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Article / Book Information

Title(English)	Effects of deuterium density on the surface of the cathode on NPR
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Citation(English)	14th US-Japan Workshop on Inertial Electrostatic Confinement, S4P2
Pub. date	2012, 10

IEC Workshop 2012

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

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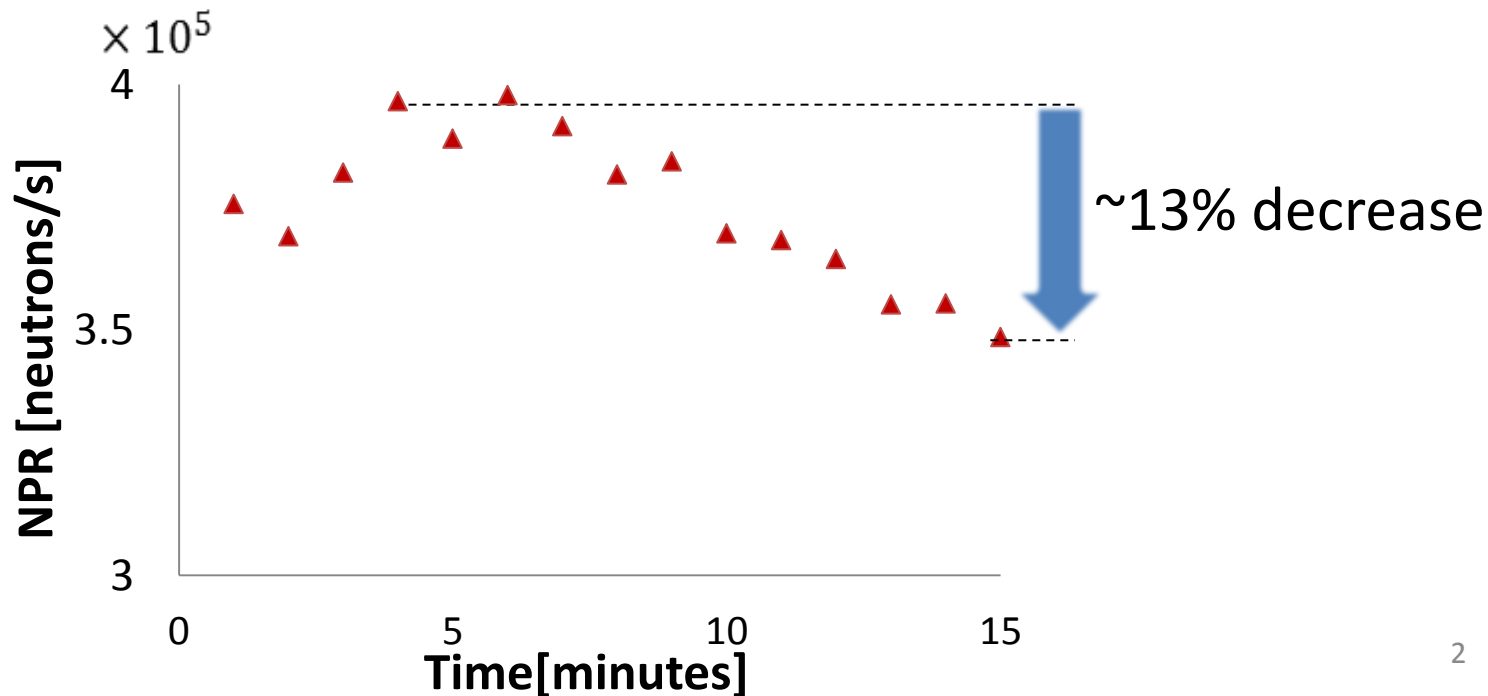
# Motivation

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

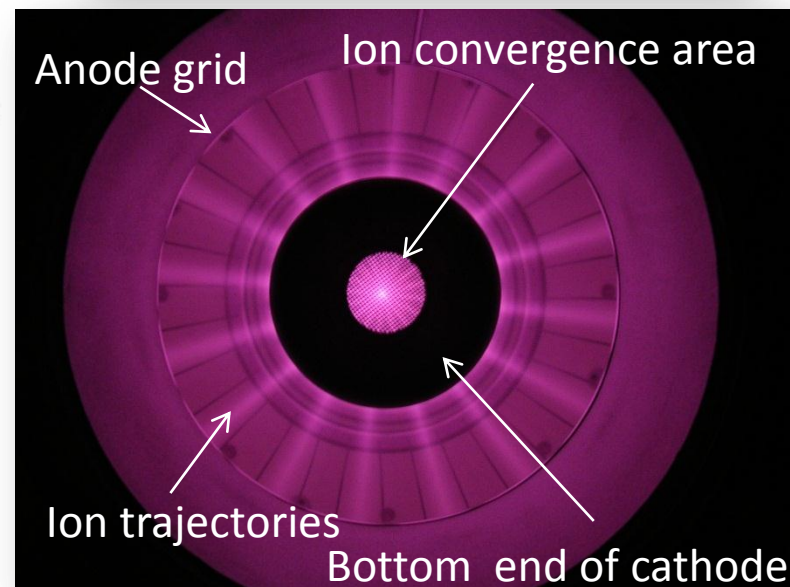
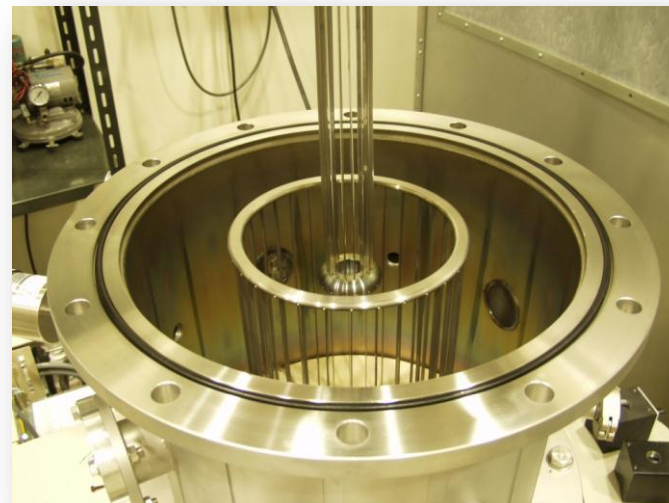
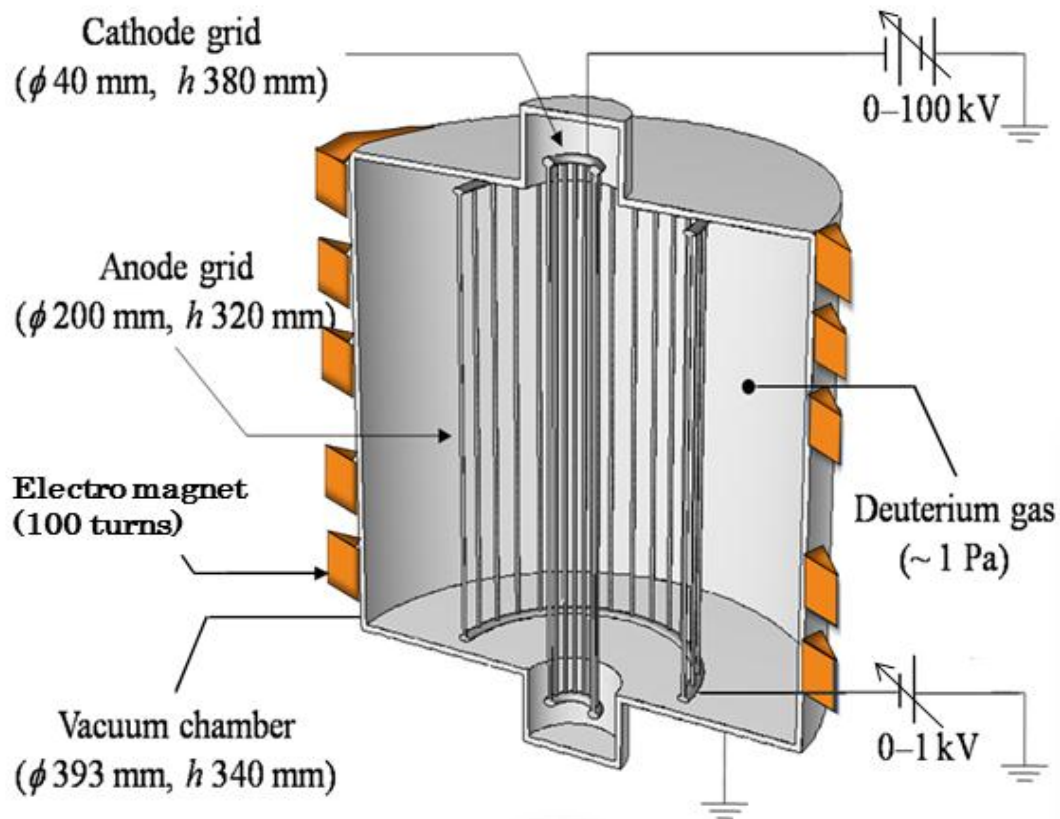
Cathode temperature affects **embedded fusion**

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 °C

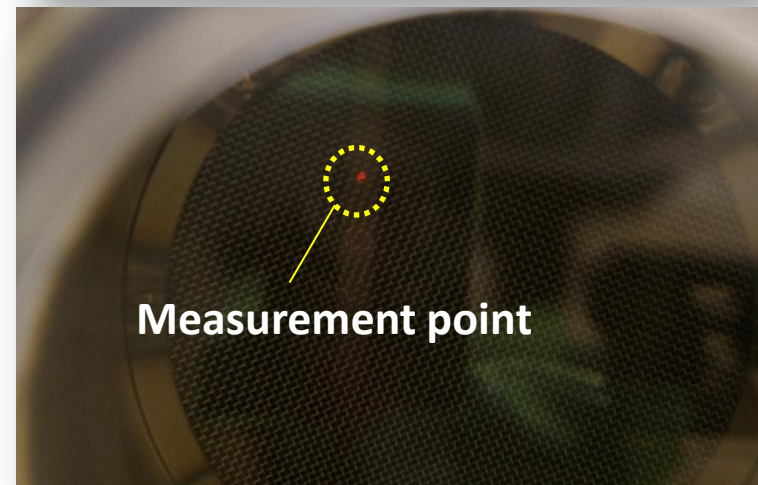
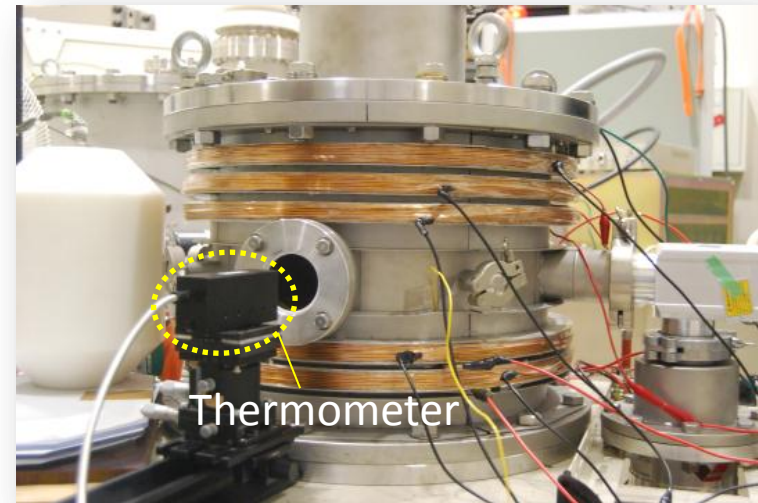
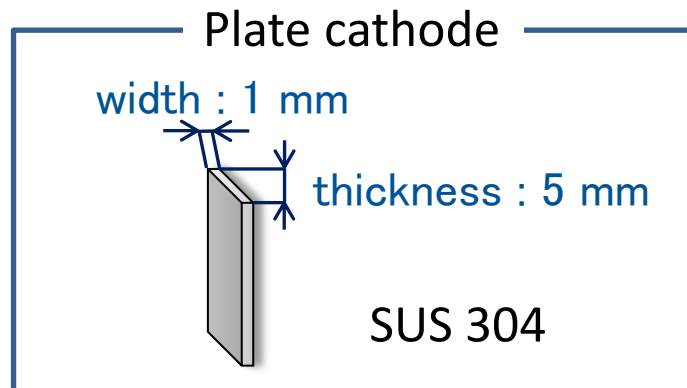
Wavelength 1.95~2 μm

Resolution : 3 °C

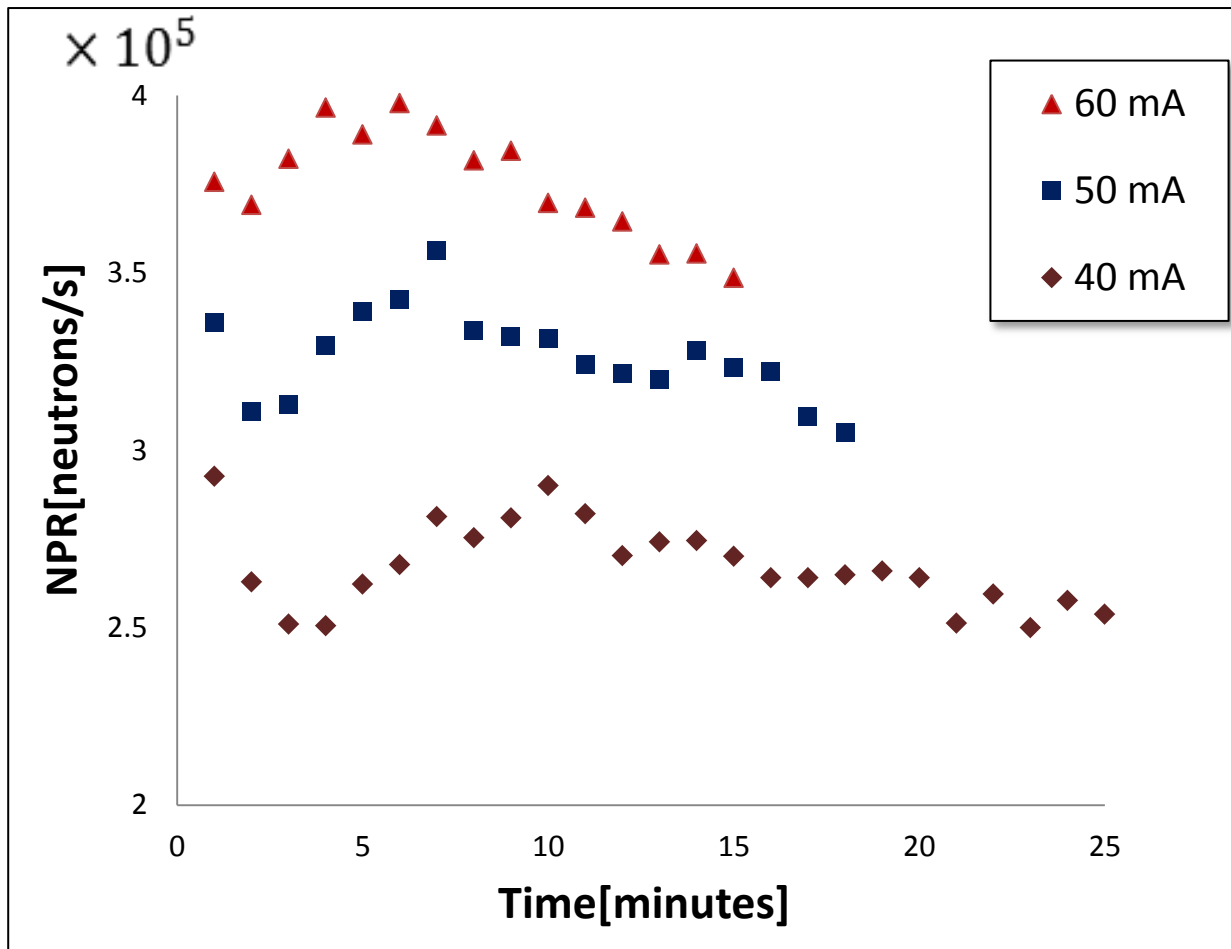
Measurement distance : 300 mm

Target diameter : 0.6 mm

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



# NPR @ -20 kV



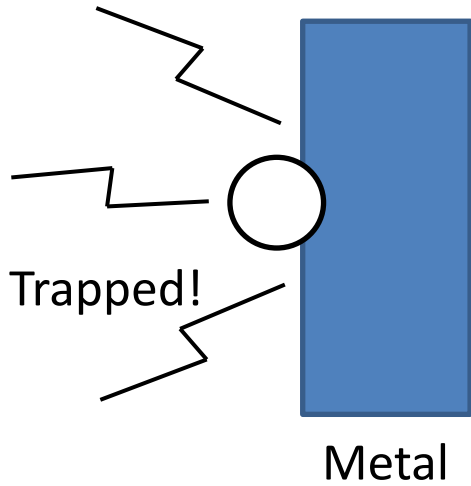
Higher input power makes the cathode hotter



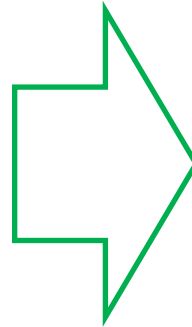
Cathode temperature affects NPR

# Embedded fusion

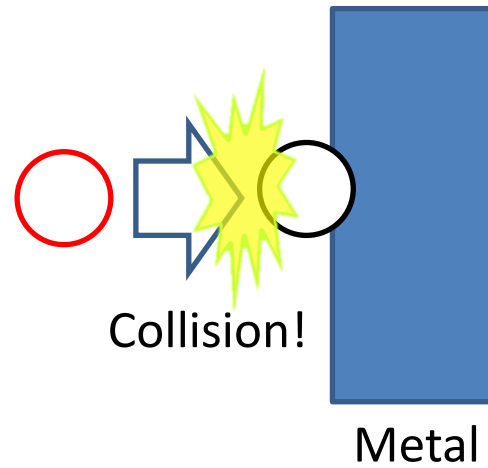
Step 1



○ : Particle of fusion gas



Step 2



○ : Fast particle



# Relationship between NPR and deuteron density

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

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

$\sigma$  : Deuteron density on the cathode

$n_{BM}$  : Ion flux

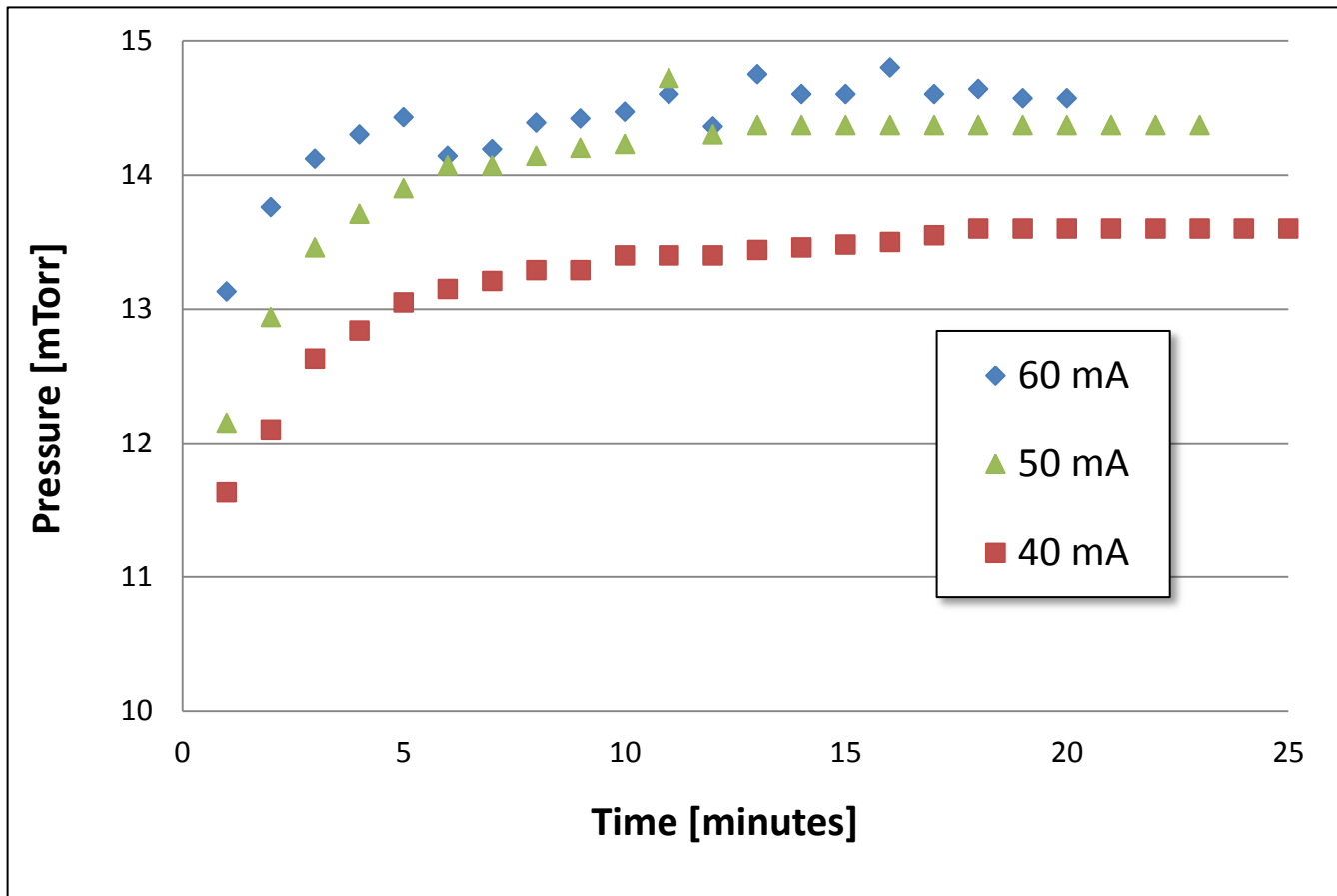
$\Sigma$  : Cross section

$v$  : relative velocity

$R_{BM-C}$  increase and decrease can be estimated from  $\sigma$

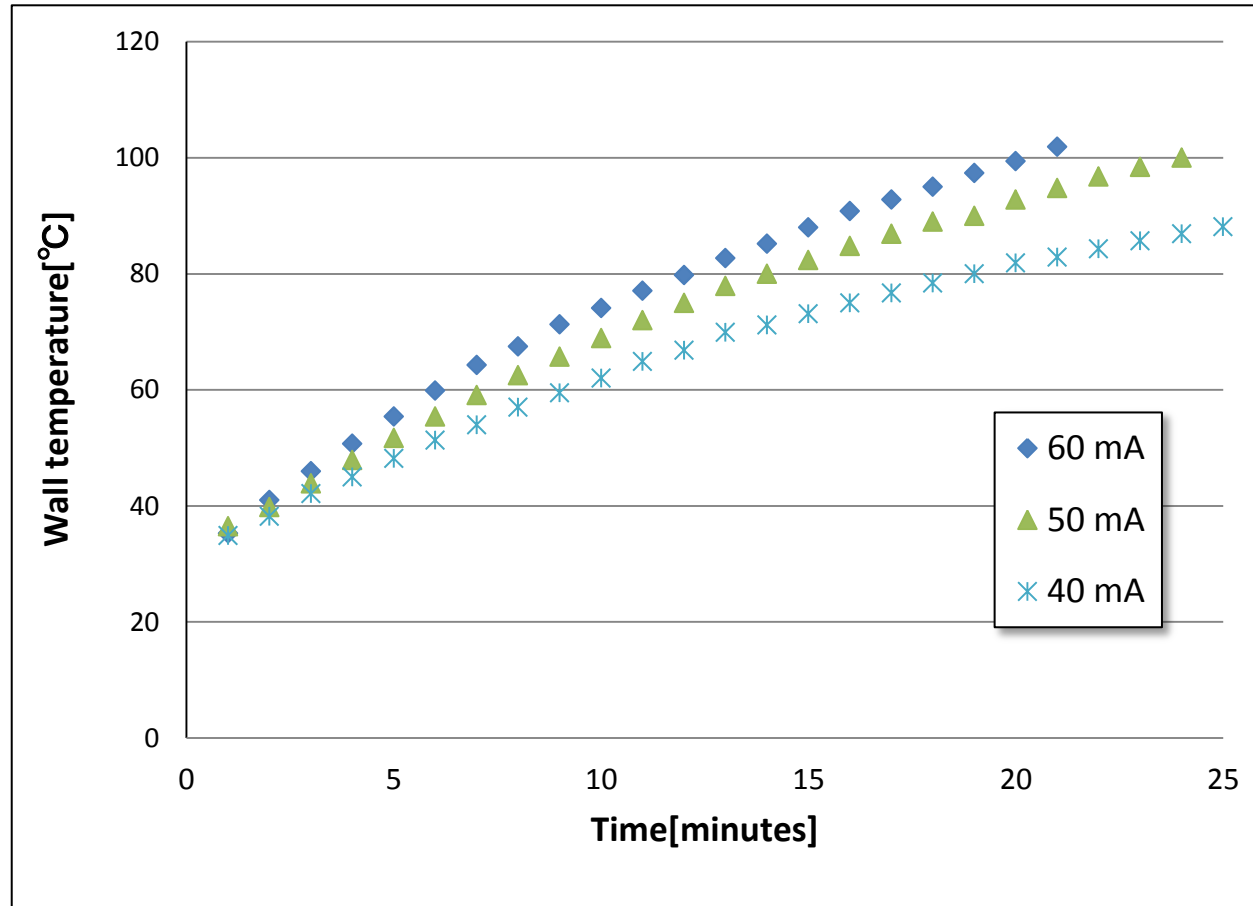
$$\frac{d\sigma}{dt} = \text{Implant}(I, T_{gas}, P) - \text{Desorption}(\sigma, T_{cathode})$$

# Pressure @ -20 kV



Pressure rises about 10% in every current condition

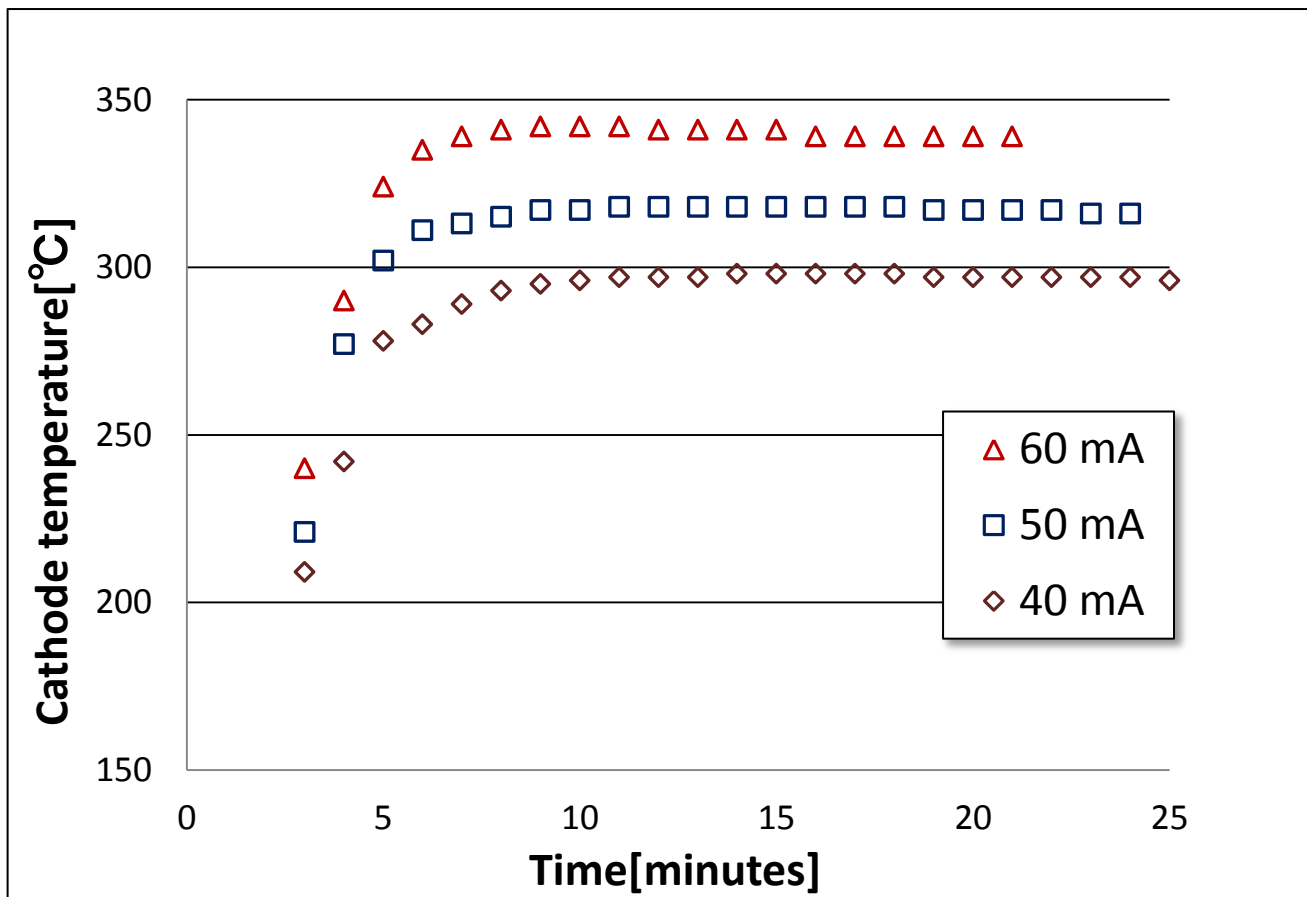
# Gas temperature @-20 kV



We assumed device wall temperature as gas temperature



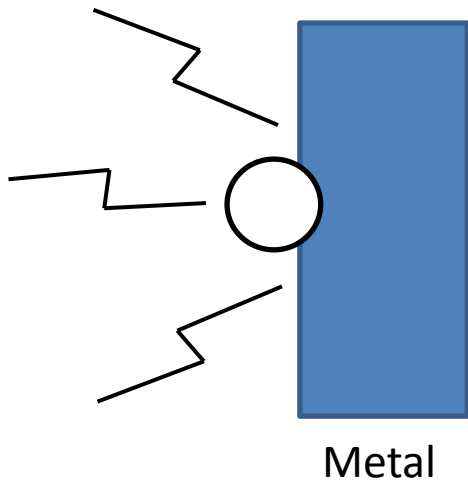
# Cathode temperature @ -20 kV



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

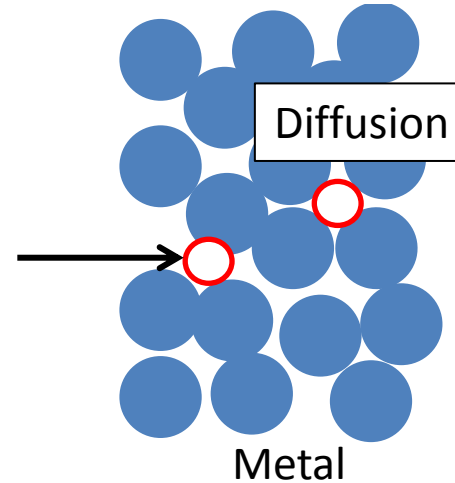
# Deuterium trap on the cathode

## Adsorption



○ : Background gas molecule

## Embedment

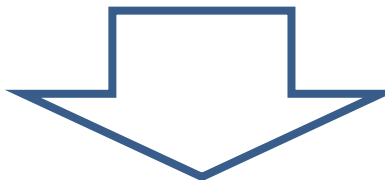


○ : Accelerated particle

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

# Adsorption

Adsorption speed can be described below

$$\left\{ \begin{array}{l} \frac{d\sigma}{dt} = \frac{1}{4} n \bar{v} s \\ \bar{v} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8RT}{\pi M}} \end{array} \right.$$


$\sigma$  : 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

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

# Embedment

Assuming  $\Gamma_{beam}$  as ion flux to the cathode,  
**embedment speed** can be described bellow

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

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

$\sigma$  : Deuterium density

$A$  : Ion embedment rate

$I$  : Cathode current

$C$  : Elementary charge

$S$  : Area of the cathode

$\gamma$  : second electron emission coefficient

We assumed  $A = 0.25$  and  $\gamma = 1$

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

Adsorption  $\approx 10^{19}$

Embedment  $\approx 10^{15}$

This effect could be stronger in spherical device



# Desorption

Desorption speed can be described below

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

$\sigma$  : Deuterium density  
 $\nu$  : Desorption reaction constant  
 $E_d$  : Activation energy of desorption  
 $R$  : Gas constant  
 $T_{Cathode}$  : Cathode temperature

Hydrogen – Tungsten desorption

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

# Summary of calculation

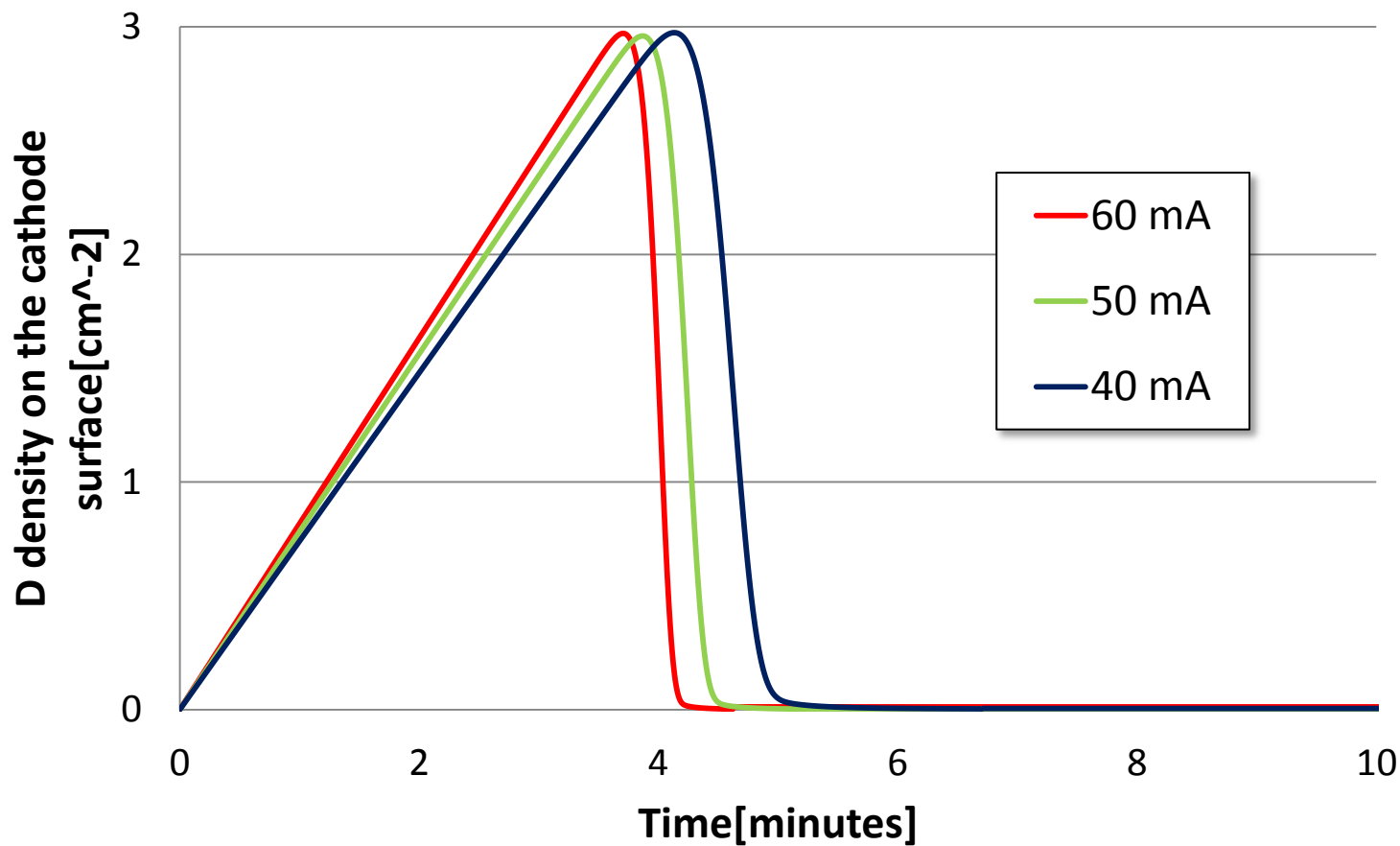
$$\frac{d\sigma}{dt} = 3.5 \times 10^{22} \frac{sp}{\sqrt{MT_{gas}}} + 7.8 \times 10^{14} \frac{I}{S} - \sigma$$

$$\times 2.2 \times 10^{13} \exp\left(\frac{-67 \times 10^3}{RT_c}\right)$$

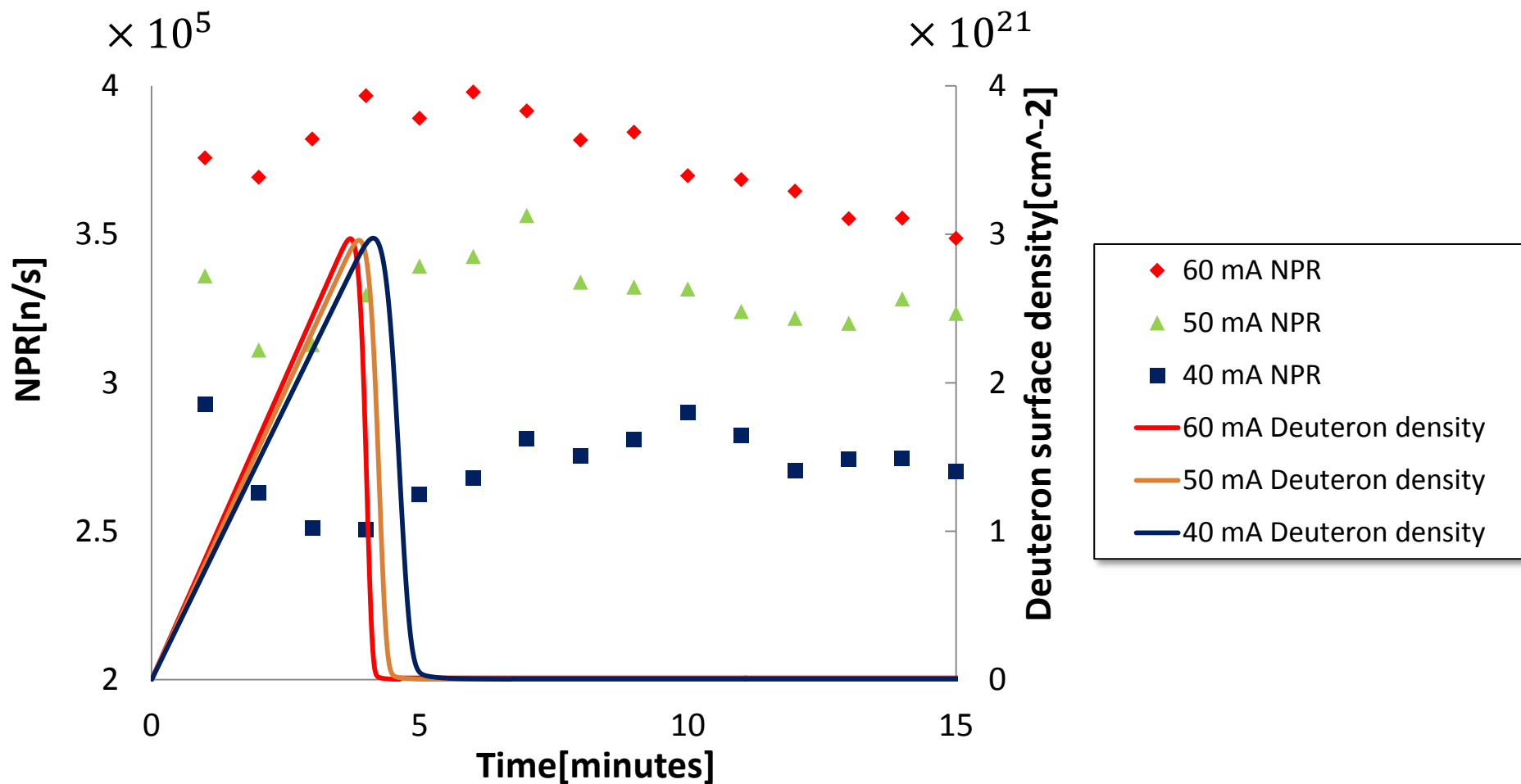
We assumed  $s=0.1$  and  $\sigma(0)=0$

Value of  $s$  was said  $0.1 \sim 1$  in reference


# Result



# Deuteron density and NPR vs. time



## How should we measure NPR?



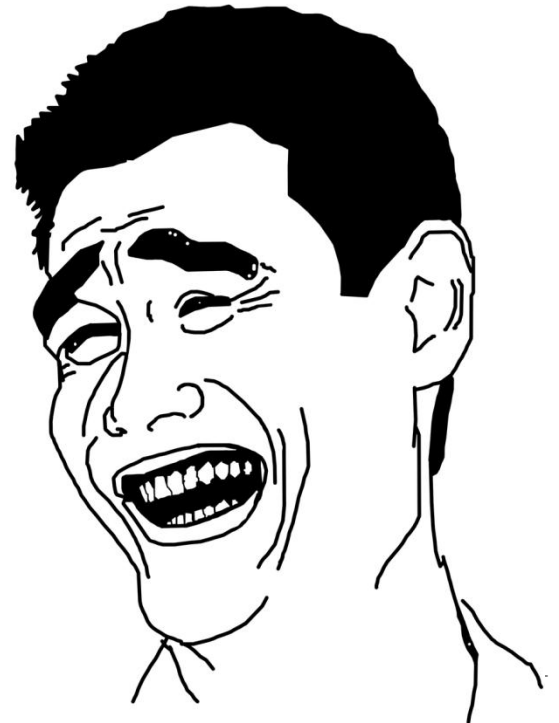
We should run a IECF device until NPR become stable  
Measurement of NPR should be done after that

### 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 ;)



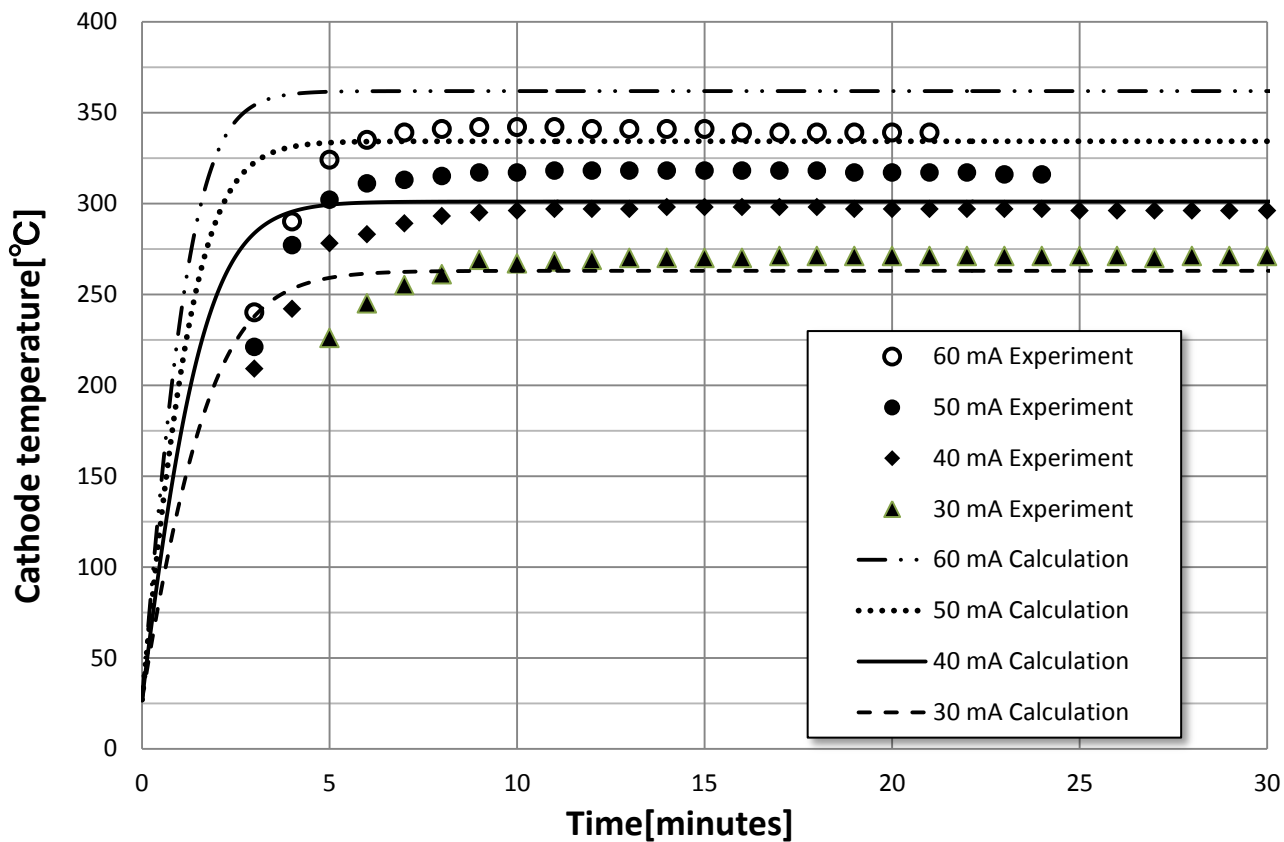


Reference

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

↓ Appendix

# Temperature calculation



# Pulse operation

