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Electron cooling project: Treatment of a SS vacuum surface by a low energy electron beam

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List of participants:

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Goal

The pressure in the cooling section should be **$1{\cdot}10^{-10}$ Torr** or below with a 0.5 A DC electron beam travelling through.

A current loss **δI** can be up to 10 μA. A gas load because of an electron-stimulated desorption $\mathbf{Q}_{\mathbf{esd}}$ is

$\mathbf{Q}_{\mathbf{esd}}$ [l·Torr/s] = 0.17·$\boldsymbol{\sigma}_{\mathbf{esd}}$[mol/e-] ·**δI**[A],

where σ_{esd} [molecules/electron] is a coefficient of electron-stimulated desorption.
For **δI**= 10 μA, $\boldsymbol{\sigma}_{\mathbf{esd}}$ = 0.1, $\mathbf{Q}_{\mathbf{esd}}$ = $1.7{\cdot}10^{-7}$ [l·Torr/s].

A thermal outgassing $\mathbf{Q}_{\mathbf{t}}$ seems to be lower,

$\mathbf{Q}_{\mathbf{t}}$ [l·Torr/s] = **S**[cm^2] ·**q**[l·Torr/s/cm^2] = $6{\cdot}10^{-9}$

where **S** = $2{\cdot}10^4$ cm^2 and a thermal outgassing rate **q** = $3{\cdot}10^{-13}$ l·Torr/s/cm^2.

We would like to have both $\boldsymbol{\sigma}_{\mathbf{esd}}$ and **q** values as low as possible.

Background information

Standard procedure of vacuum surface treatment:

- electropolishing to decrease effective surface,
- chemical cleaning to remove macro layers of high-vapor materials,
- baking 400°C to remove hydrogen from a body,
- baking in situ to remove water.

After such a procedure, the outgassing rate is q = (2- 10)· 10^{-13} Torr·l/s·cm^2 , σ_{esd} drops from 1 - 10 for an unbaked surface down to 0.05- 0.2.

On the other hand, there are many devices where electrons irradiate a vacuum surface with a much lower σ_{esd} values:

- collectors in electron cooling devices;
- electron storage rings, where synchrotron radiation produces secondary electrons;
- electron tubes.

(What's about FNAL's machines ?)

Therefore, the ESD can be significantly decreased by a low energy electron beam irradiating.

In 1995, A.Sharapa proposed to make one of INP's test benches for electron gun and collector tests without any "clean" pumps (because of simplicity). The experiment was successful, the system worked with a 2A DC beam without any pumping at $P<1\cdot10^{-10}$ Torr**.**

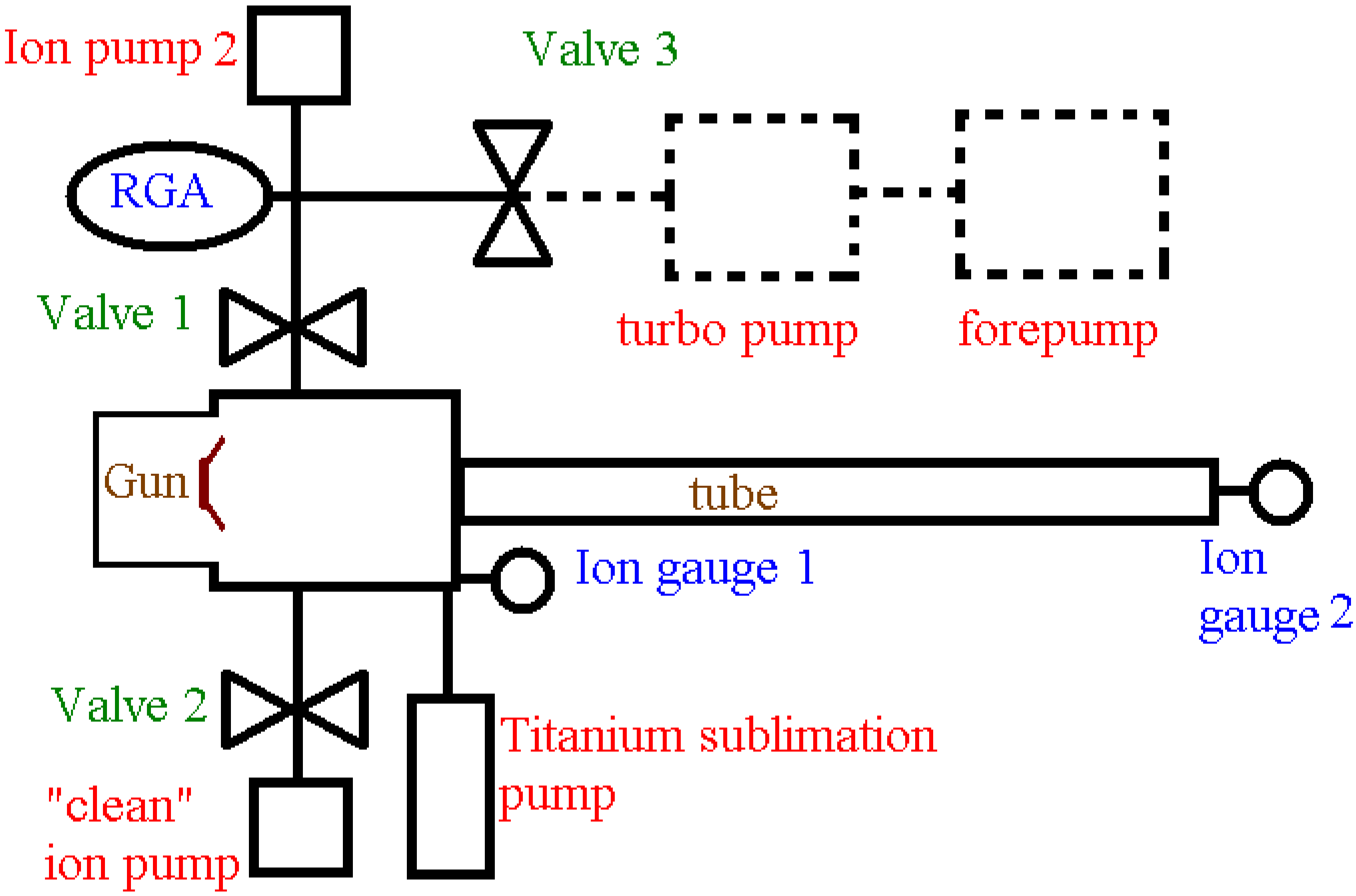
The results were discussed with G. Jackson in 1997, who proposed to check applicability of an electron beam treatment to the Fermilab’s Electron Cooling Project.

Last year a special stand was mounted in the WideBand.

Test bench parameters

Parameter	Max	Typical	units
Electron energy	5	1.5	kV
Beam current	0.5	0.14	A
Magnetic field	100	50	G
Inner diameter of solenoid		150 (~ 6”)	mm
Tube length		5	m
Tube OD		3”	
Pumping speed of a “clean” Ion Pump		50	l/s (N_2)
Pumping speed of the second IP		20	l/s (N_2)
Pumping speed of the TitaniumSP		800	l/s (N_2)

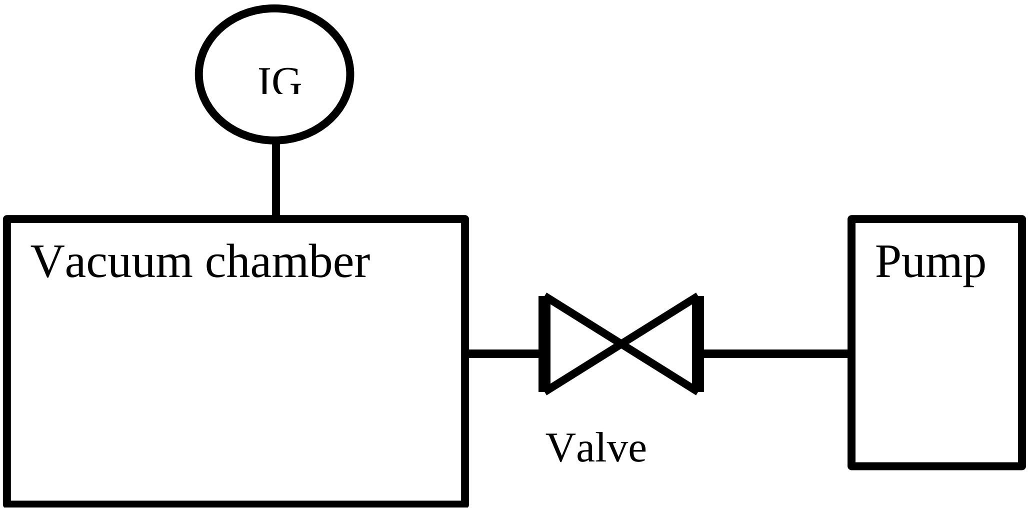
Tube type was electropolished SS 304.



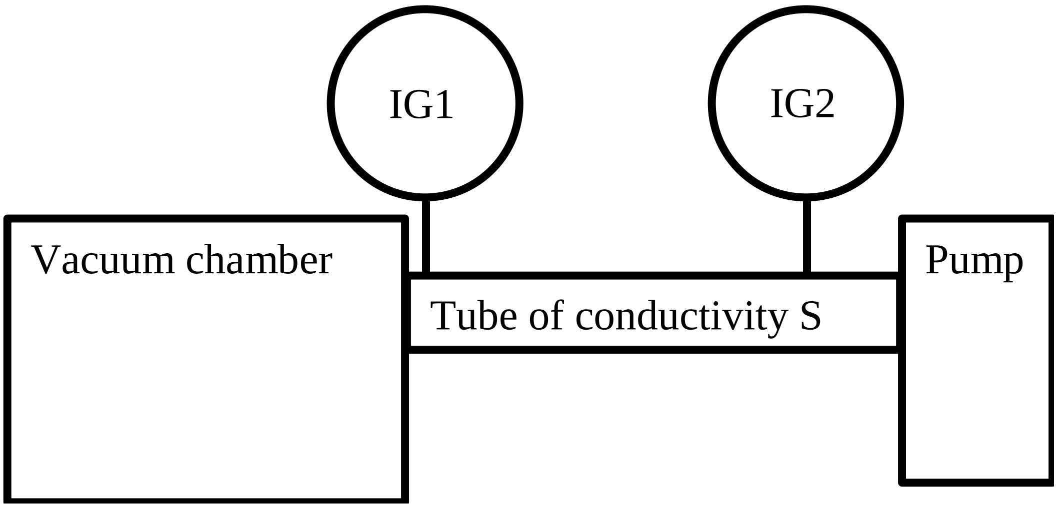
Vacuum schematic of the test bench

Two ways to measure an outgassing rate

1. **$Q = dP/dt \cdot V$** after stop of pumping (switching off a pump or closing a valve).
2. If the system is pumped by an ion pump only, the **Q** value can be estimated by the IP PS current **P_{IP}**.(if **P_{IP}** >> 1 μA).



3) **$Q = (P1-P2) \cdot S$** (in our case, a vacuum chamber is the tube).



Difficulties in these measurements

1. Homogeneity of a vacuum surface clearness. In the experiment σ_{esd} values differ approximately by 2 –3 times along the tube.

2. A gas load from ion gauges and RGA (> $1 \cdot 10^{-10}$ l·Torr/s).

3 tubes were tested.

All of them were electropolished, cleaned by a detergent (5 Star P.B.W.), washed by filtered tap water and rinsed by distilled water. A swab with alcohol was pulled through pipes to check an absence of dust just before mounting.

The tube #1 was preliminary baked for 24 hours at 350 °C. It was used for an initial system commissioning.

The tube #2 was not baked at all.

The tube #3 was preliminary baked 90 hours at 400 °C and then baked on site 90 hours at 150 °C.

Procedure of measurements:

After initial pumping during several days (and baking in the case of tube #3), the outgassing rate was measured by a pressure difference. (The outgassing rate measured by dP/dt after switching off pumping was always significanly lower.)

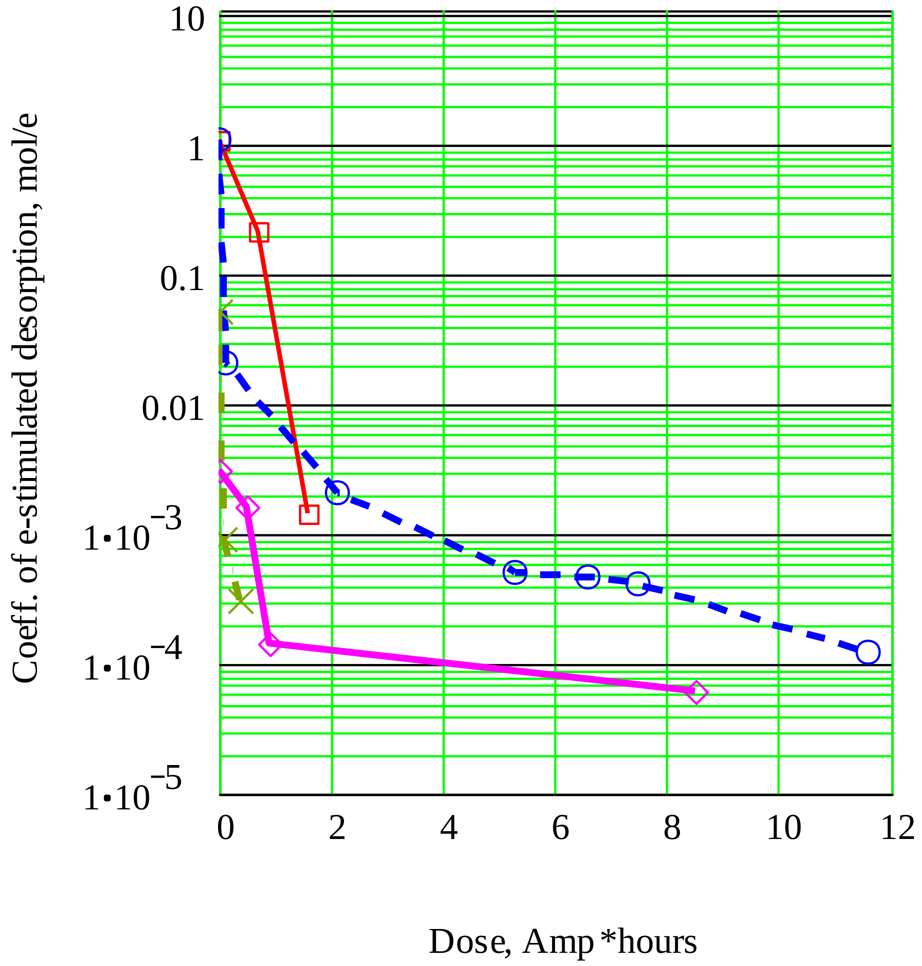
Then the treatment by an electron beam was performed. The coefficient of electron-stimulated desorption σ_{esd} was measured by the pressure difference or/and by a change of an ion pump. The system was pumped by a “dirty” ion pump during the process. The temperature in 11 points of measurement was kept under 80 °C.

Usually, the titanium sublimation pump (TSP) was activated after the treatment. The “dirty” ion pump was cut from the tube by a valve and a valve to a “clean” ion pump was opened. Then the outgassing rate was measured once more.

IGs and RGA were multiply degassed to make their gas load lower than one of the tube.

Homogeneity of cleaning was one of serious problems. It was tested by separate irradiation by the beam of different parts of the tube. Typically, the σ_{esd} value variation was less than 3-4 times.

Coefficient of electron-stimulated desorption as a function of a beam-irradiated doze

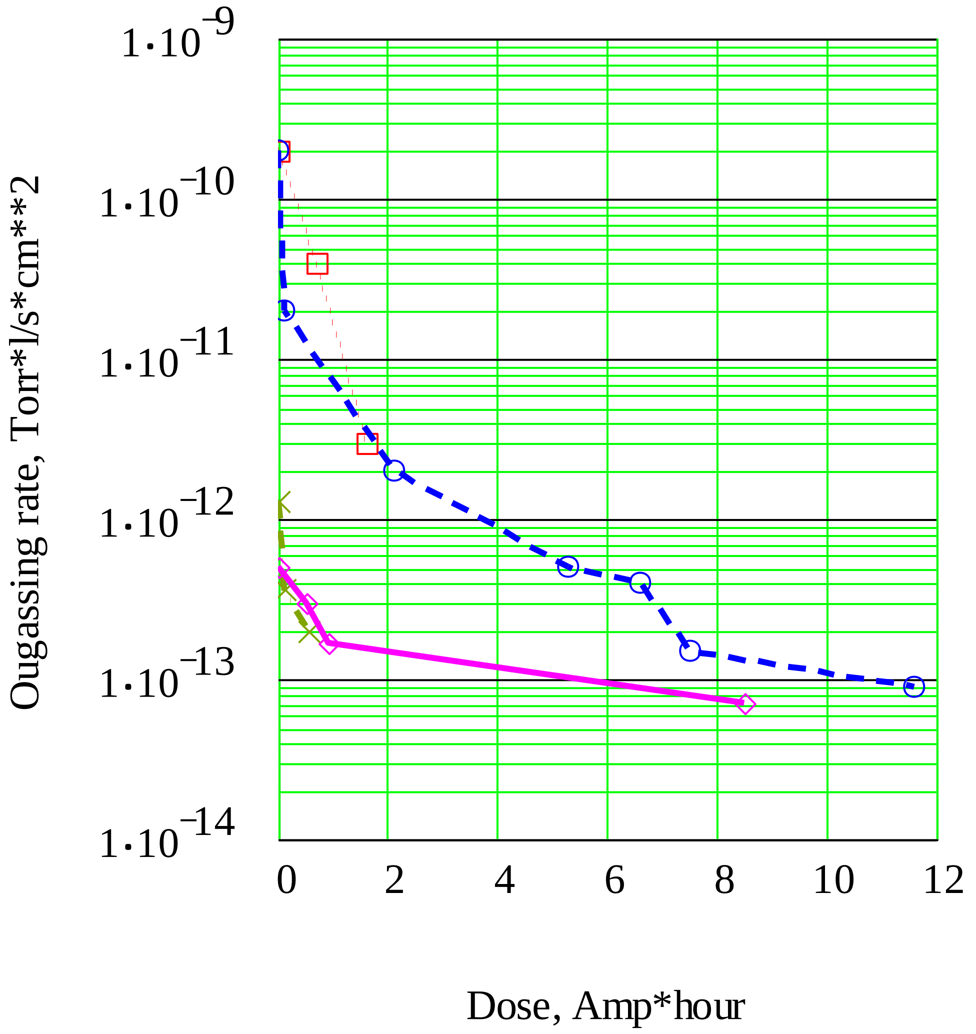


The curves show desorption behavior after exposing the tube to atmosphere. The doze counts from zero after every exposing.

Squares (□), circles (o) and crosses (x) represent results for 3 successive exposing of the tube #2, correspondingly.

The curve with diamonds (◊) is desorption of the tube #1 after irradiation by about 15 Amp·hours and exposing to atmosphere.

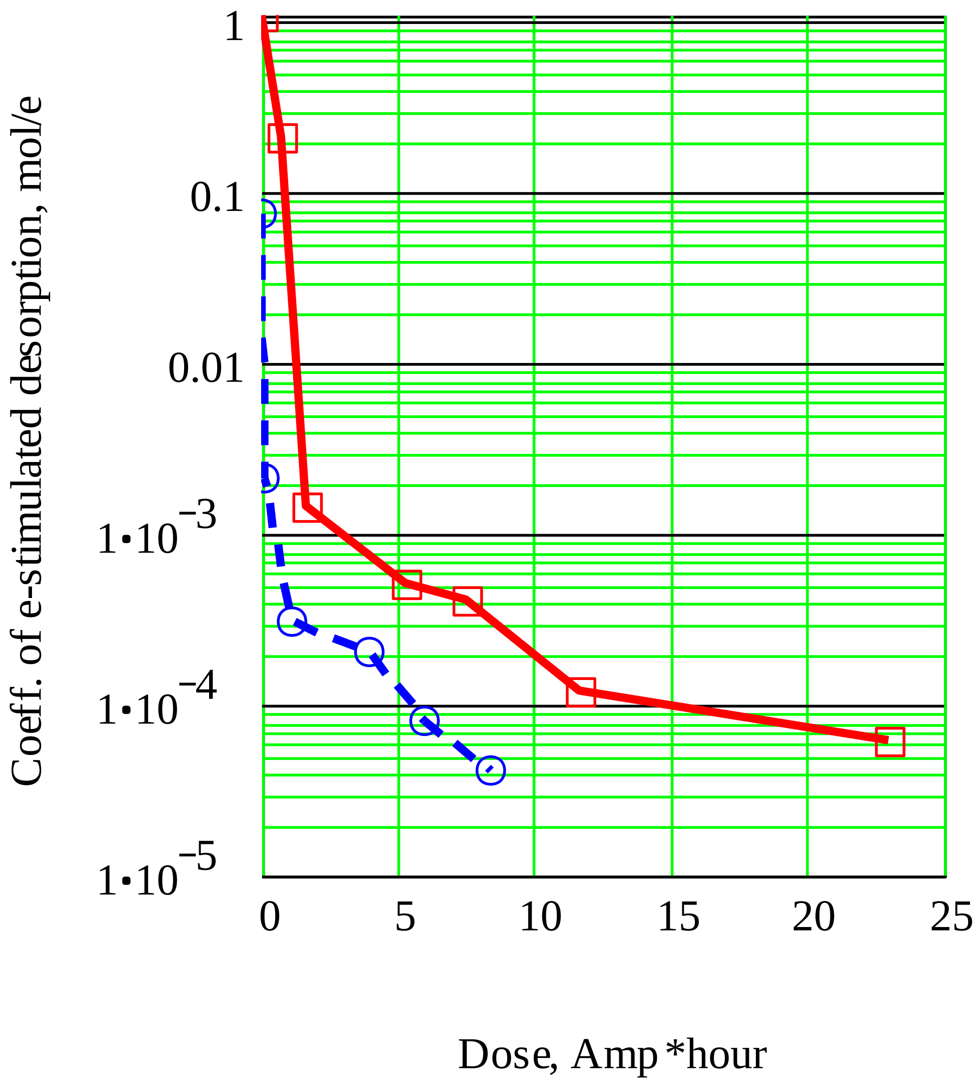
Tube outgassing rate as a function of a beam-irradiated doze



Squares (□), circles (o) and crosses (x) represent results for 3 successive exposing of the tube #2, correspondingly.

The curve with diamonds (◊) is outgassing rate of the tube #1 after irradiation by about 15 Amp·hours and exposing to atmosphere.

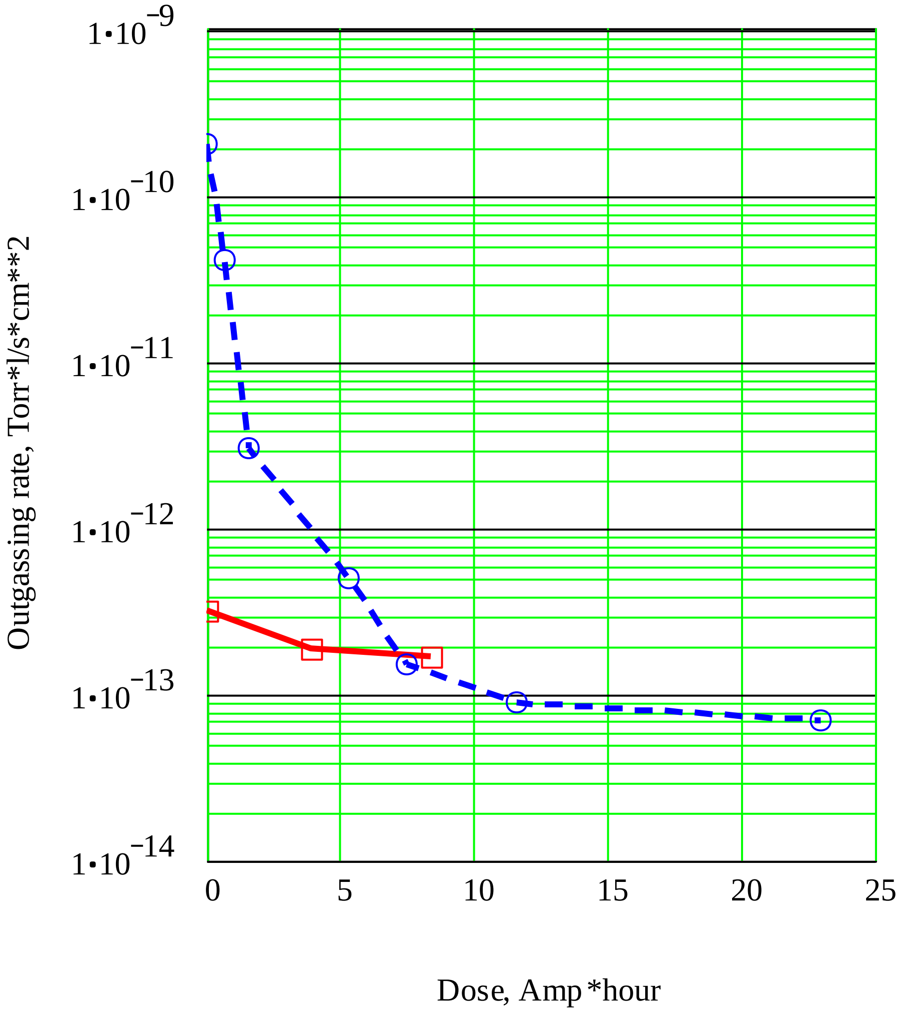
Coefficient of electron-stimulated desorption as a function of a beam-irradiated doze (composite results)



Squares (□) show a composite results of the treatment for tubes #1 and #2, and circles (o) present results for tube #3 (with baking).

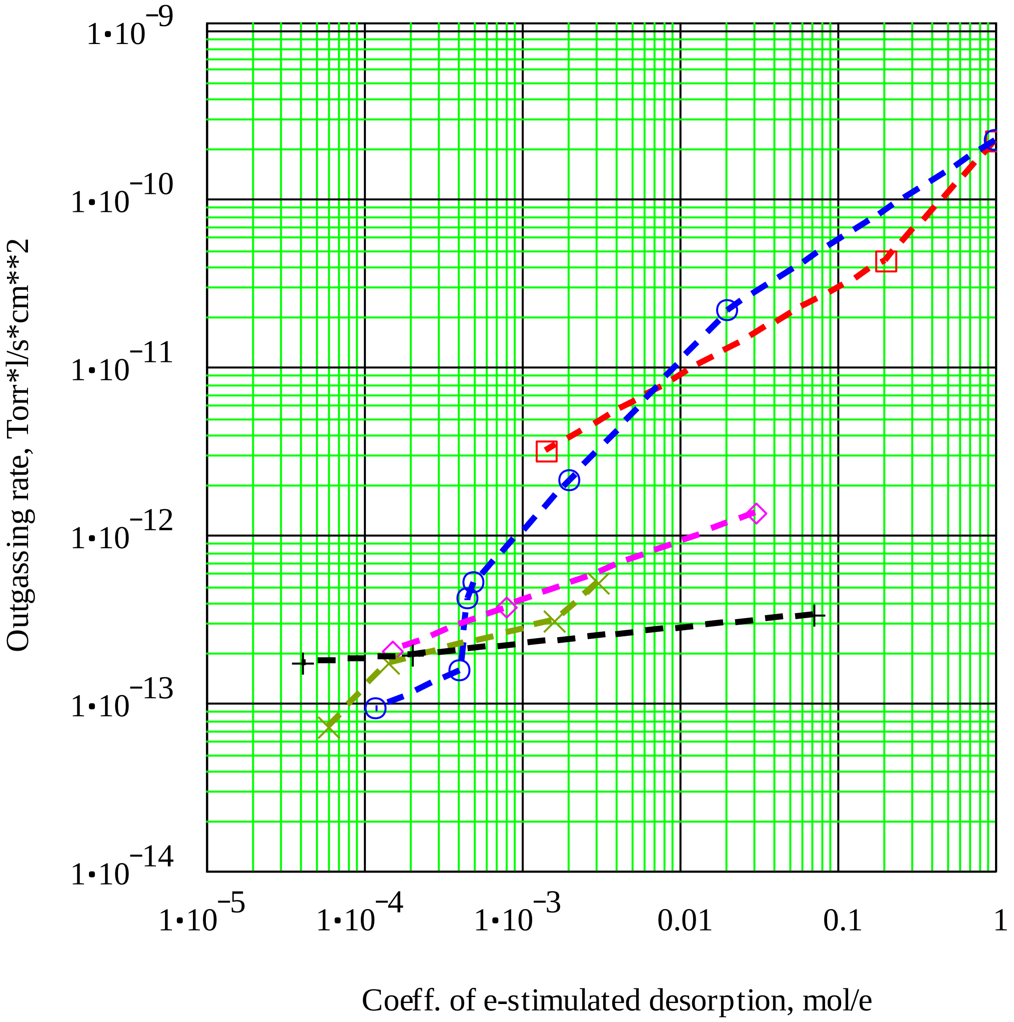
Number of removed molecules is about 10^{18} mol/cm^2 for the unbaked tube and about 10^{15} mol/cm^2 for the baked one.

Tube outgassing rate as a function of a beam-irradiated doze (composite results)



Squares (□) show a composite results of the treatment for tubes #1 and #2, and circle(o) present results for tube #3 (with baking).

Correlation between outgassing rate and electron stimulated desorption



Squares (□), circles (o) and crosses (x) represent results for 3 successive exposing of the tube #2, correspondingly.The curve with diamonds (◊) is desorption of the tube #1 after irradiation by about 15 Amp·hours and exposing to atmosphere. +’s show points for the baked tube #3.

Conclusion

1. Outgassing rate of unbaked SS tube is decreased down to value typical for a baked tube (about $3 \cdot 10^{-13}$ Torr·l/s·cm^2) after irradiation by a low energy electron beam with a reasonable dose (1 mA·hour/ cm^2). This process removes about gas equal to about 1000 monolayers of molecules.

2. Baking decreases dramatically outgassing rate and change coefficient of ESD by order of value.

3. Irradiation of a baked tube releases gas amount corresponds to about one monolayer.

4. Coefficient of ESD drops by more than 100 times after a dose of 0.1 mA·hour/ cm^2.

5. Outgasing rate decreases below $1 \cdot 10^{-13}$ Torr·l/s·cm^2 and coefficient of ESD below 10^{-4} at a dose > 2 mA·hour/ cm^2.

6. A beam with characteristics appropriate for such a treatment can be transported in a low magnetic field (< 100 G).

6. Measurements of outgassing rate by dP/dt after a stop of pumping give always lower values than ones made by a pressure difference.

7. The method can be used for decreasing of electron-stimulated desorption in the cooling section of a future Fermilab's electron cooling device.