C/Be neutron converter design for increasing production amount of medical radioisotopes in accelerator neutron method

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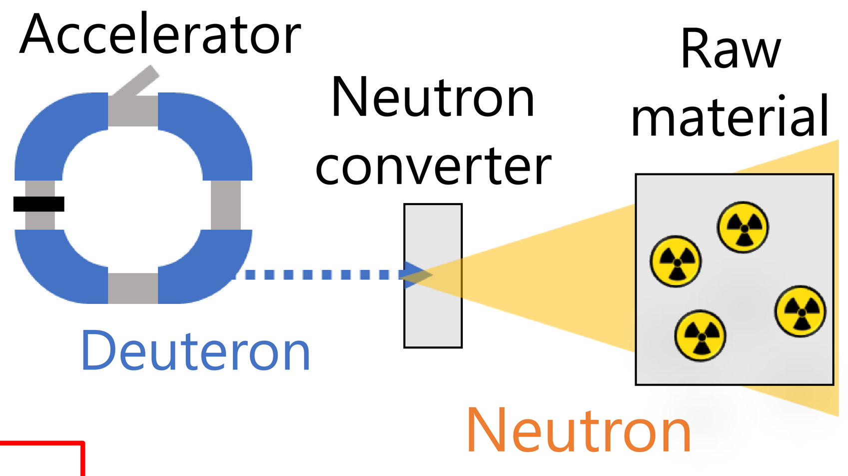
1. Introduction

Accelerator neutron generated by deuterons

→New source for RI production

Feature

- Suitable for mass production
- No need for nuclear reactors
- Large manufacturing facilities



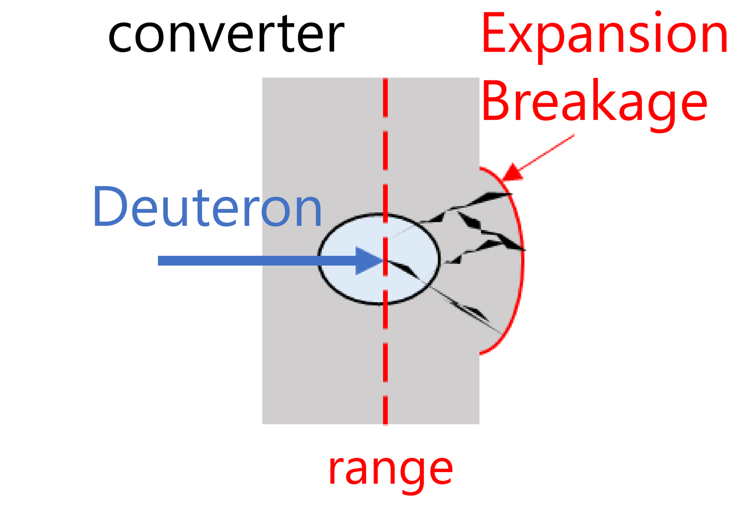
Applications in medical RI production are being considered.

Neutron converter

- C Stable
- Be Short lifetime, Neutron-rich
- Li Instability, Neutron-rich

Short lifetime : Damage of Blistering

The pressure of the residual hydrogens cause the target to swell.



Purpose

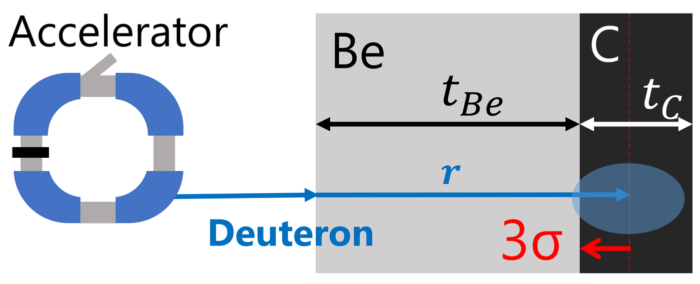
Development of an irradiation system that does not cause blistering while increasing the amount of RIs produced

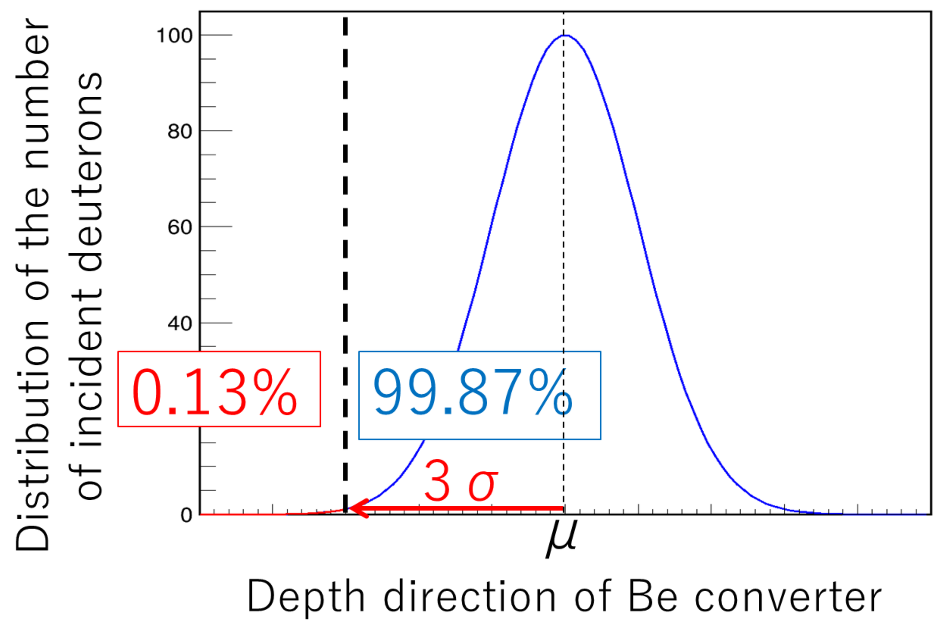
2. Method

C/Be Converter design

Be thickness : t_{Be} C thickness : t_C

$t_{Be} < r - 3\sigma$ $r \ll t_C$

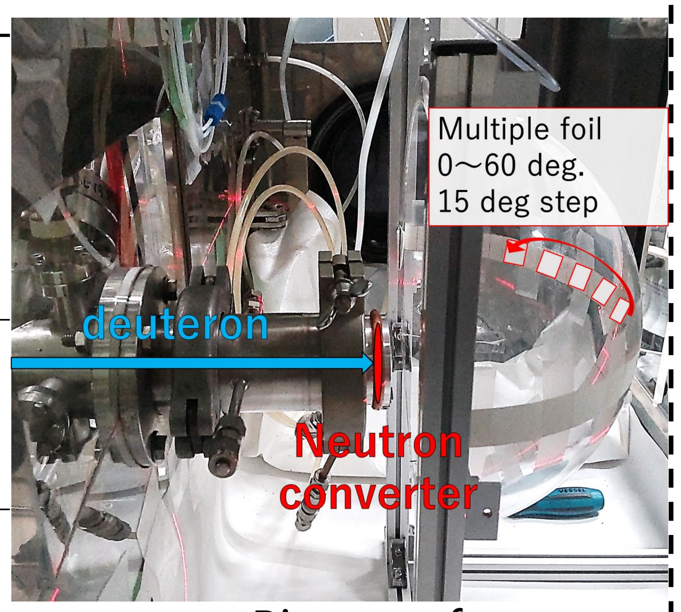




99.87% of deuterons accumulate in C

JAEA tandem experience

Deuteron energy	19.9 [MeV]
Irradiation time	12.8 [hour]
Average of electric current	0.574 [μA]
Be thickness	1.5 [mm]
C thickness	10 [mm]
Activated sample	Co, Cu, Mo, Au, Zn, Zr, Al, Ni
Multiple foil installation angle	0, 15, 30, 45, 60 [deg]



Picture of irradiation equipment

Unfolding : GRAVEL code[1]

$$\begin{pmatrix} N_x \\ N_y \\ \vdots \end{pmatrix} = \begin{pmatrix} R_{x,E_1} & R_{x,E_2} & \cdots \\ R_{y,E_1} & \ddots & \\ \vdots & & \end{pmatrix} \begin{pmatrix} \phi_{E_1} \\ \phi_{E_2} \\ \vdots \end{pmatrix}$$

Experimental value — Response function — Neutron spectrum

Unfolding Process

- Experimental values are **nuclide yield** derived from the multiple foil activation method.
- Response function is derived using the **JENDL-5[2]** cross section.
- Initial estimated neutron spectrum are calculated by **PHITS[3]**.
- This unfolding result was compared with PIHTS result(C/Be converter) and another experimental result.

[1] Matzke, Manfred. "Unfolding of pulse height spectra: the HEPRO program system", No. PTB-N-19. SCAN-9501291, (1994).
[2] O. Iwamoto, N. Iwamoto et al., "Japanese evaluated nuclear data library version 5: JENDL-5", J. Nucl. Sci. Technol. 60(1), (2023) pp. 1-60
[3] T. Sato, Y. Iwamoto, S. Hashimoto et al., "Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02", J. Nucl. Sci. Technol. 55(5-6), (2018), pp. 684-690.

3. Result and Discussion

Converter lifetime

Distribution of incident deuteron follows a normal distribution.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

μ : Average range
σ : Straggling

Durability is inversely proportional to the maximum number of deuterons accumulated per unit volume.

$$D = \frac{k}{\rho_{max}}$$

D: Durability of converter
ρ: Deuterium density per volume
k: constant

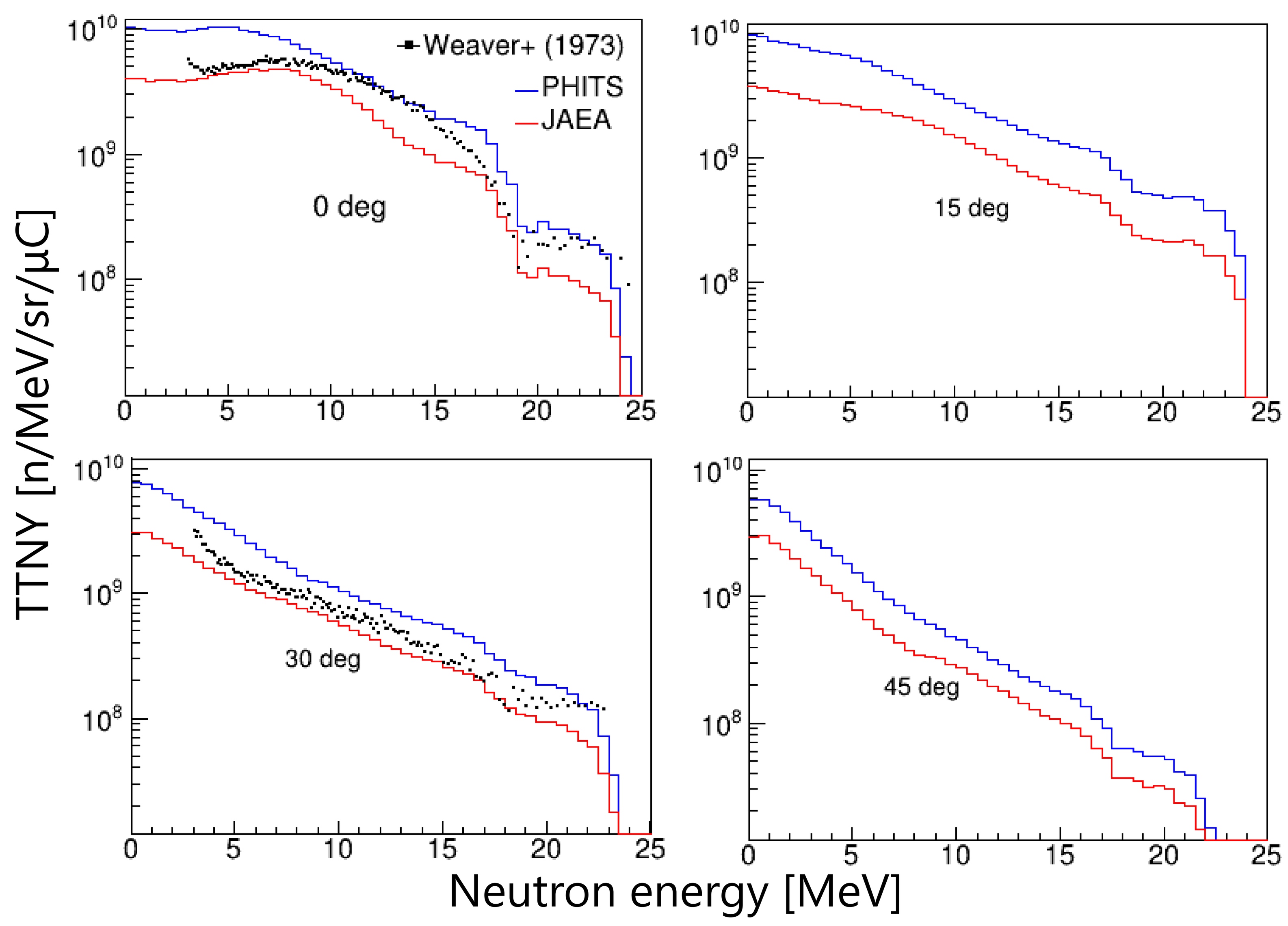
$$\rho_{max,Be} = f(\mu) = \frac{1}{\sqrt{2\pi\sigma^2}}$$

$$\rho_{max,C/Be} = f(\mu - 3\sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{9}{2}\right)$$

$$\frac{D_{C/Be}}{D_{Be}} = \frac{\rho_{max,Be}}{\rho_{max,C/Be}} = \exp\left(\frac{9}{2}\right) = 90.01$$

C/Be converters are approximately 90 times more durable than stand-alone Be converters

Thick target neutron Yield : TTNY



TTNY of JAEA experiment and PHITS simulation

Weaver's results[4] are stand-alone Be converters with 20 MeV deuteron incident energy. TTNY of PHITS are same flux of default spectrum.

C/Be converters give similar neutron yields to Be converters

[4] K. A. Weaver, J. D. Anderson, H. H. Barschall & J. C. Davis (1973) Neutron Spectra from Deuteron Bombardment of D, Li, Be, and C, Nuclear Science and Engineering, 52:1, 35-45, DOI: 10.13182/NSE73-A23287

4. Conclusion

- We developed C/Be converters that suppress blistering.
- Experiments were conducted in JAEA tandem to evaluate converter performance.

- C/Be converter is approximately 90 times more durable than stand-alone Be converter.
- C/Be converters give similar neutron yields to Be converters