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Neutron Flux Distribution in a Coaxial Double Cylindrical Device

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Application of IEC Neutron Source

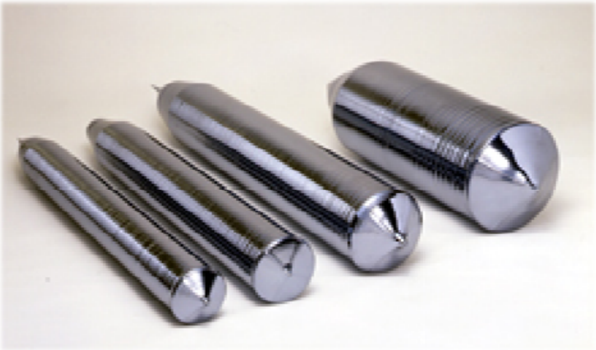
Neutron Transmutation Doping (NTD) is one of the manufacturing methods for high quality and large scale semiconductor.

Principle of NTD method

$$^{30}Si + n \Rightarrow {}^{31}Si \Rightarrow {}^{31}P + e^{-}$$

(neutron capture) (β⁻ decay)

natural abundance 3.1%



Si ingot
(http://www.sumcosi.com/products/index.html)

Nuclear reactor
(http://www.jaea.go.jp/index.shtml)

Application of IEC Neutron Source

Nuclear reactors are used as a neutron source for the production.

- Production capacity is limited now.
- Domestic demand increases year by year.

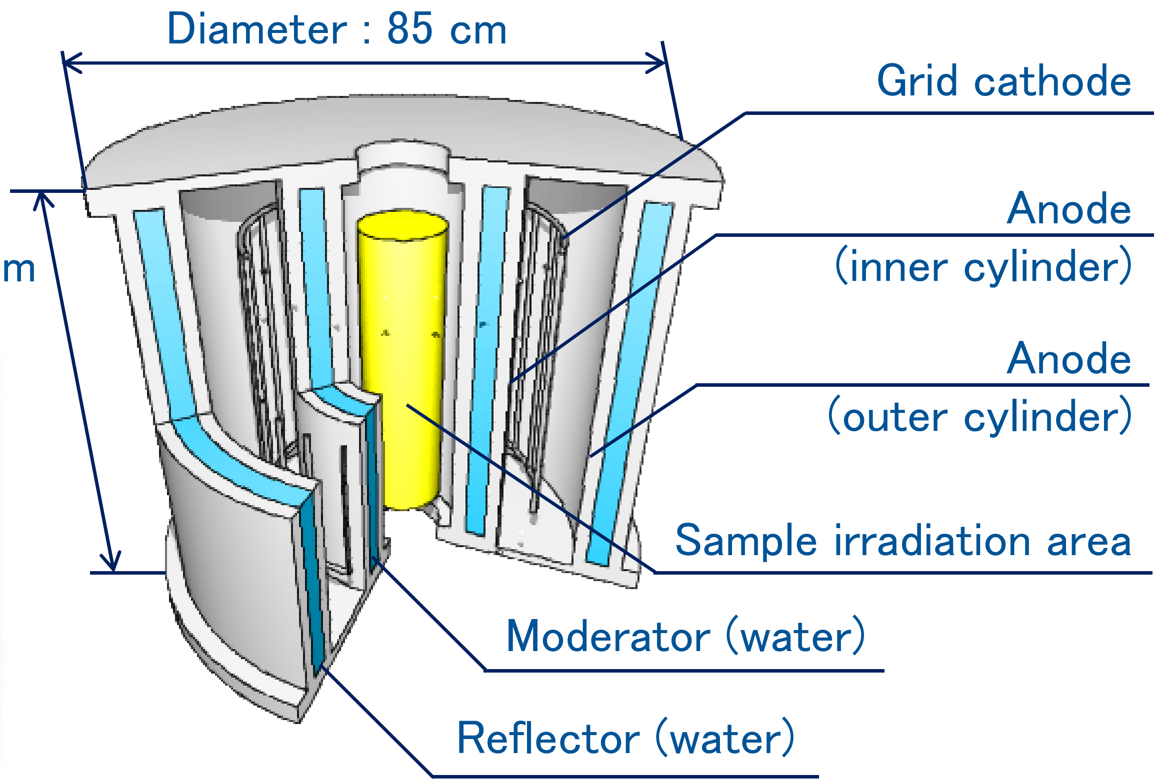
Development of a new neutron source for NTD by using an IEC device.

The uniform neutron irradiation from an IEC device, is demanded.

- In the conventional device (spherical type and cylindrical type), it is difficult to obtain uniform neutron flux.
  * The neutron flux decreases in inversely proportion to the radius.

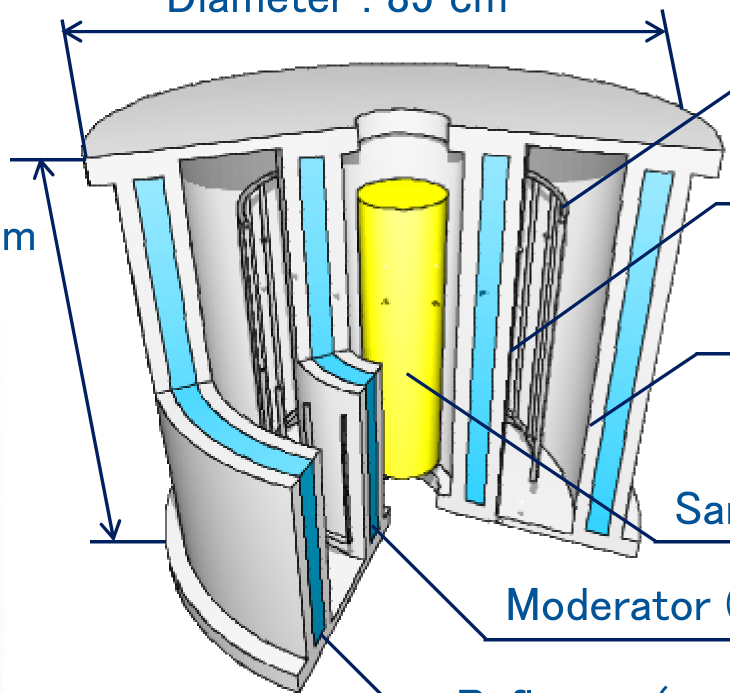
Development of a new IEC device,
especially designed to be capable of the uniform irradiation.
As such a device, we propose **a Coaxial Double Cylindrical structure**.

Coaxial Double Cylindrical Device



- This device has triple electrode structure which consists of a cylindrical grid cathode between inner and outer anode.
- Sample is irradiated in the center hole of the device.
- This device has double water jacket.
  * Inner water jacket is for cooling the chamber and moderating the neutron.
  * Outer water jacket is for cooling the chamber and reflecting the neutron.

Coaxial Double Cylindrical Device

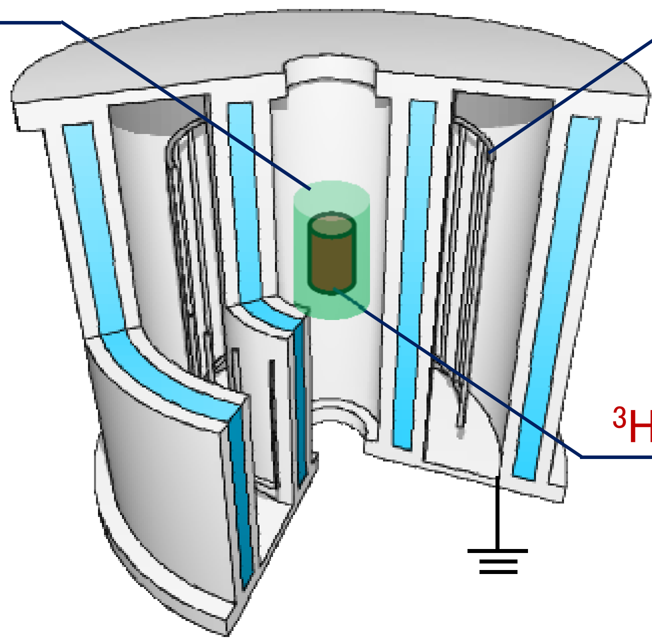


Report topic

- Measurement of the neutron production rate
- Investigation of **uniformity of a neutron flux distribution** in the sample irradiation area by a simulation and an experiment

Experimental set up I

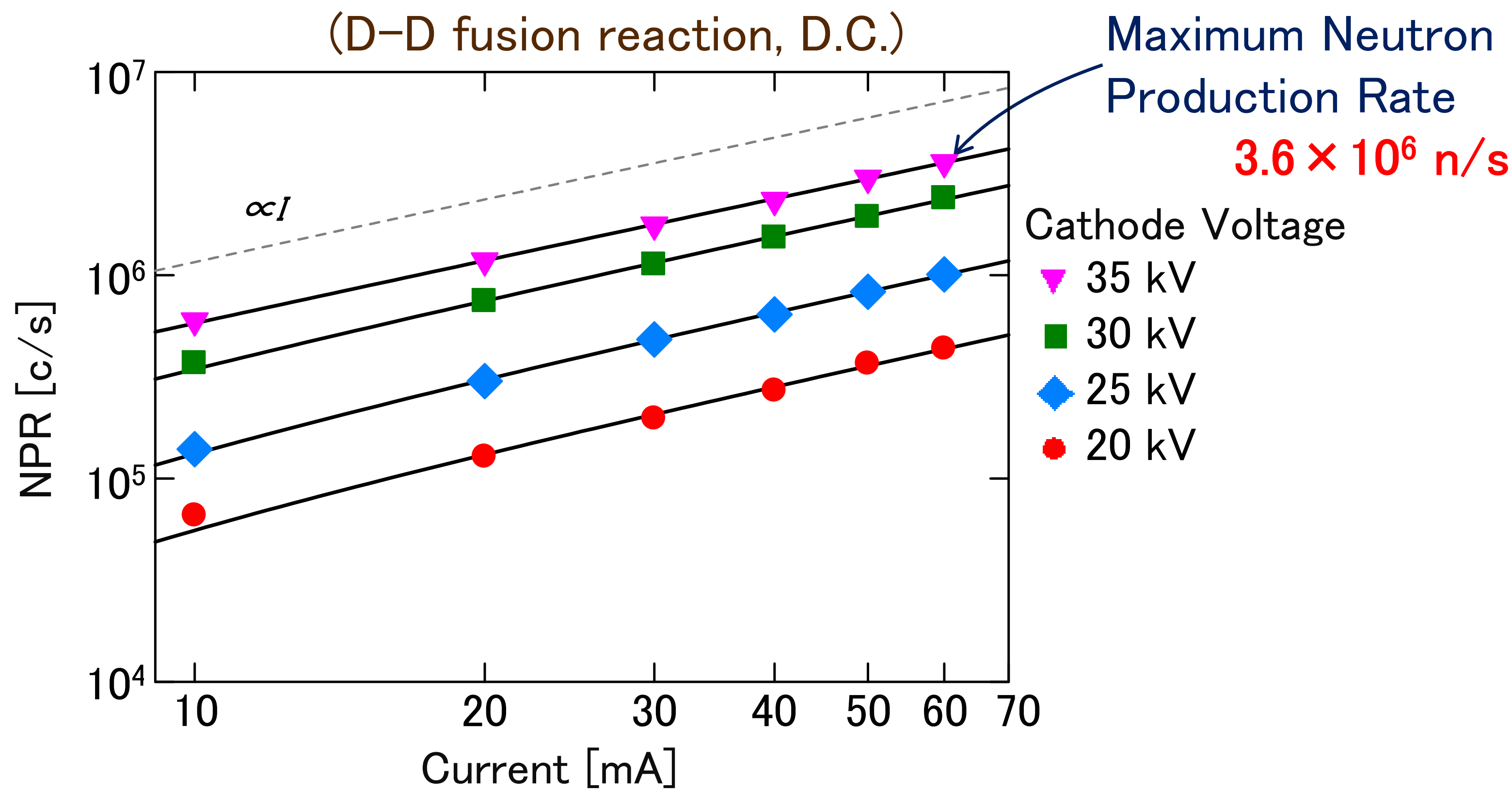
Neutron Production Rate (NPR)



- D–D fusion reaction, D.C. operation
- Neutron is counted with ^{3}He proportional counter ,
  (cylinder, diameter : 2.54 cm, length : 10.16 cm)
  surrounded by polyethylene (diameter : 20.8 cm, length : 28 cm).
- Voltage : 10 kV – 35 kV, Current : 10 mA – 60 mA (limit)

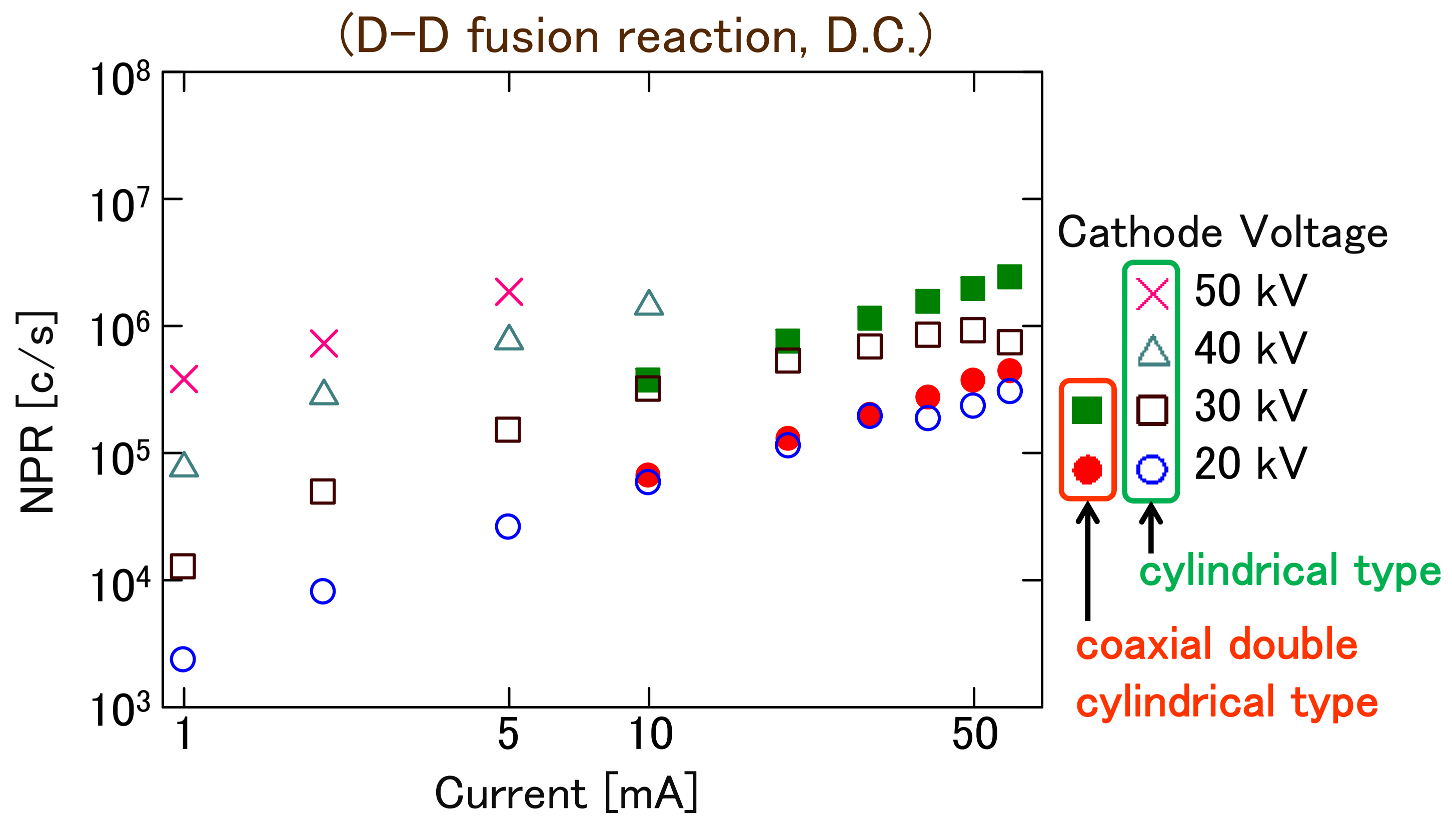
Experimental result I

Neutron Production Rate (NPR)



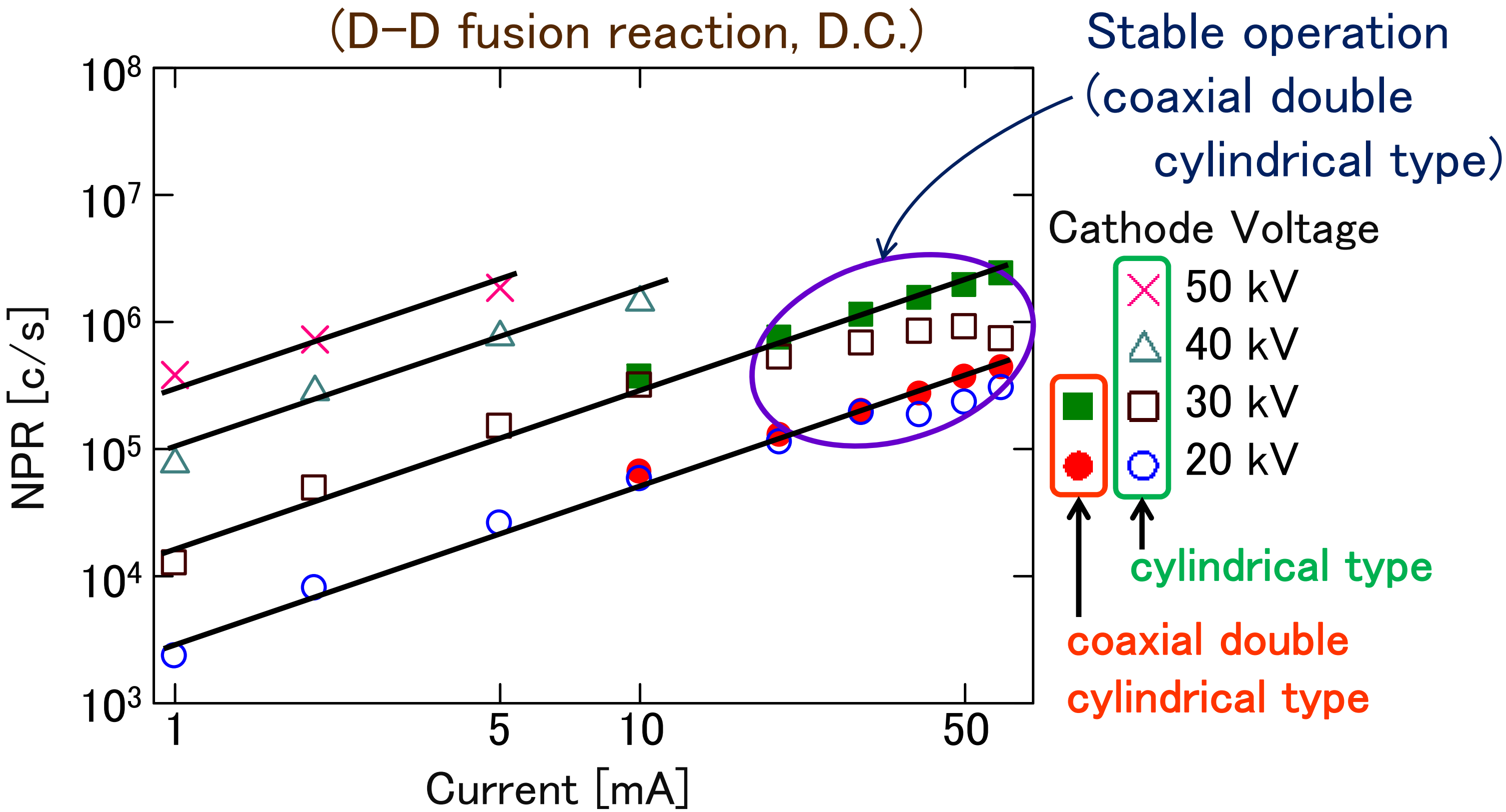
- Maximum neutron production rate (NPR) : 3.6×10^6 n/s (35 kV, 60 mA)
- NPR increases
  - * in proportion to the cathode current.
  - * when cathode voltage becomes high.

Comparing (cylindrical type and coaxial double cylindrical type)



- Tendency of the NPR is almost same in both devices.
- In large current region, NPR ···
  - ＊ tends to saturate in the cylindrical type.
  - ＊ keeps increasing in the coaxial double cylindrical device.

Comparing (cylindrical type and coaxial double cylindrical type)



- Tendency of the NPR is almost same in both devices.
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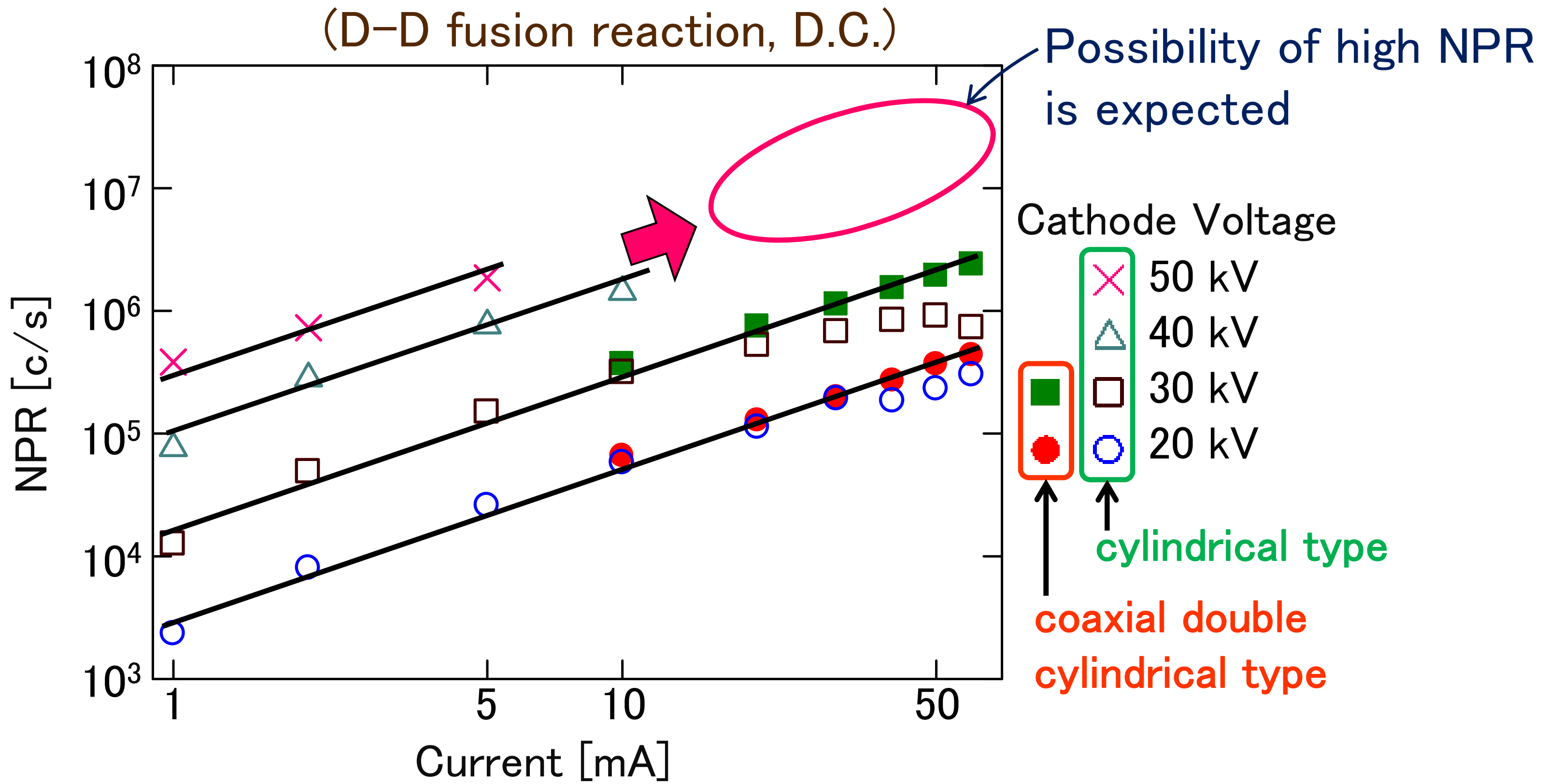
Experimental result I

Comparing (cylindrical type and coaxial double cylindrical type)



- ■ Tendency of the NPR is almost same in both devices.
- ■ In large current region, NPR ･･･
  - ＊ tends to saturate in the cylindrical type.
  - ＊ keeps increasing in the coaxial double cylindrical device.
  - ⇒ **Possibility of high NPR** (high voltage, large current)

Discussion I

Possibility of high NPR in the coaxial double cylindrical type

conditions : large current, high voltage

large current :

No problem (big cathode and low current density)

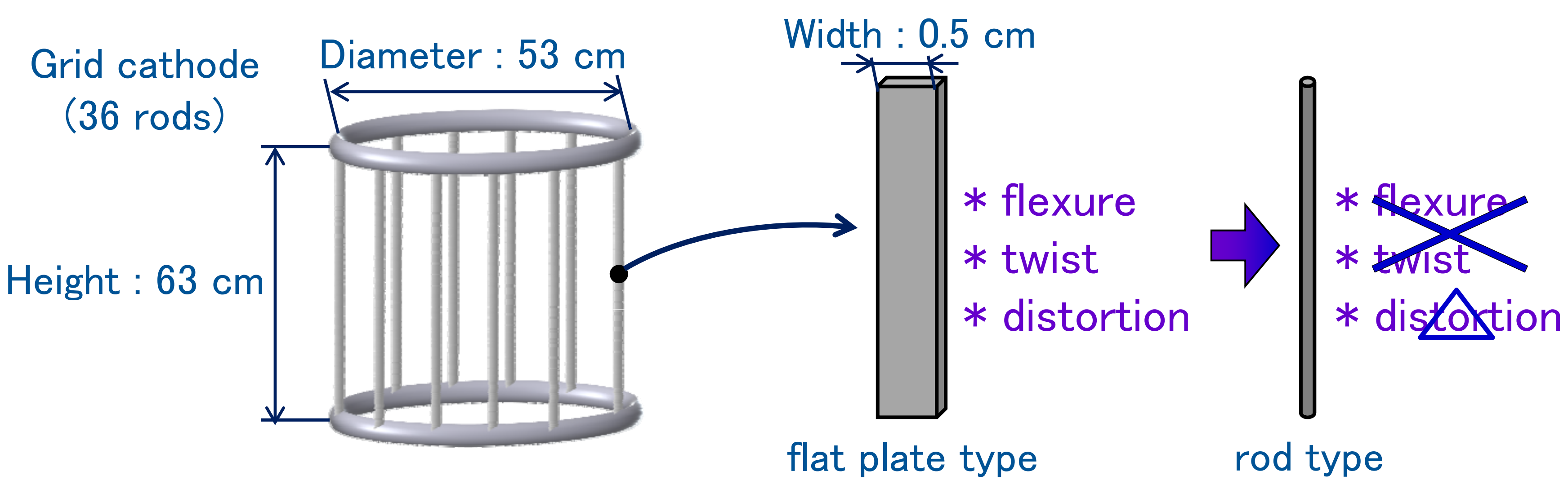
high voltage :

Breakdown voltage is low, now.

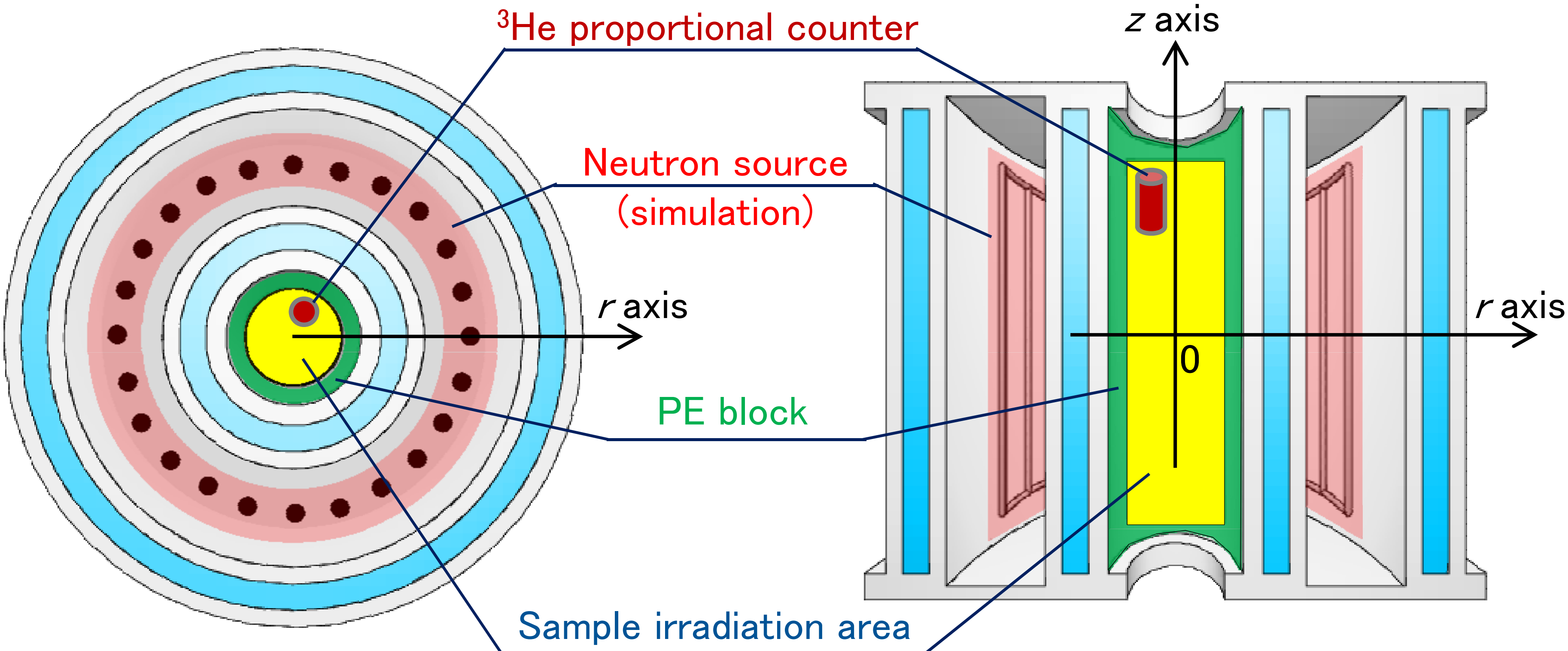
Symmetry is not maintained by using cathode electrode of flat plate type.

Electric field concentration at the corner of flat plate.

⇒ By using rod type, symmetry is maintained ? electric field relaxation ?



Device Structure



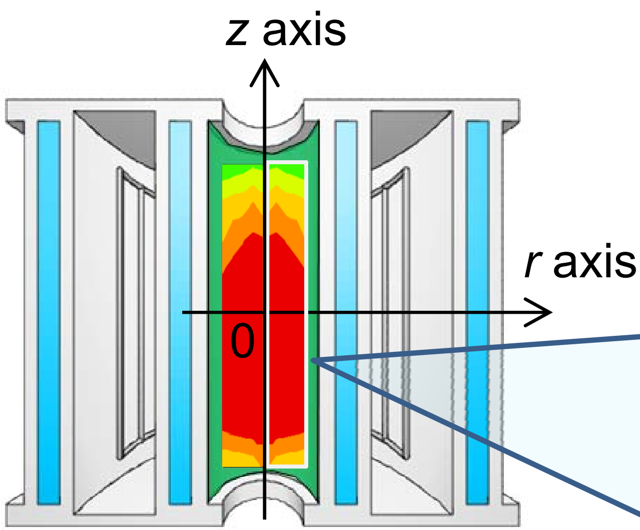
Horizontal cross section

Vertical cross section

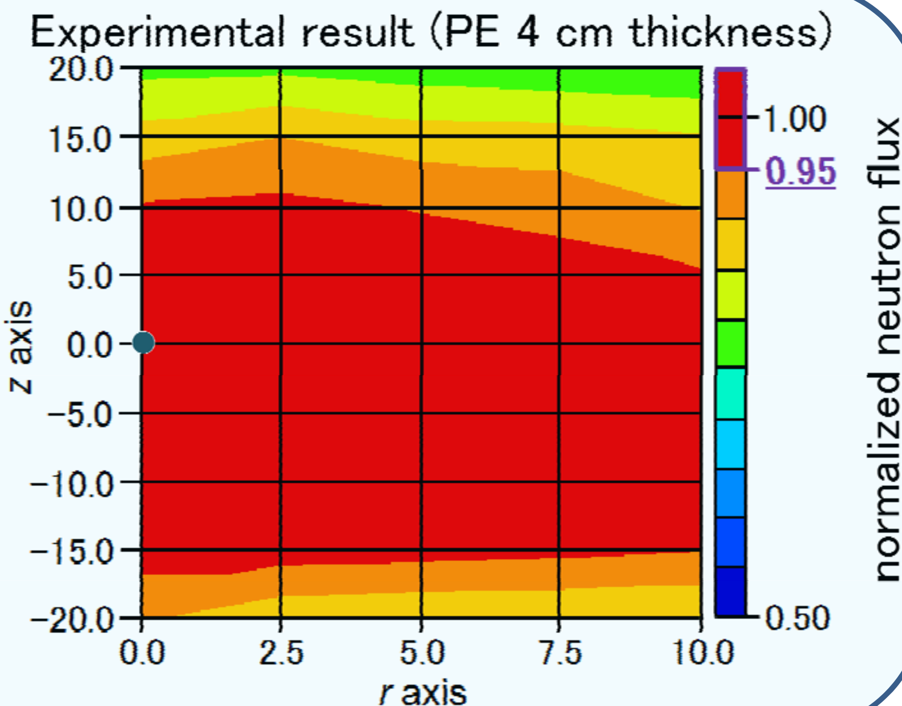
- D–D fusion reaction
- Neutron is counted with ^{3}He proportional counter.
  (2.54 cm in diameter and 10.16 cm in length cylinder)

- Additionally, for moderating the neutron, the external moderator block (polyethylene : PE) is used inside the inner anode.

Example (neutron flux distribution)



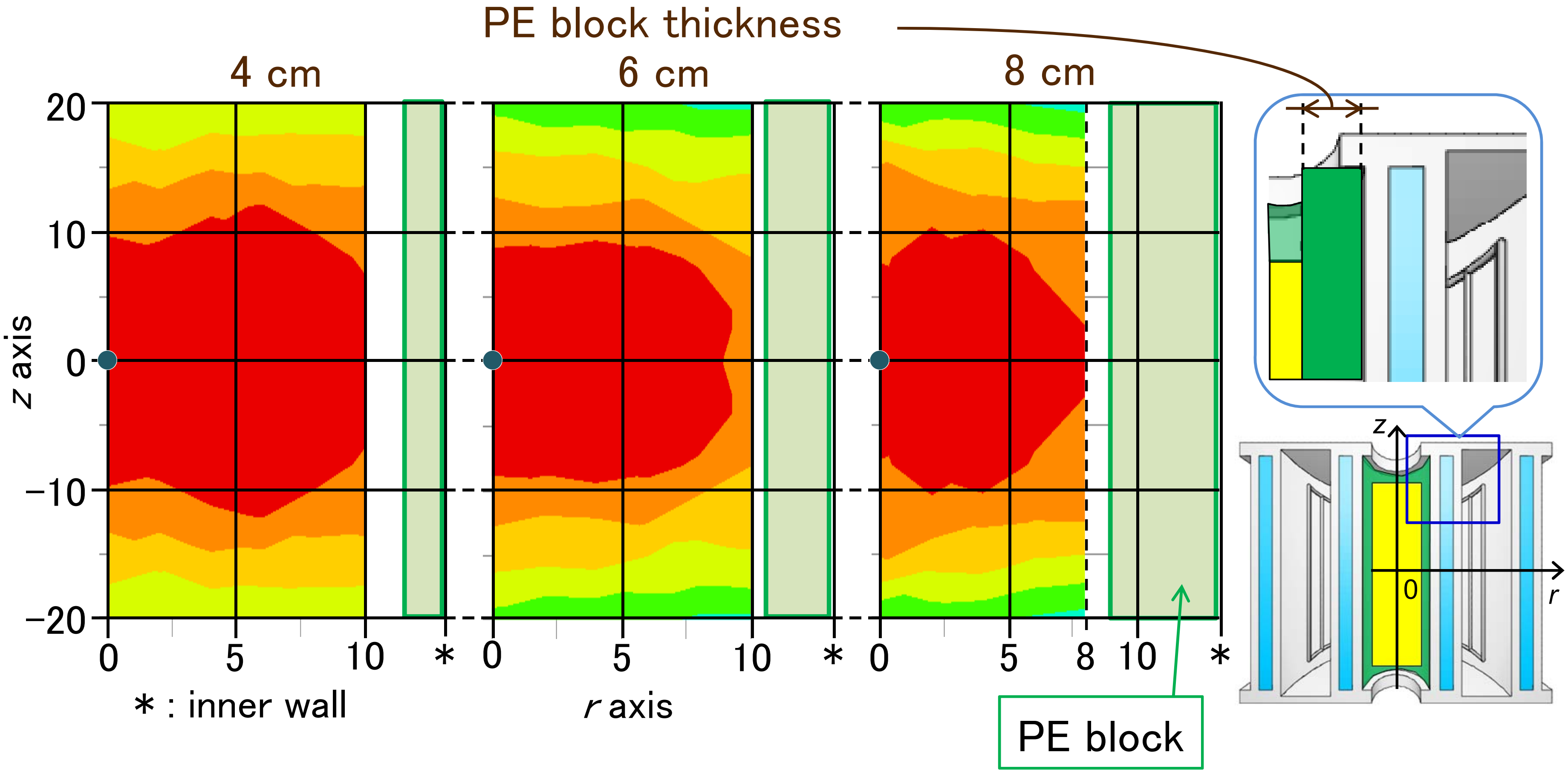
Vertical cross section



The most important matter is the **uniform neutron flux area**.

- The neutron flux distribution is normalized by the value at the origin, (0,0) : ●, in each graph.
- The uniform neutron flux area, defined as an area equal to more or less than 5% of neutron count at the origin, is drawn with red color area.
  → This definition is the same as NTD use.

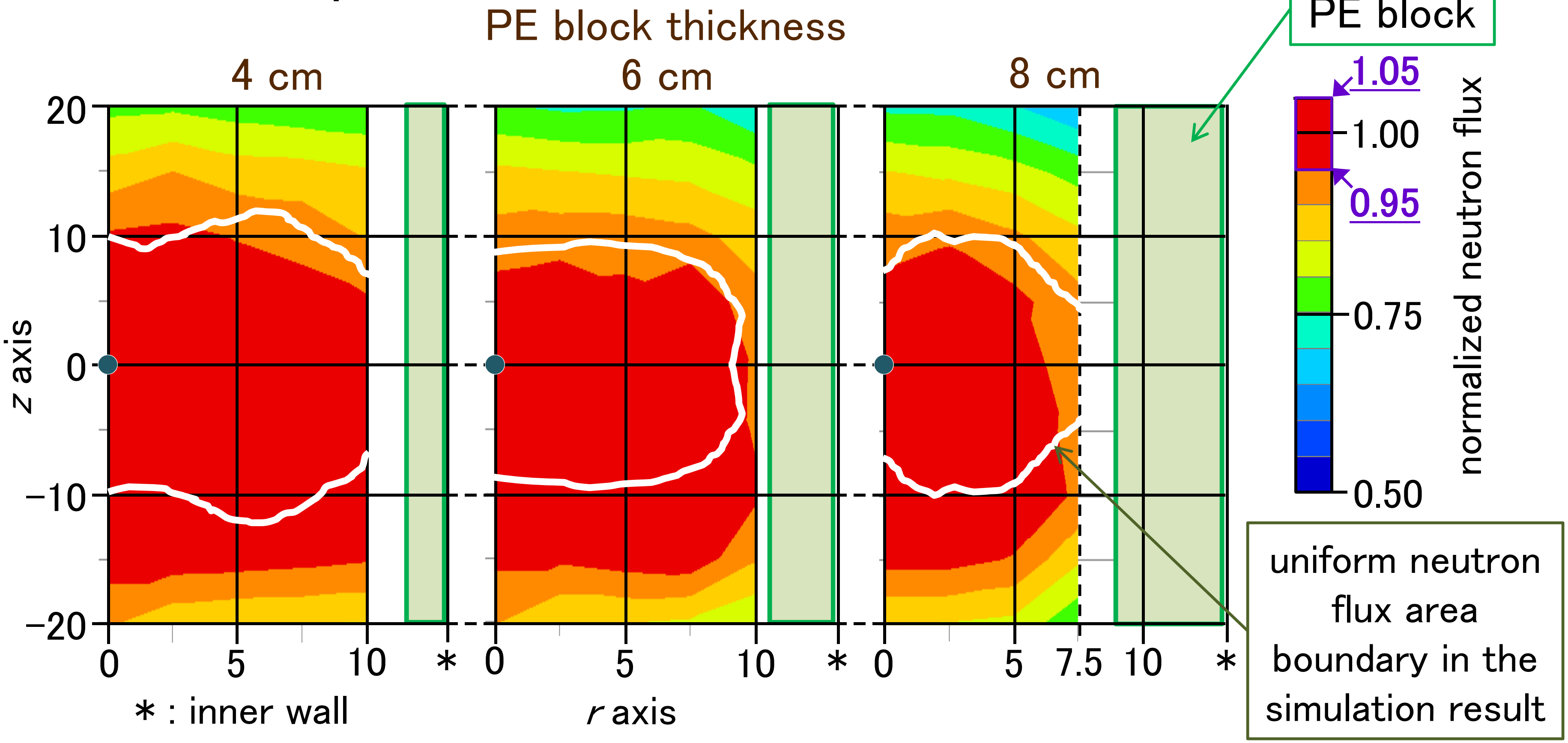
Simulation (neutron flux distribution)



By thinking about the symmetry of the device, it is assumed that the neutron flux distribution is symmetric in the z-axis direction.

- As a PE block moderator becomes thick, the uniform neutron flux area becomes small.

Experiment (neutron flux distribution)



- As a PE block moderator becomes thick, the uniform neutron flux area becomes small, coincide with simulation results.
- Neutron flux distribution has no symmetry in the z-axis direction, unlike simulation results.
- Uniform neutron flux area is larger in the lower area.

Discussion II

Neutron flux distribution has no symmetry in the experiment.

cause : **Heating of the device ?**

(Fusion reaction depends on the temperature)

simulation :

Temperature distribution is not considered, in the neutron source.

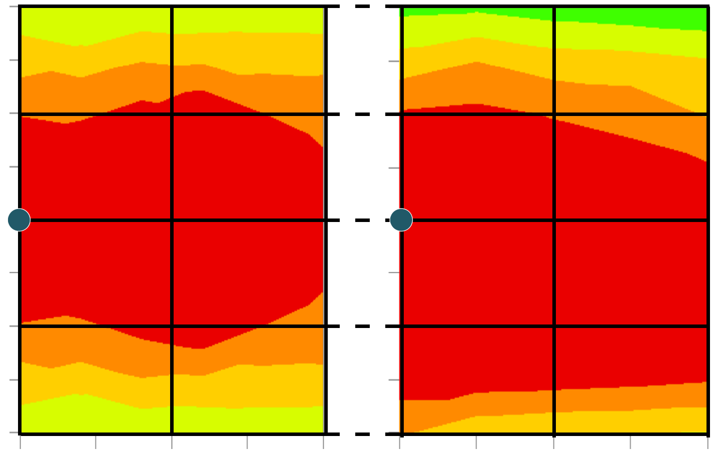
experiment :

Heat occurs, and the device has the temperature distribution.

Upper part of the device becomes very hotter than the lower part.

⇒ **Because of these reasons, different results are obtained.**

Simulation result (PE block : 4 cm)



Experimental result (PE block : 4 cm)

Conclusion

In a coaxial double cylindrical device, I investigated

neutron production rate, and **neutron flux distribution**

to consider the possibility of the uniform neutron irradiation for NTD.

⇩

Neutron production rate (NPR)

Maximum NPR : 3.6×10^6 n/s (35 kV, 60 mA)

Stable operation at the large current

⇒ Possibility of high NPR (high voltage, large current)

⇩

Neutron flux distribution

From simulation and experimental results,

Almost uniform in the central sample irradiation area as is expected

z axis direction : 25 cm [0.35 (= ratio for height of the area)]

r axis direction : 10 cm [0.53 (= ratio for radius of the area)]

(maximum uniform area, experimental result, PE thickness : 4 cm)

From experimental results, unlike simulation results,

Axial distribution is not symmetric

Future plan

I. Investigation of neutron flux distribution

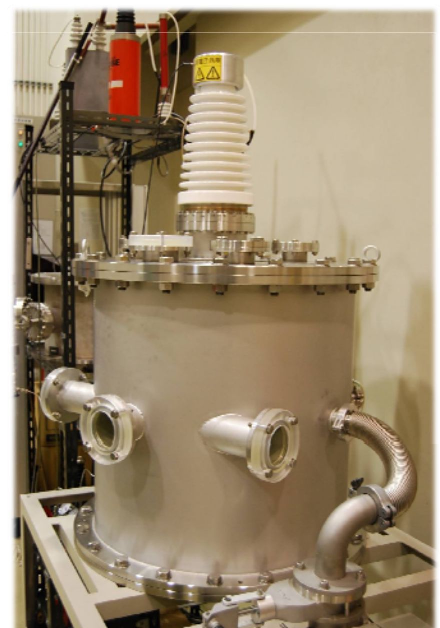
＊ simulation taking account of temperature of the neutron source

＊ temperature equalization of the device by the water circulation

II. Improvement of the neutron production rate (IEC common problem)

＊ increase discharge voltage

⇒ to increase the neutron production rate.



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Thank you for your attention