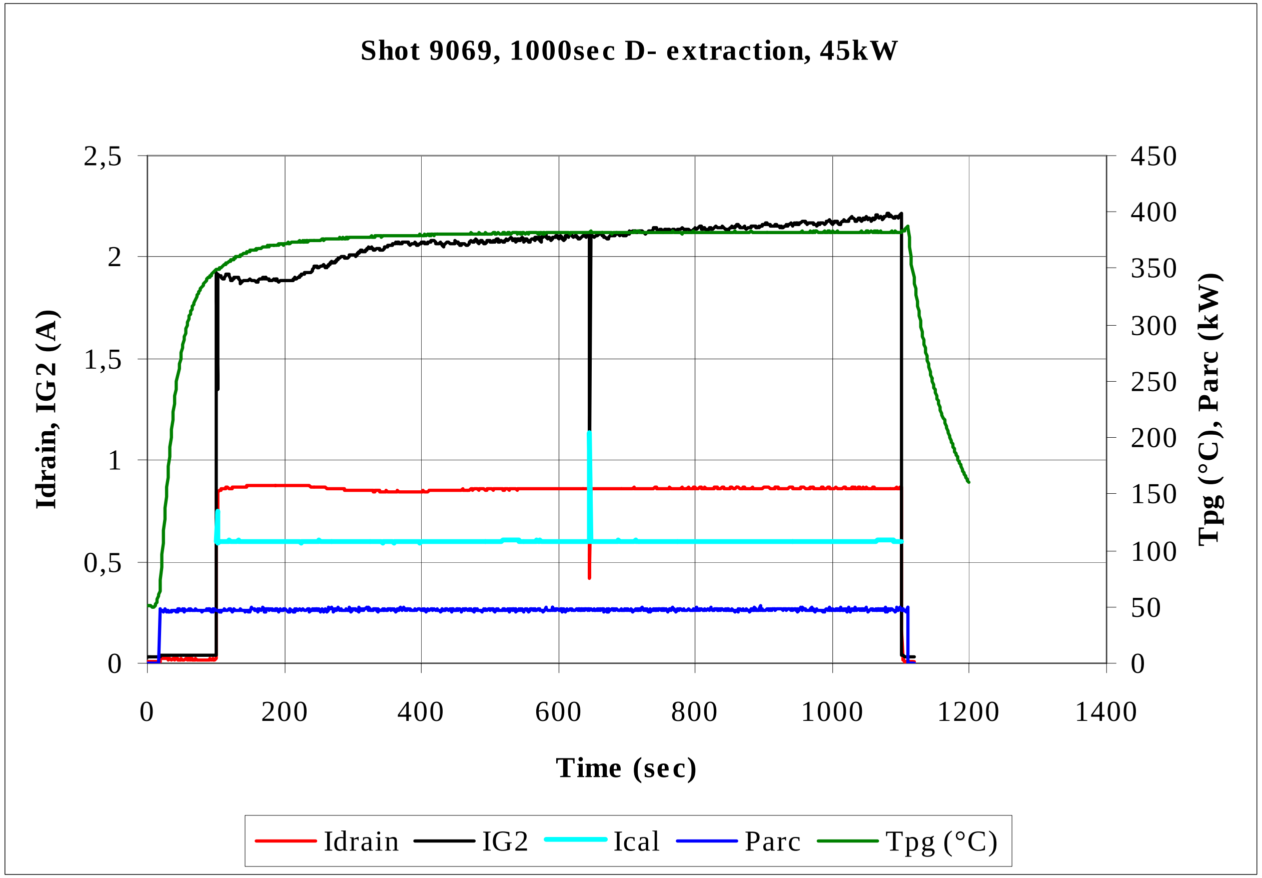
Shot 8994

1000 s extraction of H^- beam.



- ☺ 18 mA/cm^2 H^- calculated from the Idrain.
- ☹ Poor transmission: only ~50% accelerated current collected on the calorimeter ≈ 9 mA/cm^2

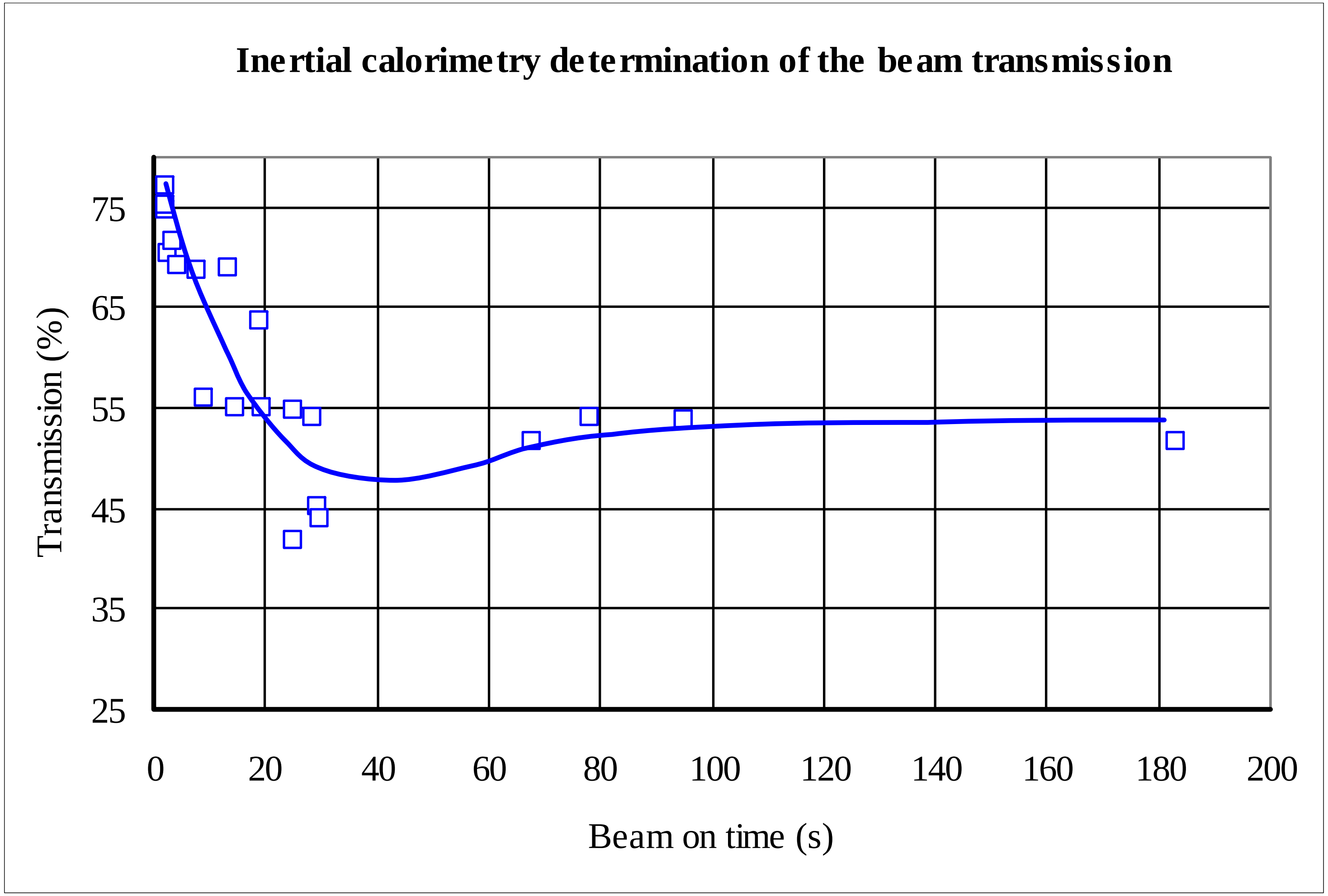
1000 s extraction of D$^-$ beam.



☺ **11.5 mA/cm^2 D$^-$ calculated from the Idrain.**

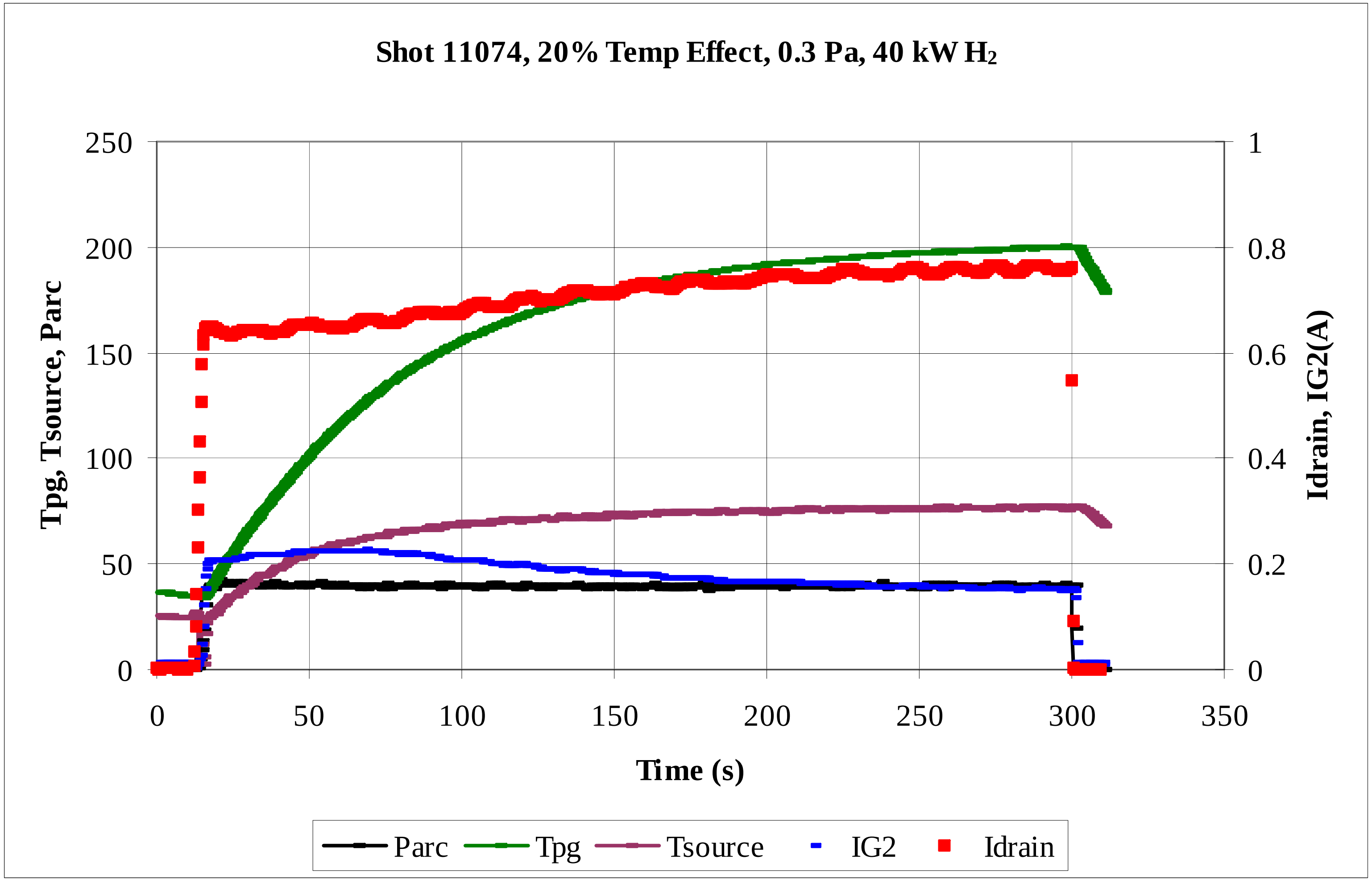
☹ **~60% of accelerated current arrives at the calorimeter ≈ 7 mA/cm^2**

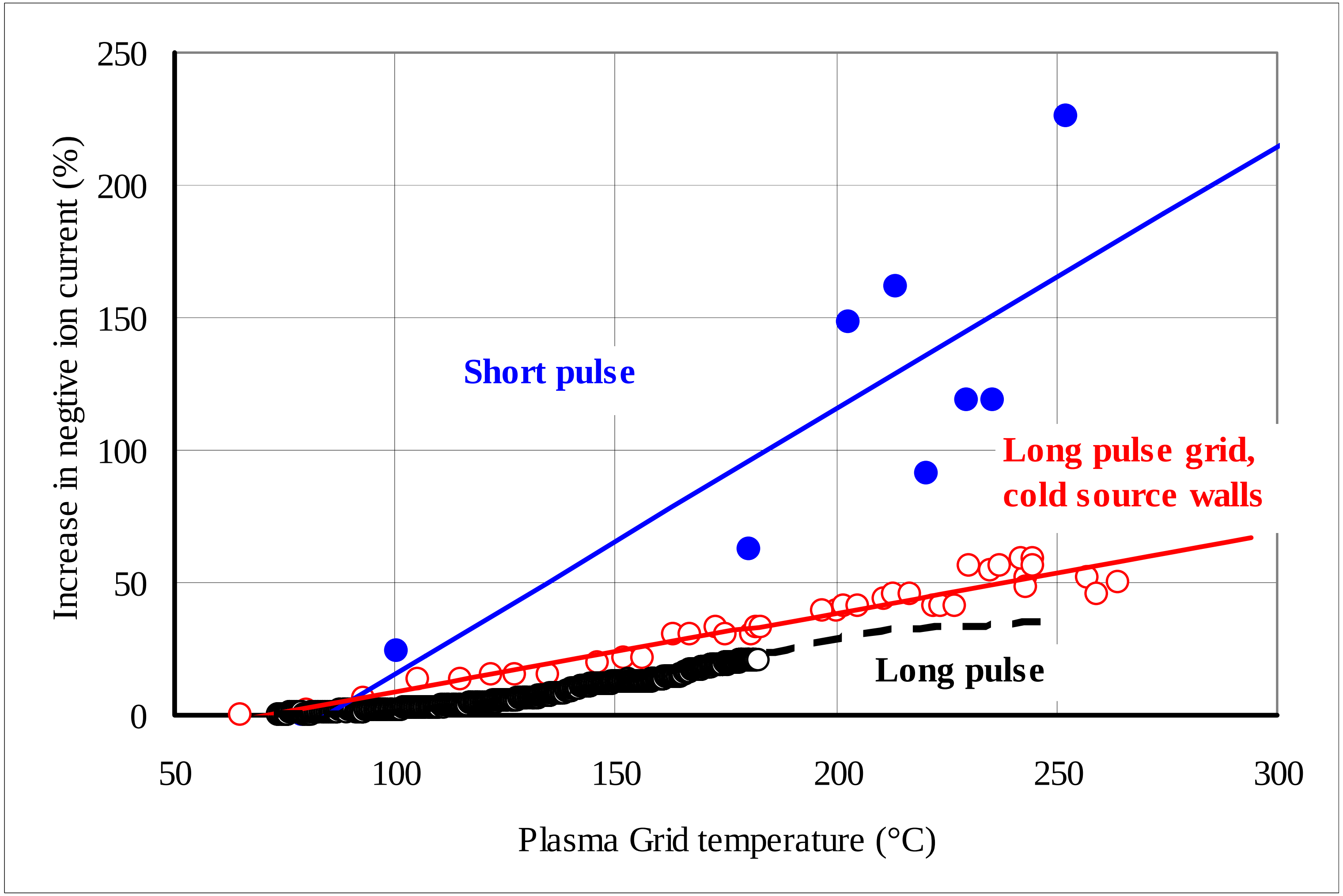
☹ **Low transmission of accelerated current to the calorimeter ≈55%**



Wednesday 11 May 2005
9:25-9:50 D. Boilson: Power transmission from the ITER model negative ion source

☹ **No significant change in IH^- as the PG temperature increased**

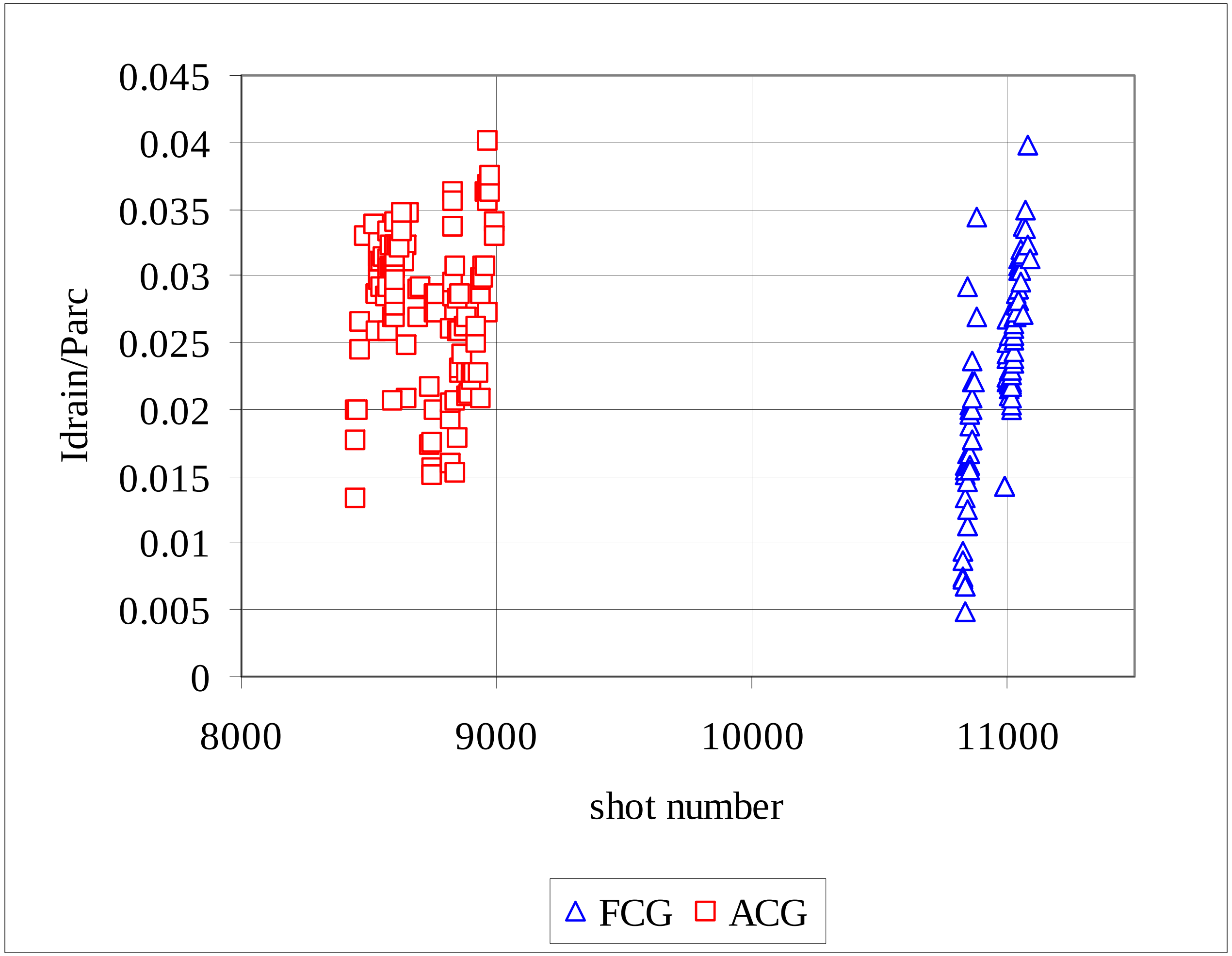




Effect of plasma grid temperature on the accelerated negative ion current with the KAMABOKO III ion source.

Parc ≈ 40 kW, Psrc ≈ 0.3 Pa, Bias ≈ 5 V, with Cs

No obvious effect of grid material



☹ Cs “consumption”

Long pulse operation: $4.6*10^{-6}$ g/s/aperture.

Estimate for the ITER ion source $2.8*10^{-9}$ g/s/aperture)
(Short pulse or low power operation)

The ratio is >1600

Source cleaned with water and the “polluted” water was chemically analysed.

The polluted water contained ≈4.5 g ±20% of Cs & a similar amount of tungsten.

Tuesday 10 May 2005:
9:50-10:15 A. Krylov: Caesium and Tungsten behaviour in filamented arc driven KAMABOKO-III beam source

Suggestions:

1 **Cs consumption: The Cs effect disappears not because the Cs has left the ion source, but because the Cs is somehow "blocked" on the walls and the PG surface in loosely bound tungsten – caesium mixture, the tungsten being evaporated from the filaments during the arc operation.**

2 **Reduced/no PG temperature effect: The composition of the surface of the PG will change dynamically during a long pulse due to the tungsten evaporation from the filaments. This could mask any effect of the PG temperature on the negative ion yield.**

Other long pulse effects:

Dark current

This appear when HV is applied on the Cadarache 1 test bed.

HV only - no gas
- no filaments operating,
- no discharge in the source

Reduced by conditioning, i.e. apply HV in series of shots
wait for dark current to reduce
increase HV & repeat

50 – 100 mA at V >250 kV

Seemingly spread generally over the "anode" and cathode" surfaces (measured in all places that have been checked)

But: We increased the (conditioning) pulse length ability and….

We melted a hole in an electrostatic screen!!!


P5215413.jpg
© CEA/DSM/DRFC/Patrice Fiet


P5215417.jpg
© CEA/DSM/DRFC/Patrice Flet

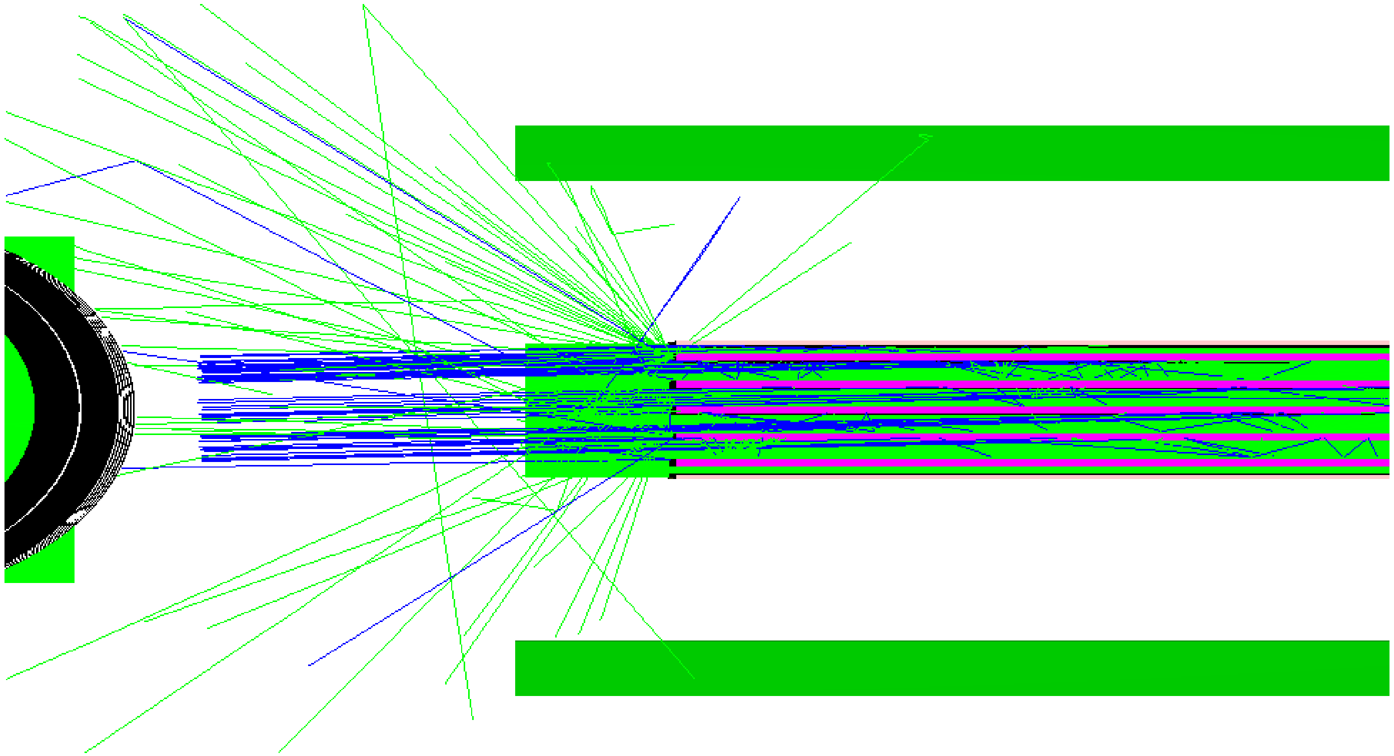
Other long pulse effects:

Future????

With the ITER system we foresaw a possible problem with power deposited on the cryopumps by X-rays created by accelerated electrons (stripping).

The UKAEA have started to investigate this using the MCNP package.

Because they (M Kovari) had to input data on electron back scattering, a potential new problem appeared – 40 kW of electron power to the 80 K cryopump screens.



This time we have been lucky, the problem has been identified and can be solved.

The future will be interesting.

Conclusion

Long pulse operation of the MANTIS test bed has thrown up several important potential problems with the ITER negative ion source.

The longer conditioning pulses on the Cadarache 1 MV test bed have reminded us that small powers can be very important over long periods.

Studies in the EU on the ITER NBI test bed have reminded us that other potential problems are to be expected