IEC Workshop 2012

Effects of cathode temperature on neutron production rate in inertial electrostatic confinement fusion

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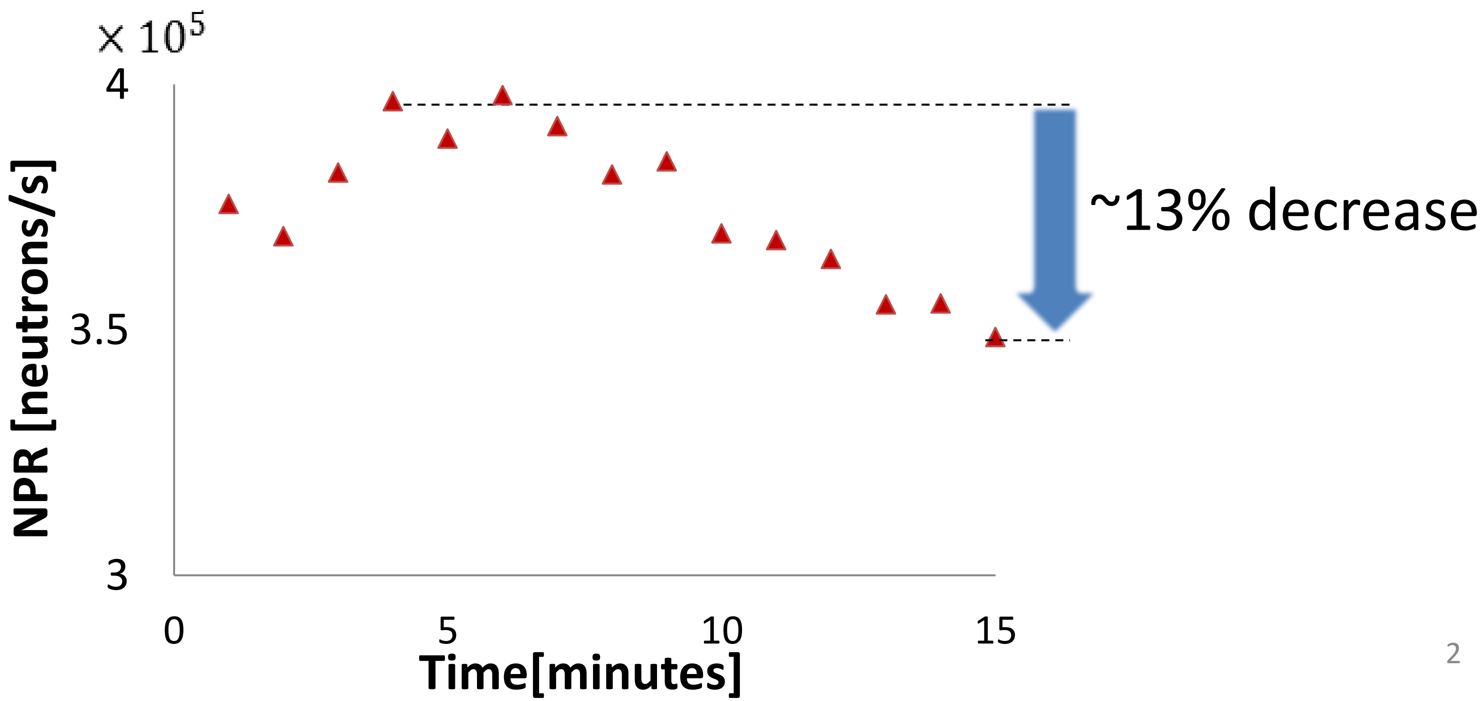
Motivation

NPR decreases as operating time increases

Problem for
- NPR measurement
- long period of time operation

NPR vs. Operating time@-20 kV 60 mA



Motivation 2

If we operate IECF device for a long period of time…

- Cathode temperature
- Pressure

rises

Hypothesis

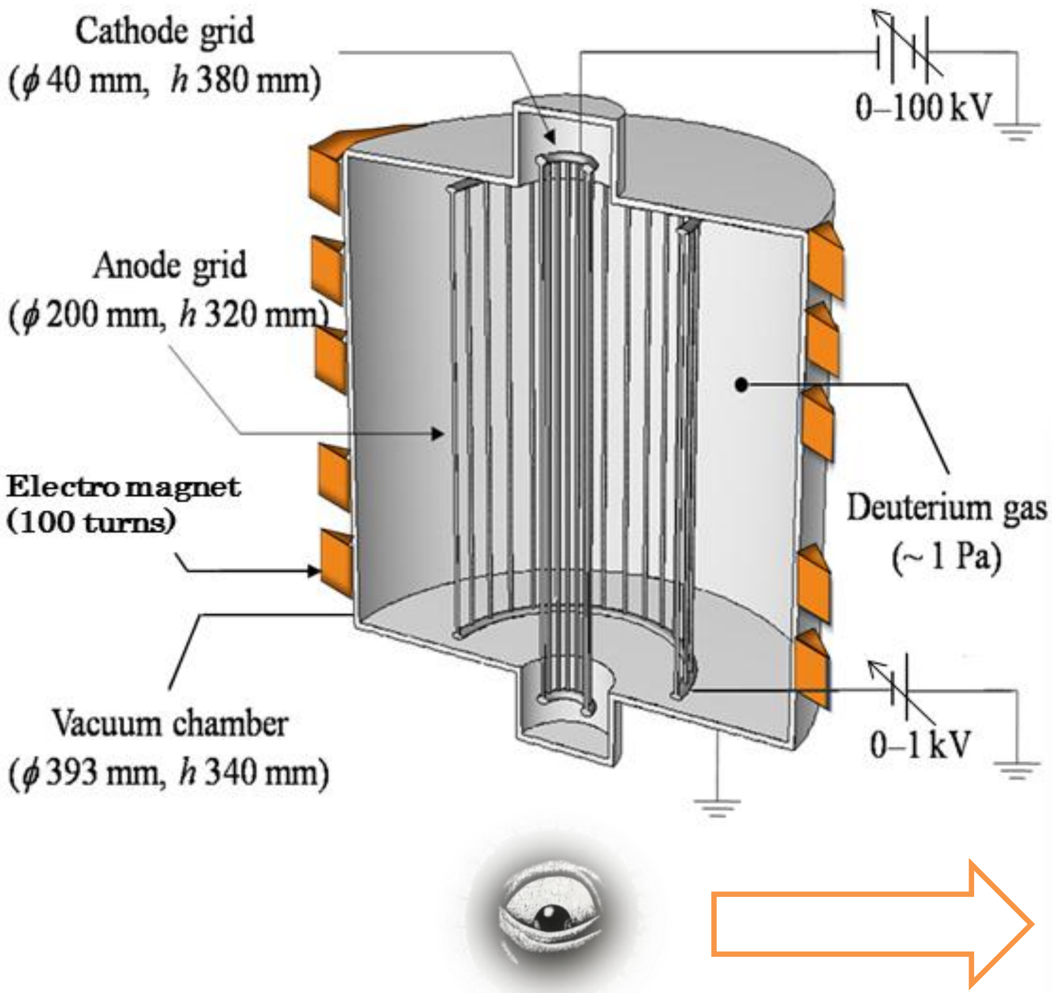
Cathode temperature affects embedded fusion

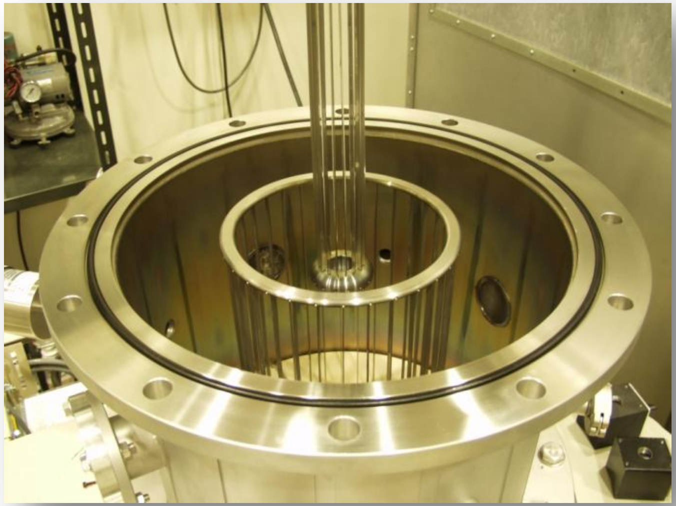
To prove the idea…

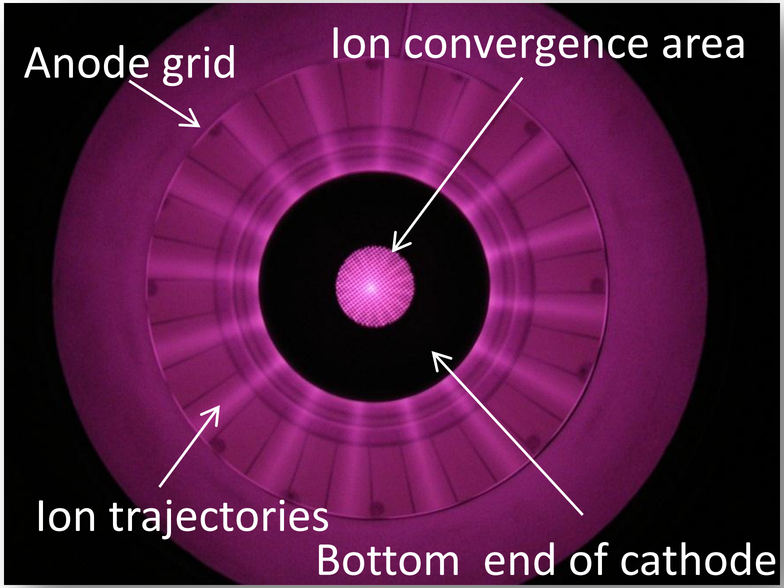
Cathode temperature was measured to calculate deuteron density on the surface of the cathode

Experimental setup

Cylindrical IECF device







Observing from a bottom side

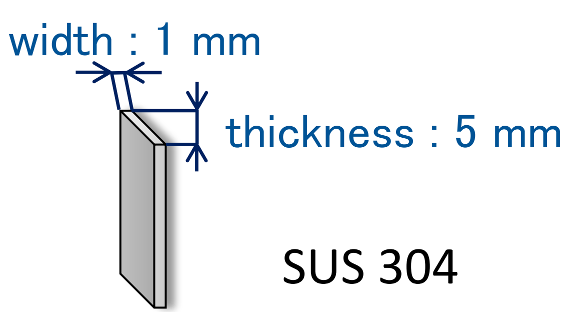
Experimental setup 2

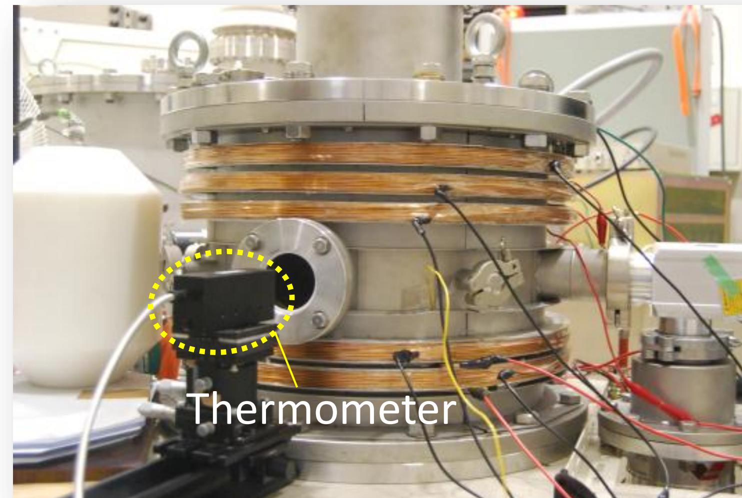
Radiation thermometer specs

Measurement range : 220~2000 ℃
Wavelength 1.95~2 μm
Resolution : 3 ℃
Measurement distance : 300 mm
Target diameter : 0.6 mm

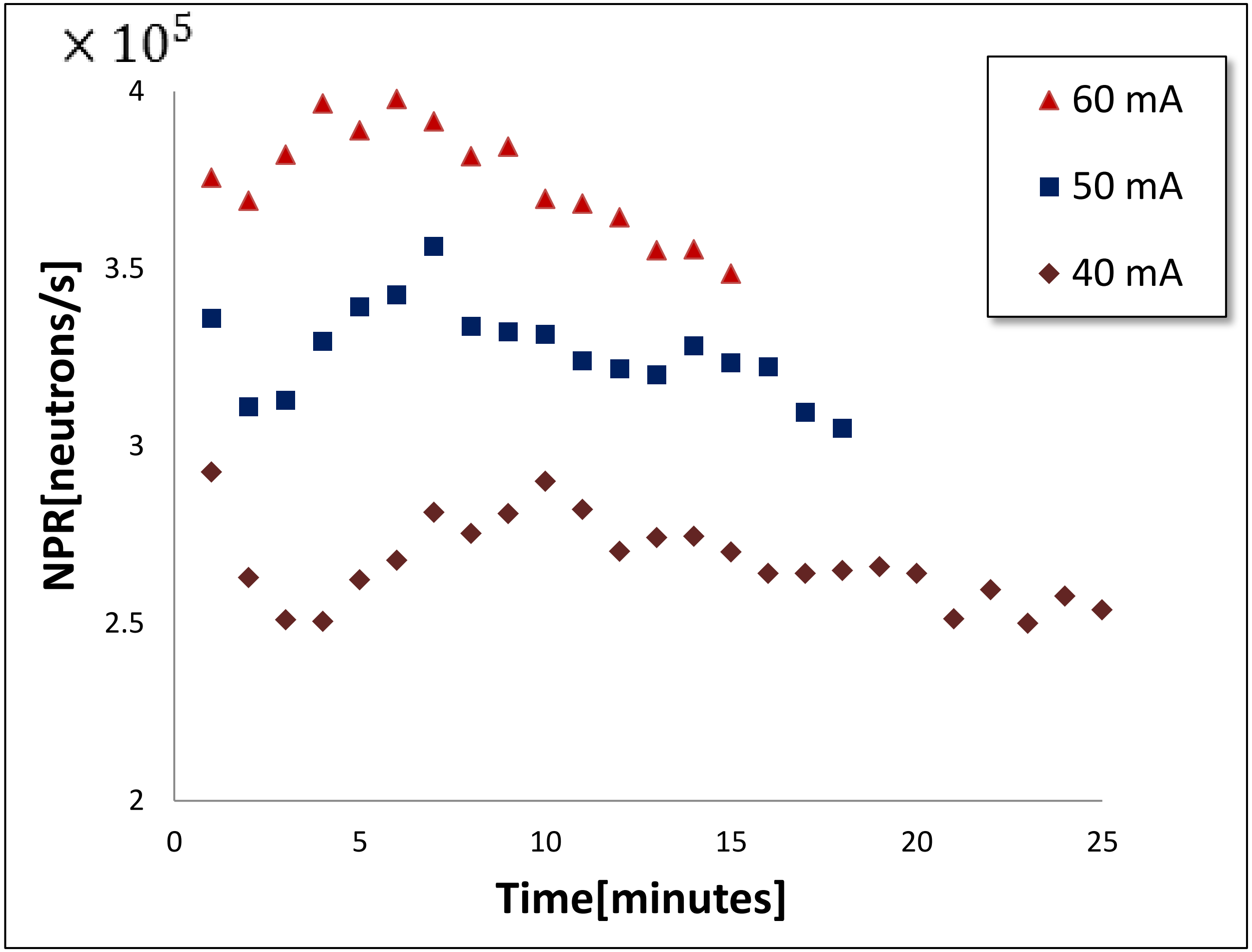
- ✓ Emissivity was assumed as 0.74
- ✓ Plasma emission can be ignored

Plate cathode





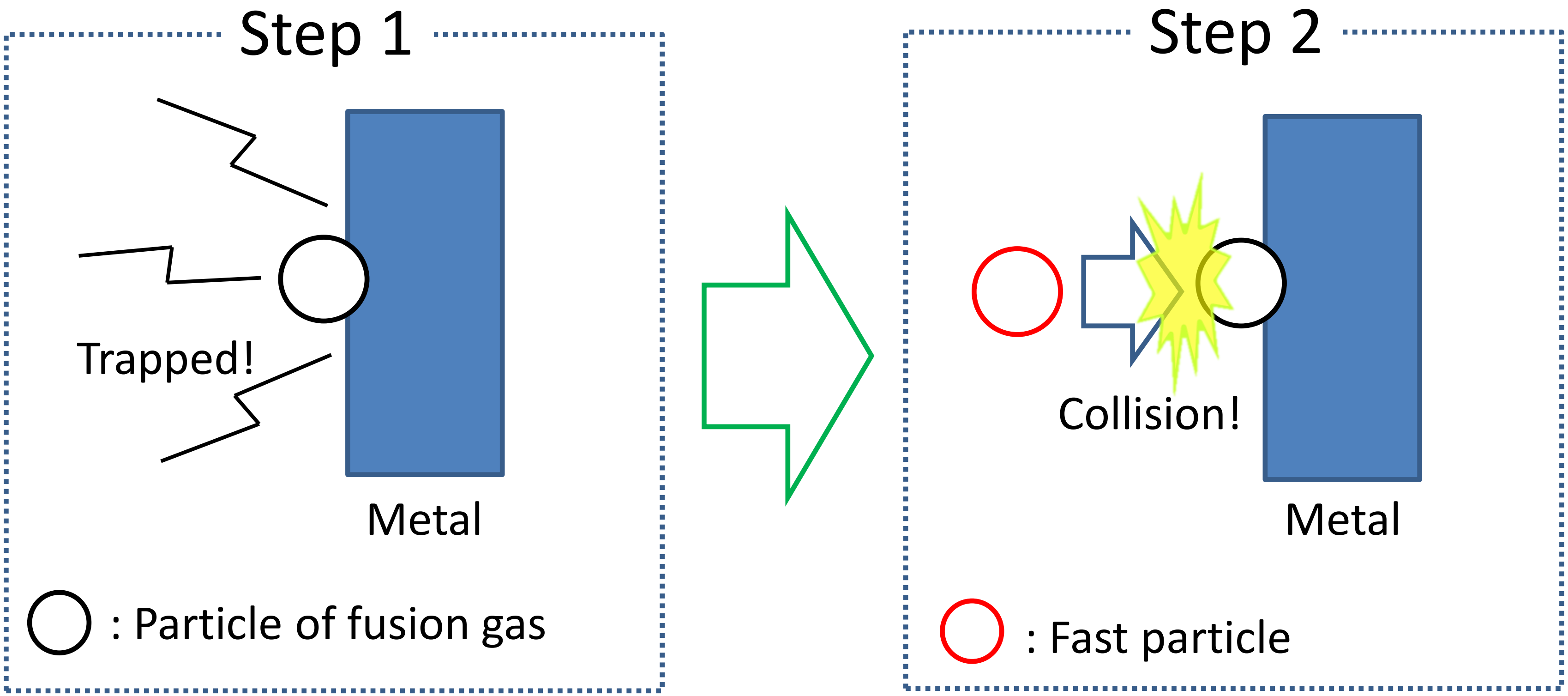
NPR @-20 kV



Higher input power makes the cathode hotter

Cathode temperature affects NPR

Embedded fusion



Relationship between NPR and deuteron density

Embedded fusion reaction rate R_{BM-C} can be described bellow

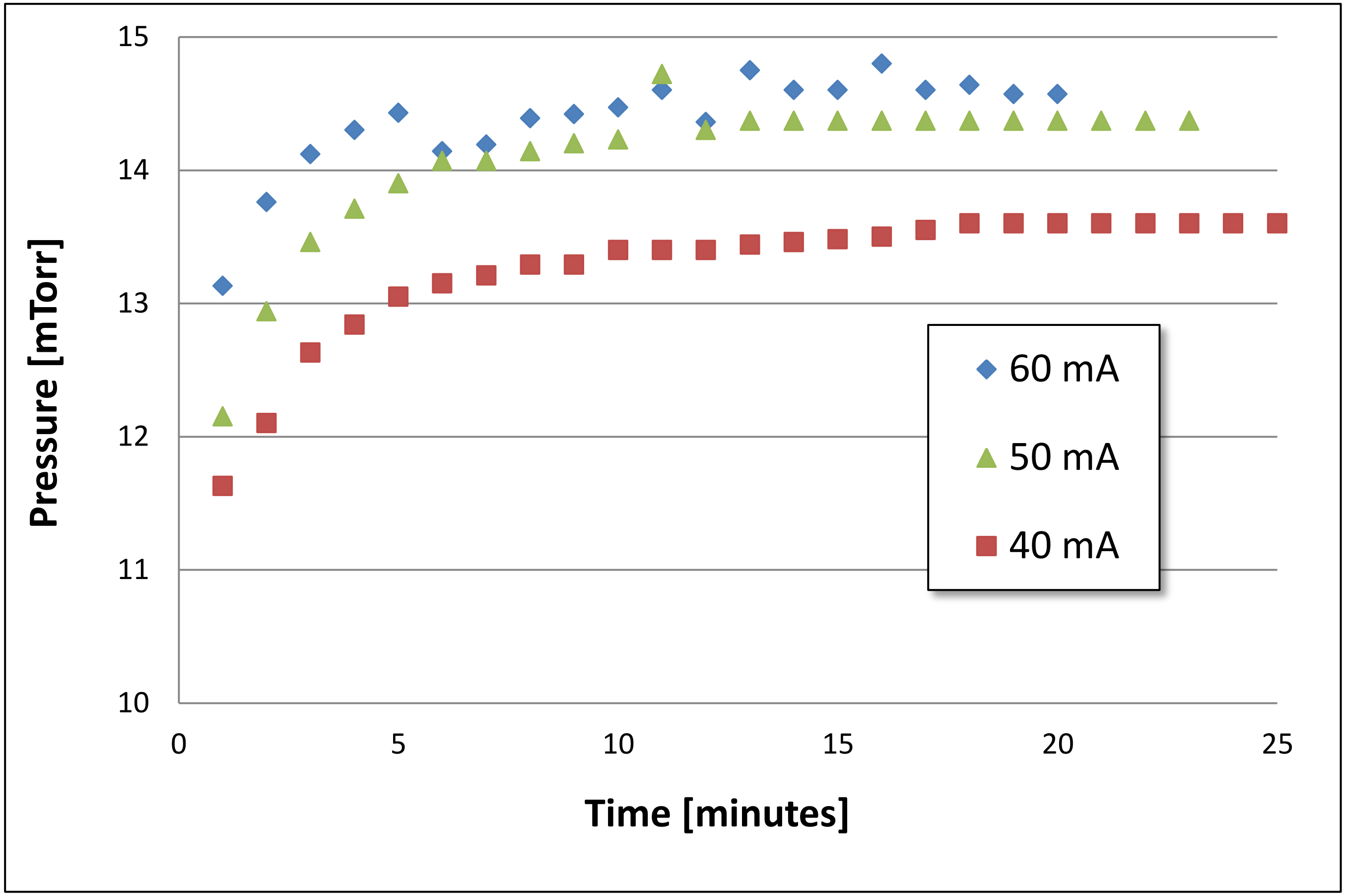
$$R_{BM-C} = \int_S \sigma n_{BM} \langle \Sigma v \rangle \, dS$$

σ : Deuteron density on the cathode
n_{BM} : Ion flux
Σ : Cross section
v : relative velocity

R_{BM-C} increase and decrease can be estimated from σ

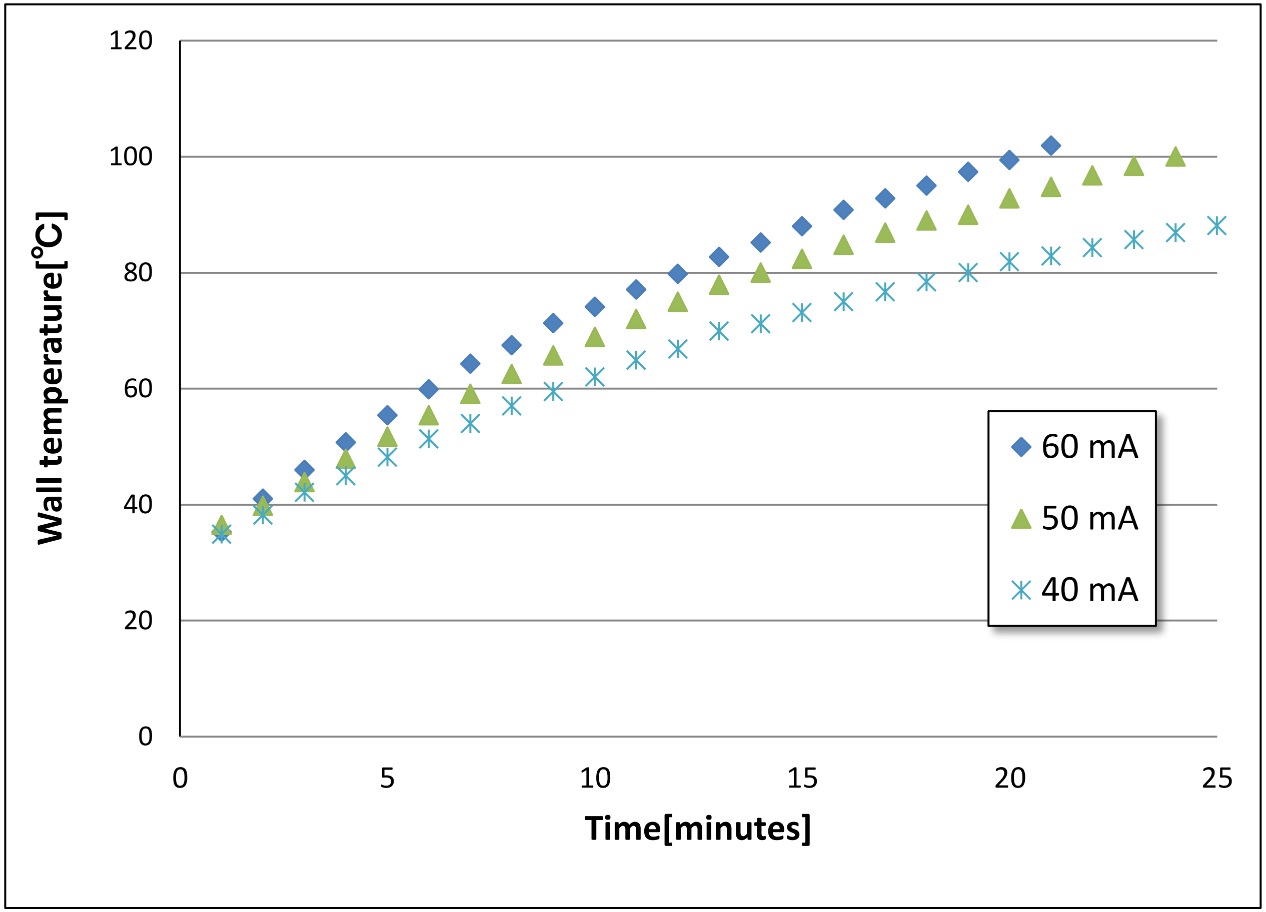
$$\frac{d\sigma}{dt} = Implant(I, T_{gas}, P) - Desorption(\sigma, T_{cathode})$$

Pressure @-20 kV



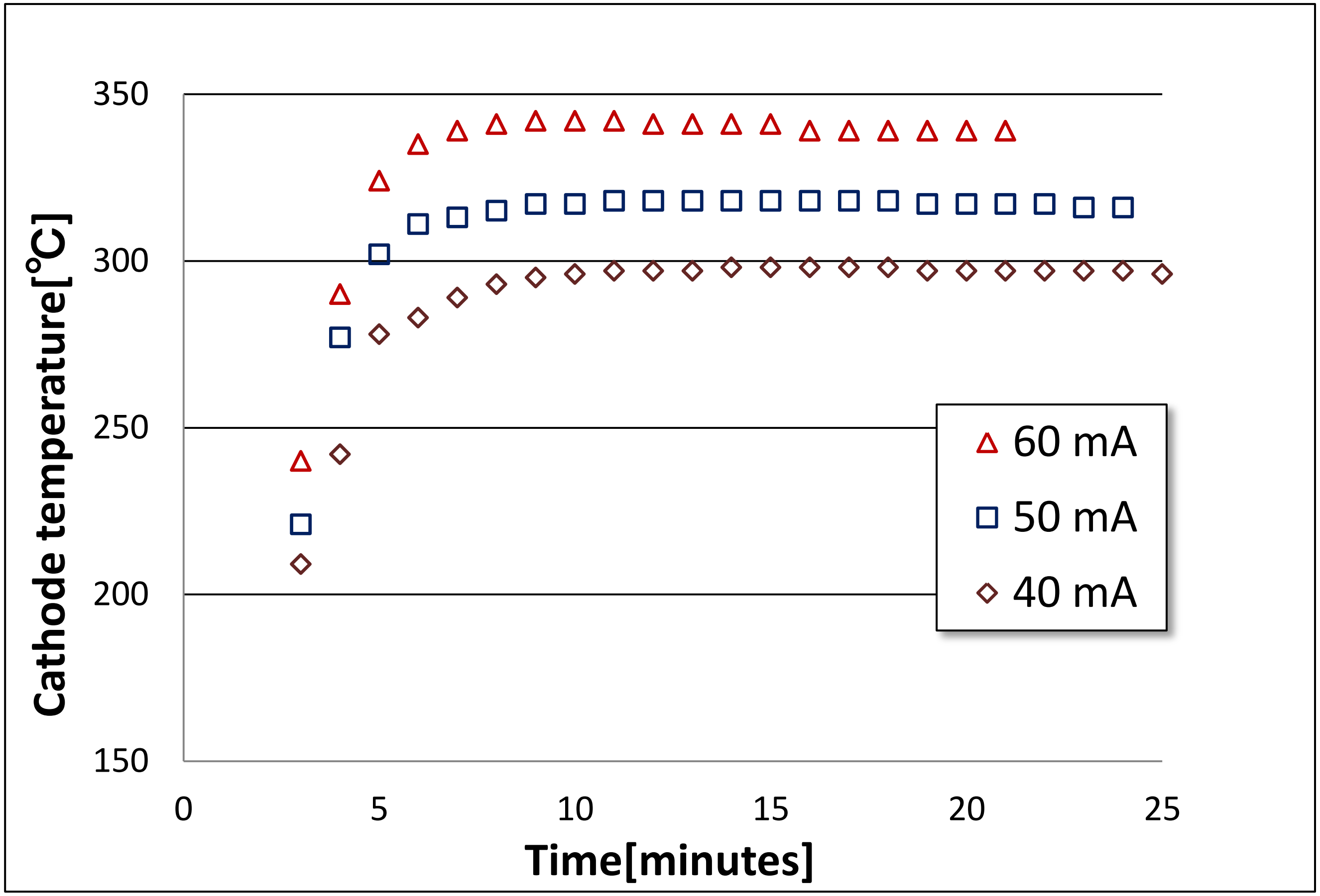
Pressure rises about 10% in every current condition

Gas temperature @-20 kV



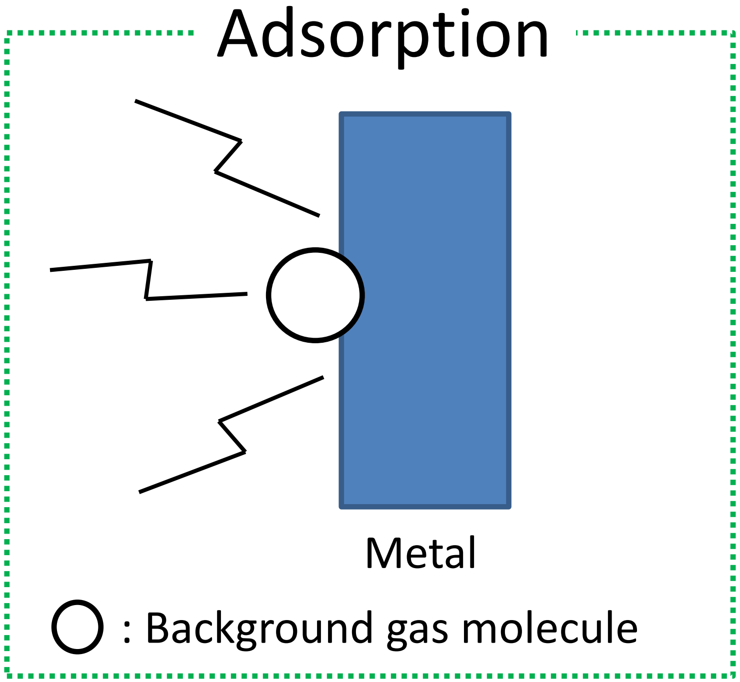
We assumed device wall temperature as gas temperature

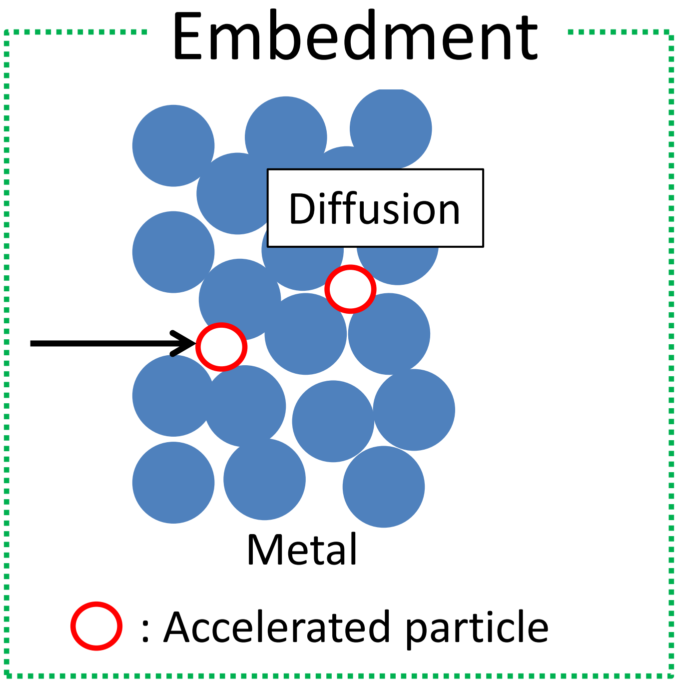
Cathode temperature @-20 kV



SUS(Cathode material)'s Melting point : about 1400 ℃

Deuterium trap on the cathode





- ➢ Physical adsorption
- • Van der waals attraction
- • Electro-static attraction
- ➢ Chemical adsorption
- • Ion binding

Adsorption

Adsorption speed can be described bellow

$$\begin{cases} \dfrac{d\sigma}{dt} = \dfrac{1}{4} n \bar{v} s \\ \bar{v} = \sqrt{\dfrac{8kT}{\pi m}} = \sqrt{\dfrac{8RT}{\pi M}} \end{cases}$$

σ : Deuterium density
n: Molecule density
$\bar{v}$: Average velocity of molecules
T : Gas temperature
s : Adsorption rate
k : Boltzmann constant
m : Mass of molecules
M : Molecular weight
R : Gas constant
p : pressure

$$\boxed{\frac{d\sigma}{dt} = 3.5 \times 10^{22} \frac{sp}{\sqrt{MT_{gas}}} \qquad p\ [\mathrm{Torr}],\ T_{gas}\ [\mathrm{K}]}$$

Embedment

Assuming Γ_{beam} as ion flux to the cathode,
embedment speed can be described bellow

$$\frac{d\sigma}{dt} = A\Gamma_{beam}$$

$$\Gamma_{beam} = \frac{I}{CS} \times \frac{1}{1+\gamma}$$

σ : Deuterium density
A : Ion embedment rate
I : Cathode current
C: Elementary charge
S : Area of the cathode
γ : second electron emission coefficient

We assumed $\mathrm{A} = 0.25$ and $\gamma = 1$

$$\boxed{\frac{d\sigma}{dt} = 7.8 \times 10^{14} \frac{I}{S}}$$

Adsorption$\approx 10^{19}$
Embedment $\approx 10^{15}$

This effect could be stronger in spherical device

Desorption

Desorption speed can be described bellow

$$-\frac{d\sigma}{dt} = -\sigma\nu \exp\left(-\frac{E_d}{RT_{Cathode}}\right)$$

σ : Deuterium density
ν : Desorption reaction constant
E_d : Activation energy of desorption
R : Gas constant
$T_{Cathode}$: Cathode temperature

Hydrogen – Tungsten desorption

$$\boxed{-\frac{d\sigma}{dt} = -\sigma \times 2.2 \times 10^{13} \exp\left(\frac{-67 \times 10^3}{RT_C}\right)}$$

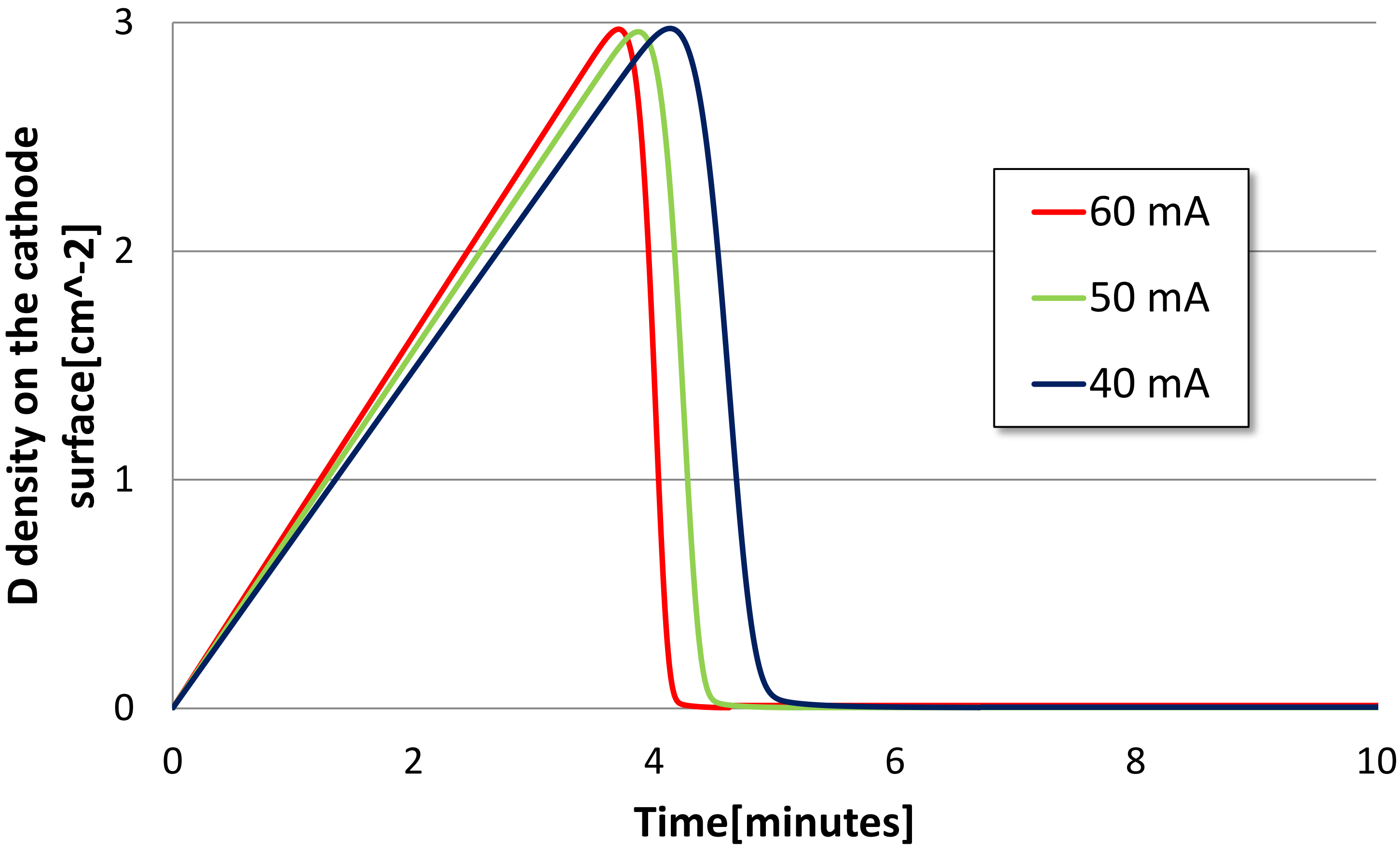
Summary of calculation

$$\frac{d\sigma}{dt} = 3.5 \times 10^{22} \frac{sp}{\sqrt{MT_{gas}}} + 7.8 \times 10^{14} \frac{I}{S} - \sigma \times 2.2 \times 10^{13} \exp\left(\frac{-67 \times 10^{3}}{RT_{C}}\right)$$

We assumed s=0.1 and σ(0)=0

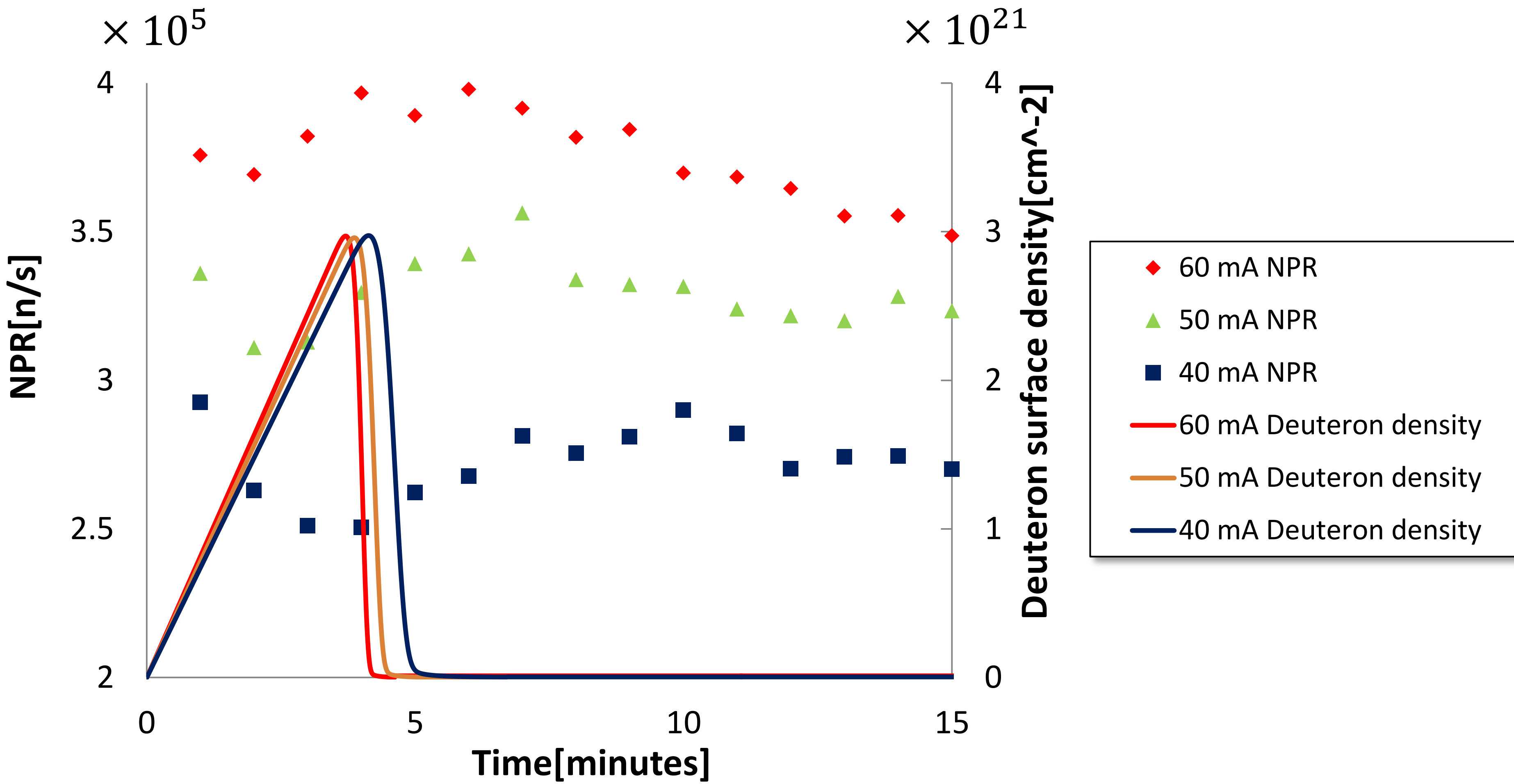
Value of s was said 0.1~1 in reference

Result



D density on the cathode surface[cm^-2]
3
2
1
0
0
2
4
6
8
10
Time[minutes]
60 mA
50 mA
40 mA

Deuteron density and NPR vs. time



How should we measure NPR?

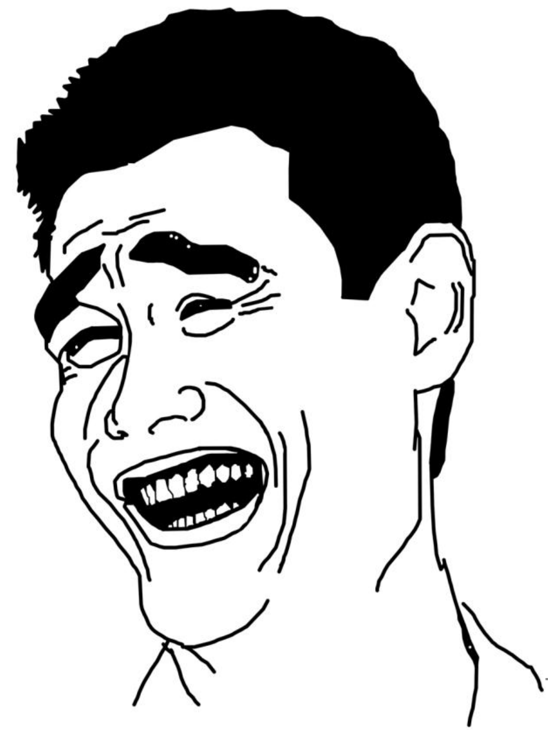
We should run a IECF device until NPR become stable
Measurement of NPR should be done after that

Summary

- ✓ Introduced how to calculate deuteron density on the cathode.
- ✓ NPR vs. time tendency can be explained by embedded fusion on some level.

Any questions or suggestions?

Speak slowly, use easy word plz ;)

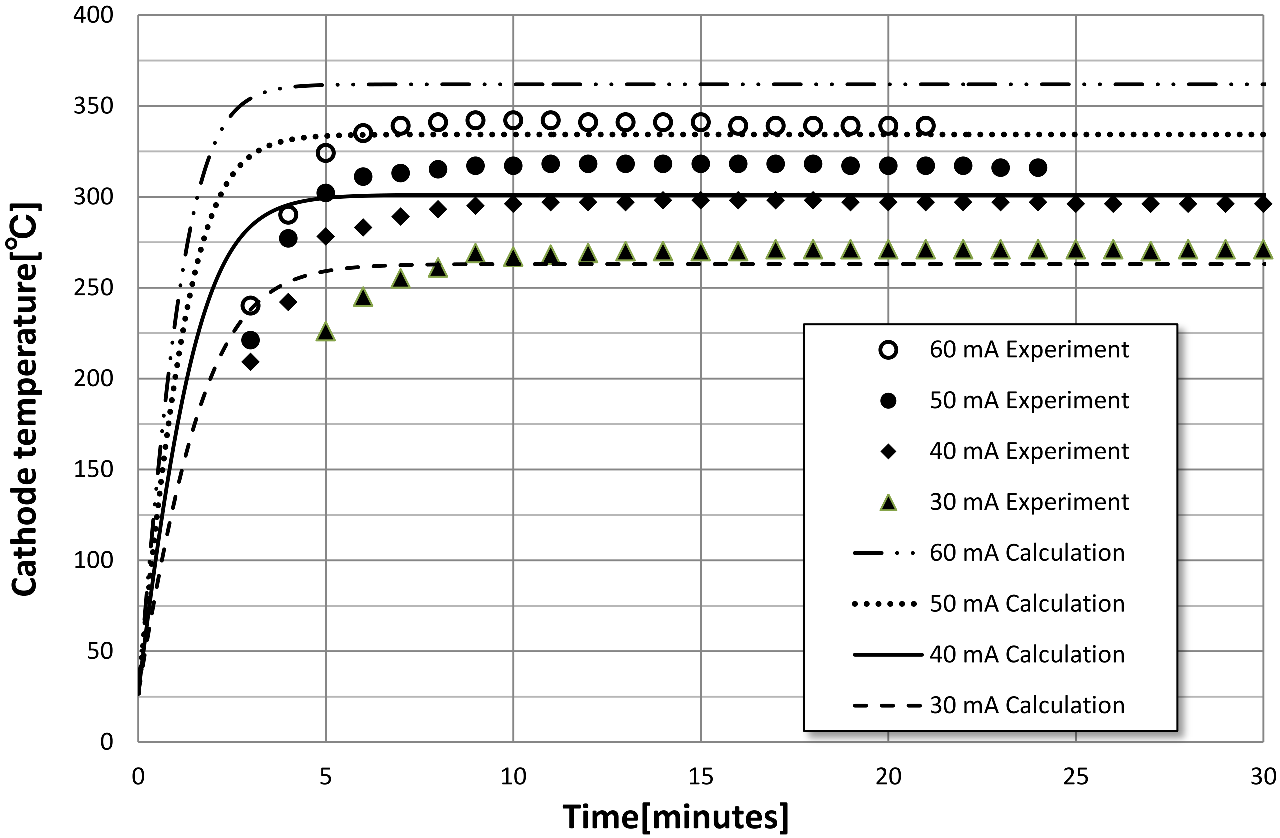


Reference

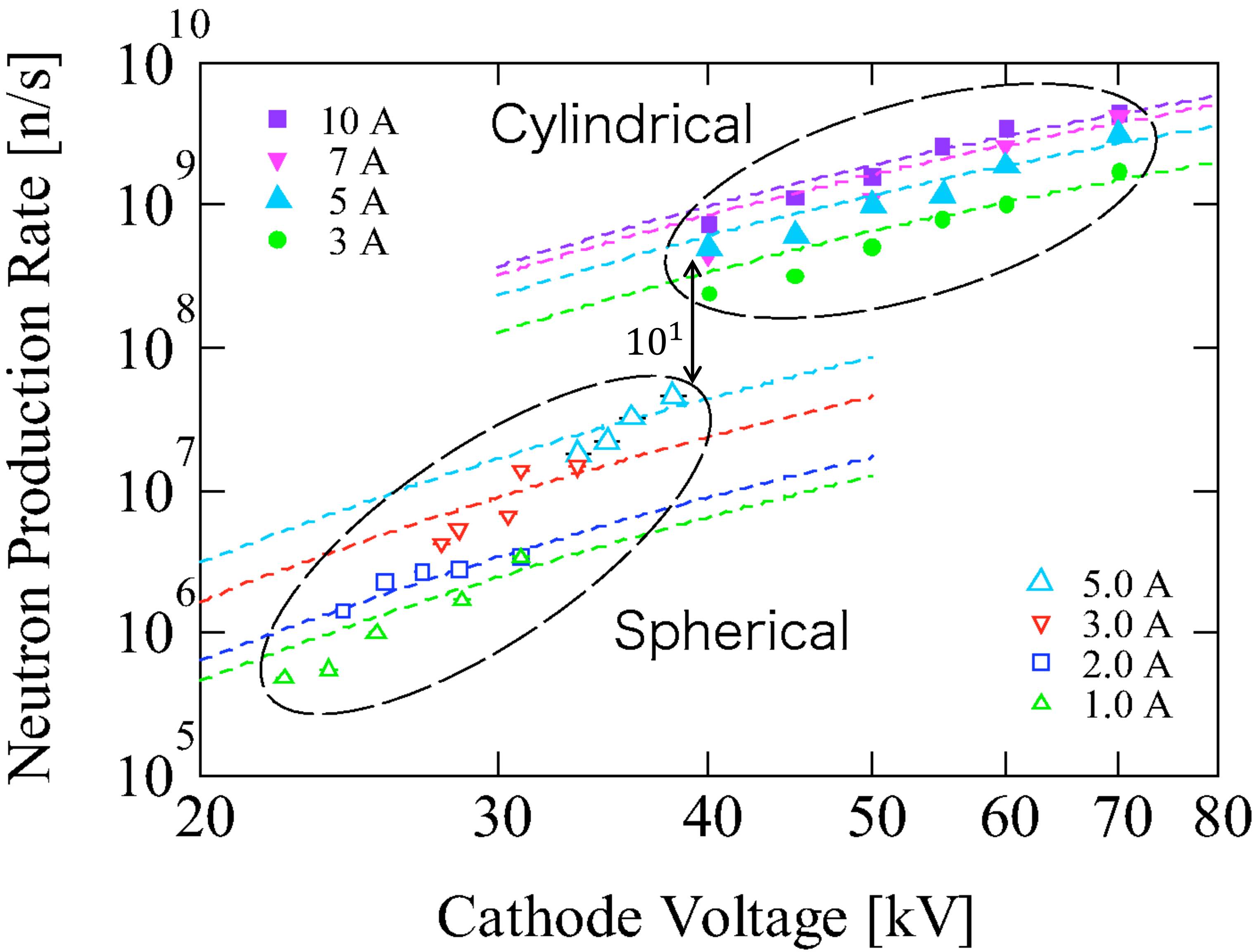
H.Kumagai, G.Tominaga :「真空の物理と応用(Vacuum physics and applications)」

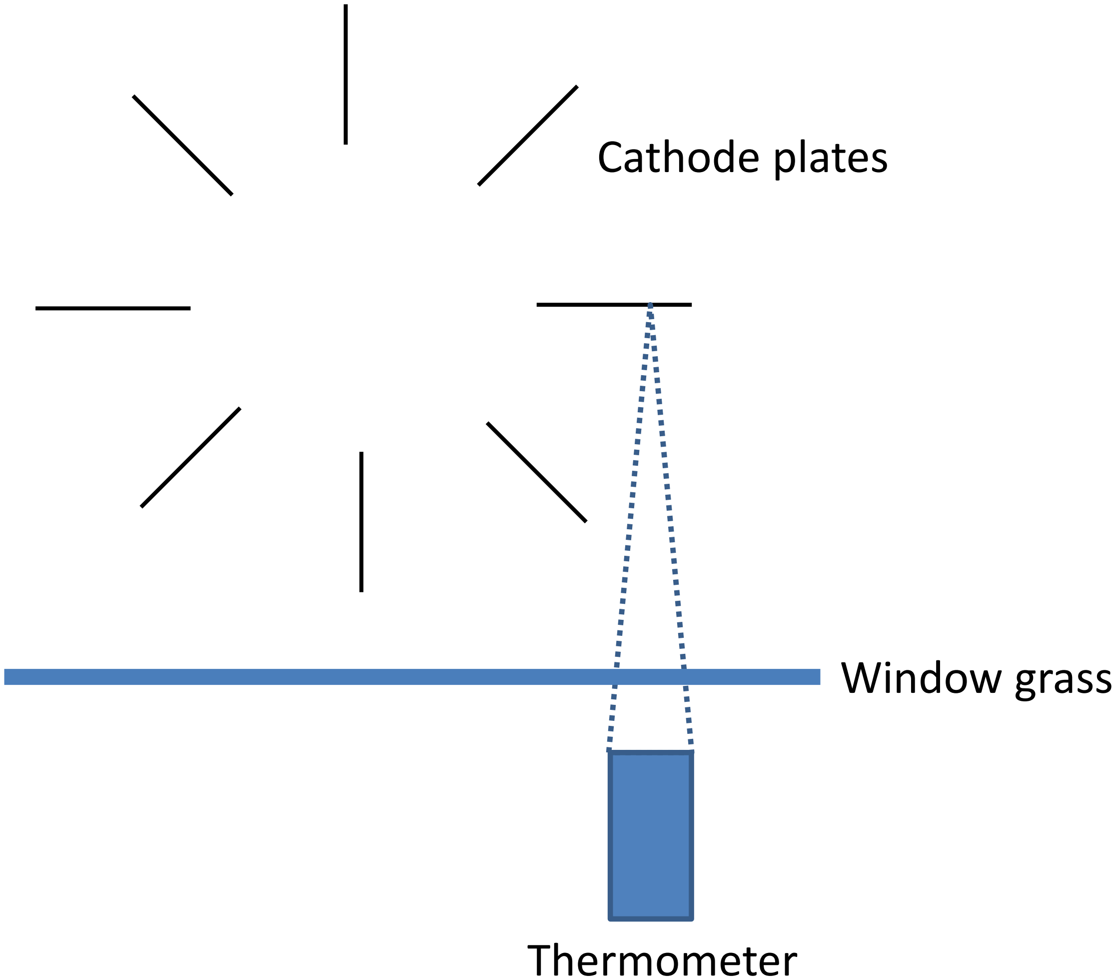
↓Appendix

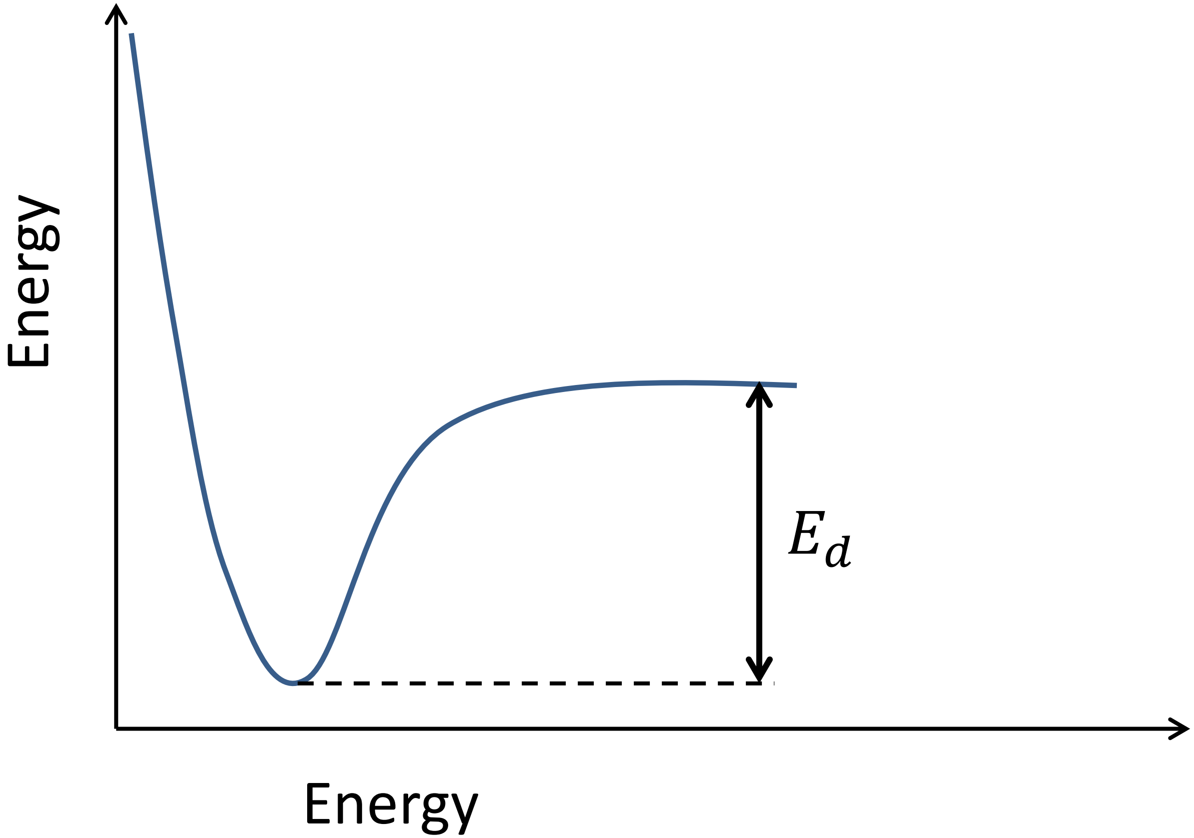
Temperature calculation



Pulse operation




Cathode plates
Window grass
Thermometer



Energy
E_d
Energy