November 2023 Nuclear Human Resources Initiative Practicum

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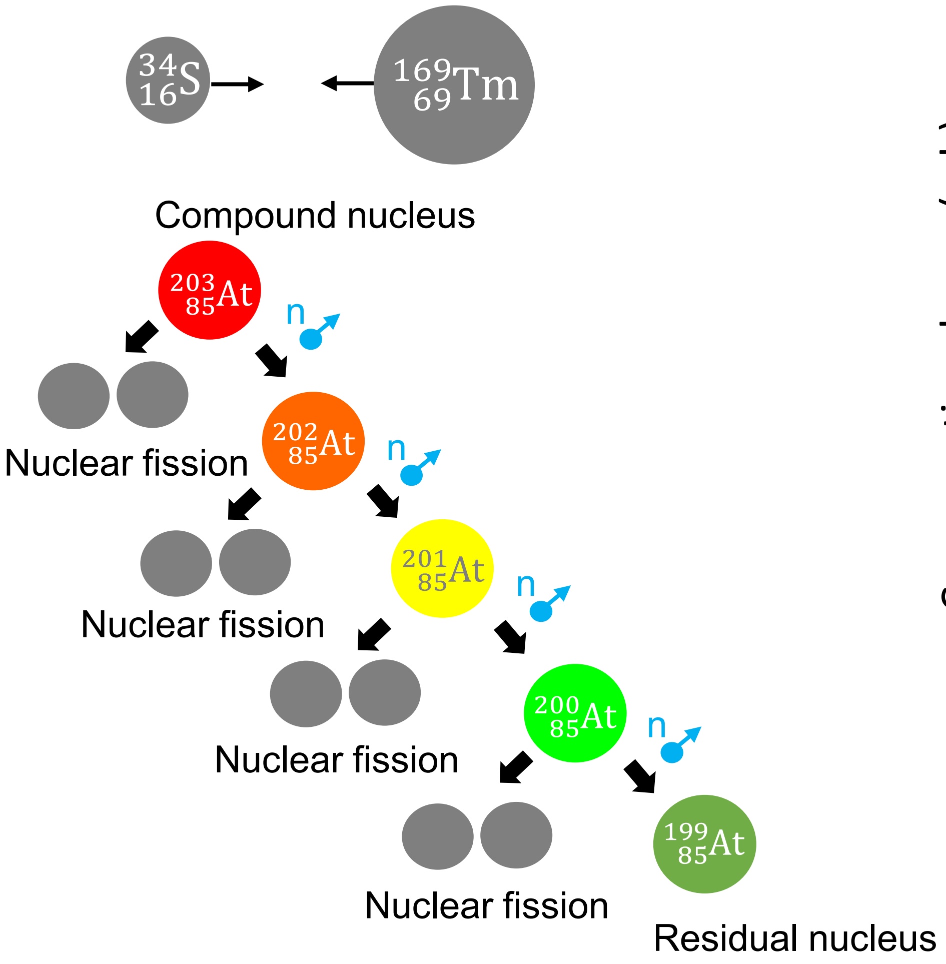
# Derivation of evaporation residual nucleus cross section

# Nuclei produced in the evaporation process following nuclear fusion



Compound nucleus

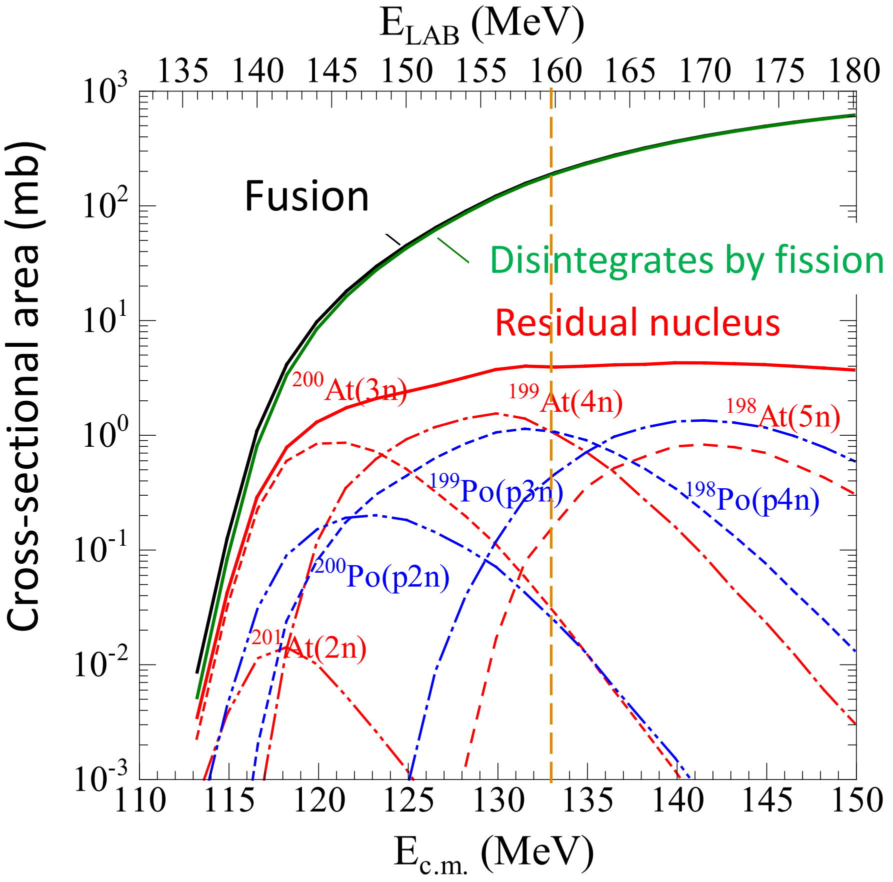
Nuclear fission

Nuclear fission

Nuclear fission

Nuclear fission

Residual nucleus



$^{34}$SBeam = 10 pnA

Cross-sectional area = 1.0 mb

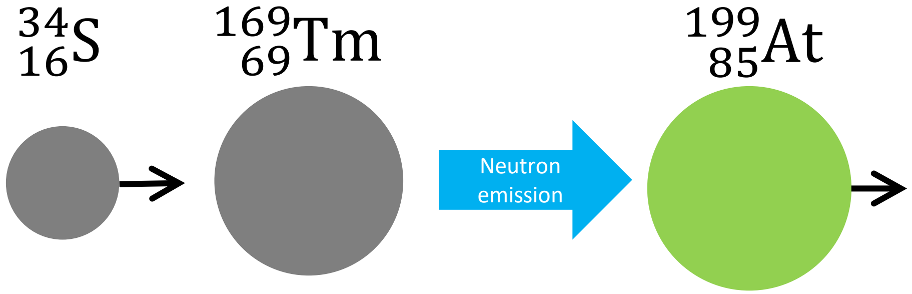
Target thickness = 100μg/cm$^2$

RMS Transport Efficiency = 10%

→ 800 events in 1 hour

**About a few percent of the composite nuclei survive as evaporated residual nuclei**

# Cross-sectional area・・・Ease of reaction



The nuclear beam ${}^{34}\mathrm{S}$ is applied to the target nucleus ${}^{169}\mathrm{Tm}$, The number of residual nuclei ${}^{199}\mathrm{At}$produced is,

Number of ${}^{34}\mathrm{S}$ beam nuclei to be hit

Number of target nuclei ${}^{169}\mathrm{Tm}$ to be hit

is proportional.

Number of ${}^{199}_{85}\mathrm{At}$ [1]

Number of incident nuclei [1]

Density of target nuclei [1/cm³]

Target thickness [cm]

Areal density of target [1/cm2] =“Target thickness”

$$N\left({}^{199}_{85}\mathrm{At}\right) \propto N_B \; n \cdot t \;=\; N_B \cdot N_T$$

$$N\left({}^{199}_{85}\mathrm{At}\right) = \sigma \cdot N_B \cdot N_T$$

Let $\sigma$ be the proportionality constant.

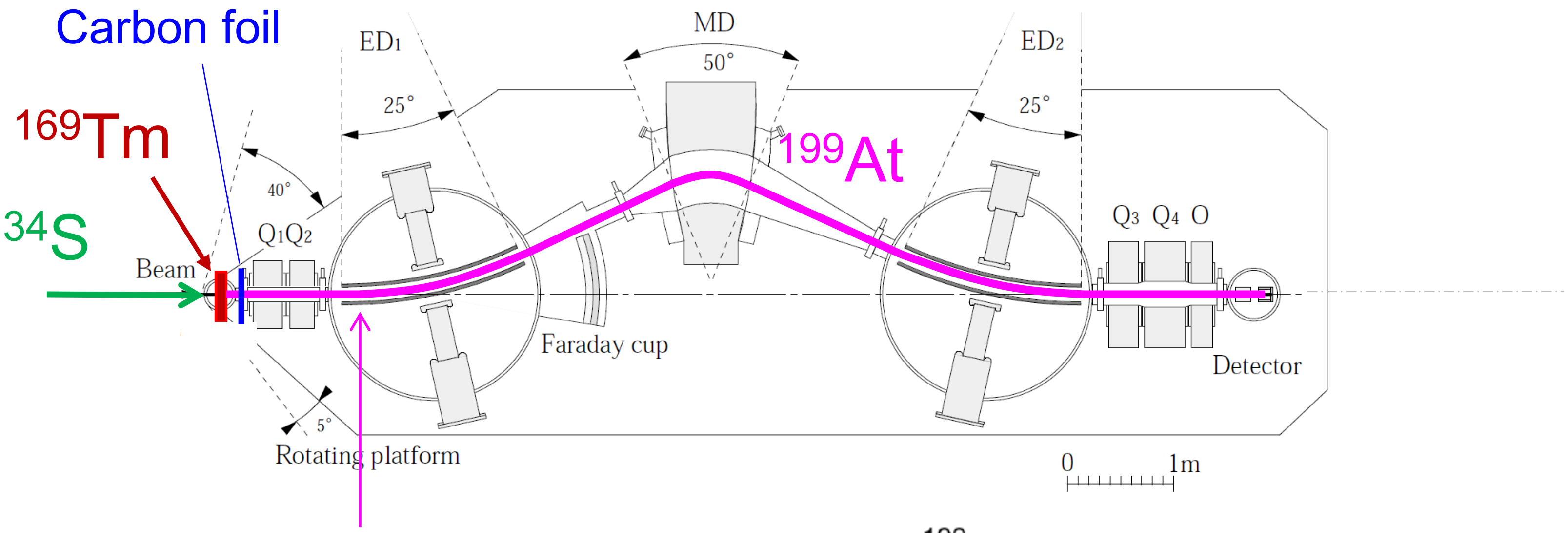
$$\frac{N\left({}^{199}_{85}\mathrm{At}\right)[1]}{N_B[1] \cdot N_T[1/\mathrm{cm}^2]} = \sigma[\mathrm{cm}^2]$$

$\sigma$ is the dimension of area.
A value specific to the reaction.

(*) 1[cm$^2$] is too large a unit
Use $10^{-28}$[m$^2$] = 1[b] (b:barn).

# Counting $N\left({}^{199}_{85}\mathrm{At}\right)$ (1/2)

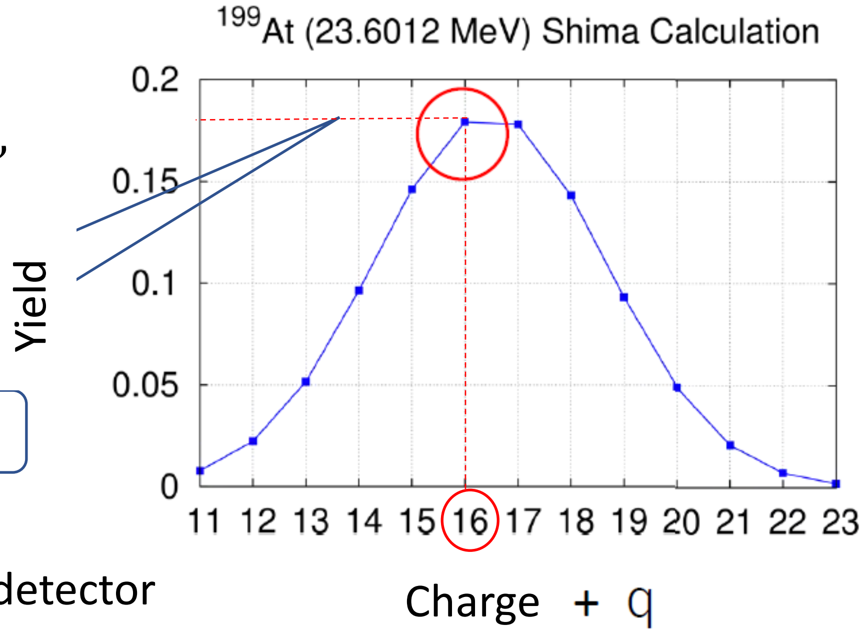
$$\sigma = \frac{N\left({}^{199}_{85}\mathrm{At}\right)}{N_B \cdot N_T}$$



${}^{199}\mathrm{At}^{q+}$ (Orbit of charge state $q$)

If q=16 is set to pass through the RMS, q=15, 17, etc. will not reach the terminal detector.

The ${}^{199}$At ratio for q=16 is 18%



18% of the ${}^{199}$At generated reaches the end detector

# Count the number $N\left(^{199}_{85}\text{At}\right)$ of $^{199}$At (2/2) $\sigma = \dfrac{N\left(^{199}_{85}\text{At}\right)}{N_B \cdot N_T}$

$^{198}_{85}\text{At}$ — $E_\alpha = 6.753\text{MeV}(97\%)$, $T_{1/2} = 4.2\text{s}$ → $^{194}_{83}\text{Bi}$

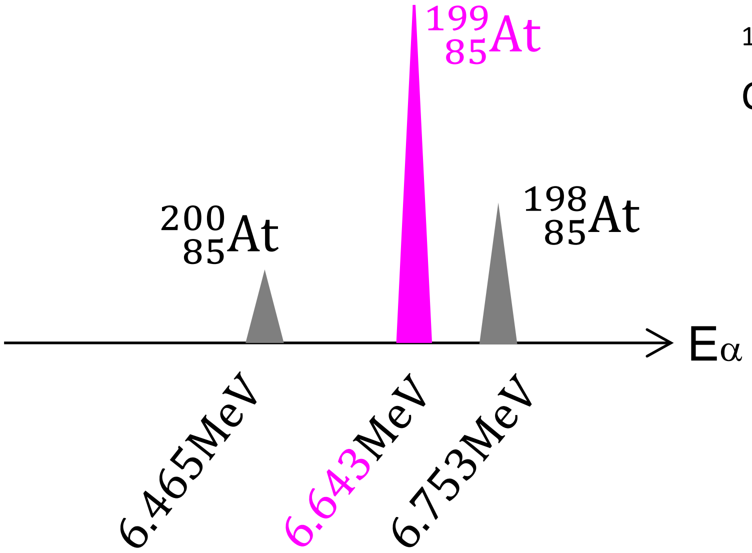
$^{199}_{85}\text{At}$ — $E_\alpha = 6.643\text{MeV}(90.0\%)$, $T_{1/2} = 7.03\text{s}$ → $^{195}_{83}\text{Bi}$

$^{200}_{85}\text{At}$ — $E_\alpha = 6.465\text{MeV}(57\%)$, $T_{1/2} = 43\text{s}$ → $^{196}_{83}\text{Bi}$

| | charge state | | |
|---|---|---|---|
| | 16 | 17 | 18 |
| $^{198}$At | 12.38 | 11.65 | 11.00 |
| $^{199}$At | 12.44 | 11.71 | 11.06 |
| $^{200}$At | 12.50 | 11.76 | 11.11 |

No difference in m/q = orbits are close

→Not only $^{199}$At reaches the detector



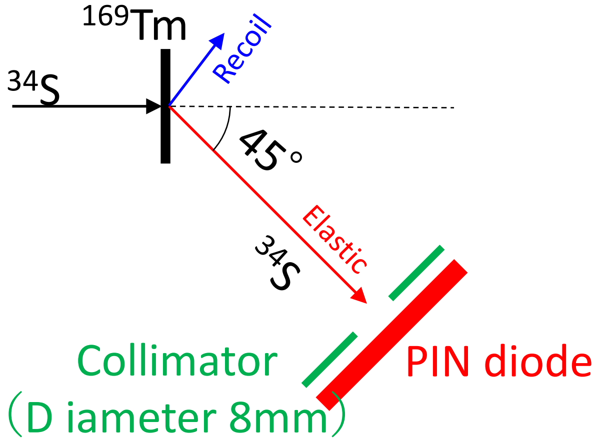
$^{199}$At has a 90% probability of emitting an alpha ray of 6.643 MeV.
Count the number from the spectrum measured by the detector.

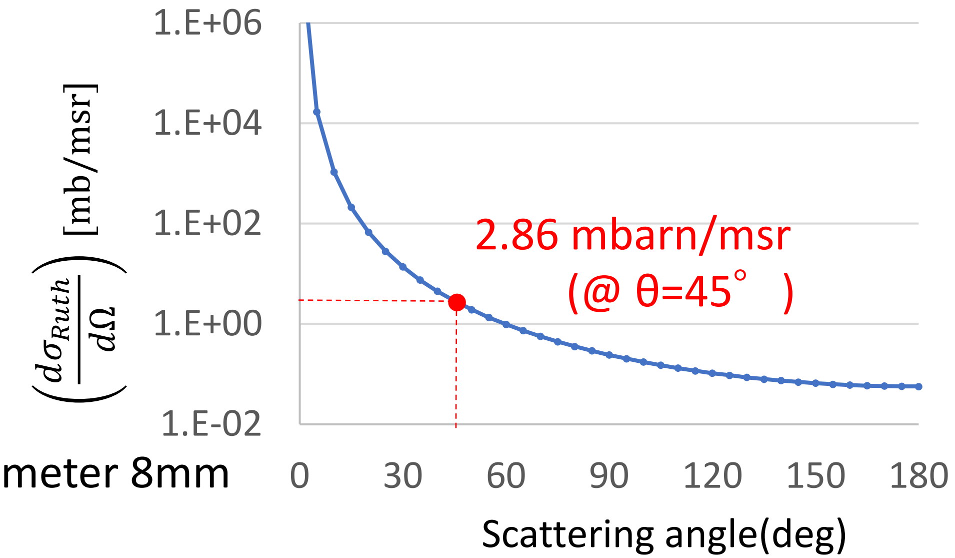
$$\boxed{N(6.643\text{MeV}) = N\left(^{199}_{85}\text{At}\right) \times 0.18 \times 0.90}$$

Probability of reaching the detector → 0.18

Probability of emitting an alpha ray of 6.643 MeV → 0.90

# Count (number of incident beams $N_B$) × (number of targets $N_T$) $\sigma = \dfrac{N\left({}^{199}_{85}\mathrm{At}\right)}{N_B \cdot N_T}$





Distance 120mm、 Diameter 8mm

→ ΔΩ=3.49 msr

$$N_{ela} = \left(\frac{d\sigma_{Ruth}}{d\Omega}\right) \cdot \Delta\Omega \cdot N_B \cdot N_T$$

$$\frac{1}{N_B \cdot N_T} = \left(\frac{d\sigma_{Ruth}}{d\Omega}\right)\frac{\Delta\Omega}{N_{ela}} = \frac{9.98}{N_{ela}} \ [\mathrm{mbarn}]$$

Variables $N_B$ and $N_T$ can be erased.
You don't need to know directly how much of the beam you hit!
No need to know the variation of $N_T$ due to irradiation!
Furthermore, these errors are not reflected in the results!

$$\boxed{\sigma = \frac{N\left({}^{199}_{85}\mathrm{At}\right)}{N_B \cdot N_T} = \left(\frac{d\sigma_{Ruth}}{d\Omega}\right)\frac{\Delta\Omega \cdot N\left({}^{199}_{85}\mathrm{At}\right)}{N_{ela}} = \frac{9.98}{0.18 \times 0.90}\frac{N(6.643\mathrm{MeV})}{N_{ela}} \ [\mathrm{mbarn}]}$$

(*) Peak at 6.643 MeV measured with Si detector , cross sections can be derived by simply counting the number of elastic scattering peaks measured with a PIN diode.