Measurement of the spallation neutron spectrum by unfolding at 180° from 3-GeV protons and ^{nat}Hg with the ^{209}Bi(n,xn) reactions

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Abstract: A neutron energy spectrum is important for shiedling design at an ADS facility (1.5-GeV p + LBE). A similar spectrum can be obtained at J-PARC (3-GeV proton + ^{nat}Hg). To check the validity of the unfolding, the unfolding with the ^{209}Bi(n,xn) reactions and the response functions (JENDL/HE-2007 and TALYS) was applied. In our poster, we present the derivation of the spectrum and comparison with TOF.

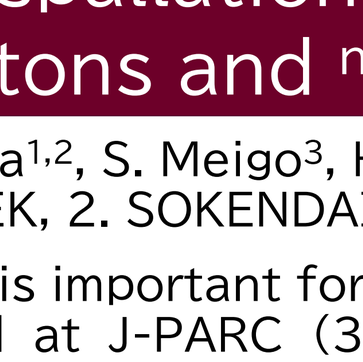
Introduction

・Source term estimation
Unfolding of activation Reaction Rate (RR)
e.g., Isotope Production Facility (Los Alamos), ISIS

・Accelerator-Driven System(ADS)
High-intensity proton beam
Continuous Wave (CW)
Beam duct streaming
Source term confirmation
(1.5 GeV p + LBE)

1) H. Iwamoto *et al.*, JAEA-Research 2021-012 (2022).

LBE: Lead-Bisumuth Eutectic



PHITS system[1)]

・J-PARC MLF
3 GeV p + ^{nat}Hg: Similar $\phi_n(E)$ of p + LBE

・Unfolding(Applicable to CW)
Derivation of $\phi_n(E)$ from RRs and $\sigma(E)$
^{209}Bi(n,xn) reactions

$\phi_n(E)$: Energy spectrum
$\sigma(E)$: Cross sections

Validation of unfolding is essential.

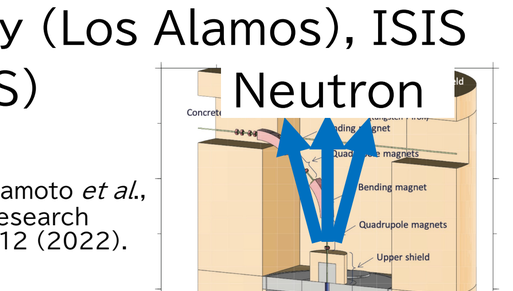
Purpose of this study
1. Derivation of $\phi_n(E)$ with unfolding
2. Comparison among unfolding, TOF, and calculation

Experiment

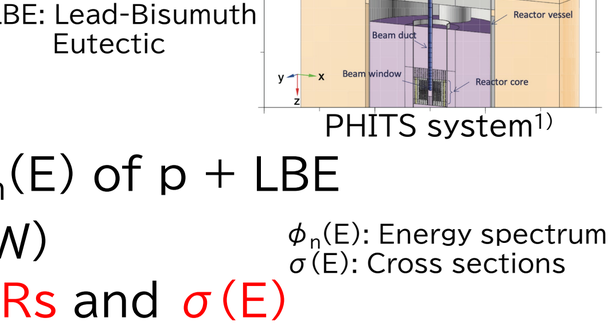
・Proton beam
3-GeV p + ^{nat}Hg
Irradiation Period: 6/16 - 6/22
(operation rate: 97.4%)
N_p: 1.76 x 10^{15} protons/s
(Beam power: 869.4 kW)

・Activation detector (^{209}Bi)
Mass: 13.7 g
Size: □26 mm x 2 mm-t

・γ-ray measurement
HPGe detector



Setup of the target



γ-ray spectrum

Properties of the ^{209}Bi(n,xn) reactions (x=4,5,6,7)

	$T_{1/2}$	E_γ [keV]	E_{th} [MeV]
^{209}Bi(n,4n)^{206}Bi	6.24 d	803.1	22.5
^{209}Bi(n,5n)^{205}Bi	14.91 d	703.45	29.6
^{209}Bi(n,6n)^{204}Bi	11.22 h	899.15	38.1
^{209}Bi(n,7n)^{203}Bi	11.76 h	820.2	45.4

RR with nuclear data library

・Cross section
JENDL/HE-2007[2)]
< TALYS[3)] (about 20%)

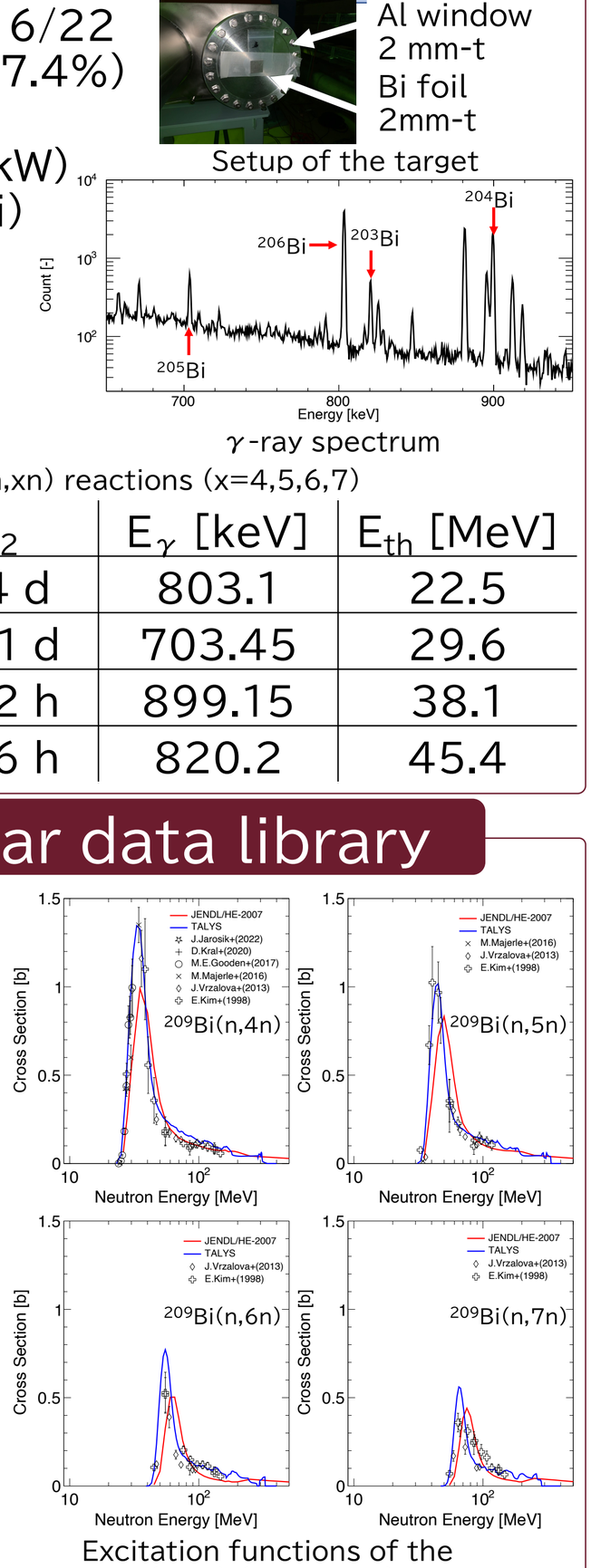
・(n,4n), (n,5n) reactions
Reproducibility
Peak: TALYS
100 MeV: JENDL/HE

・Reaction rate (RR)

$$RR = \int dE\phi(E)\sigma(E)$$

$\phi(E)$: neutron energy spectrum obtained by the TOF
$\sigma(E)$: cross section

2) Y. Watanabe *et al.*, J. Korean Phys. Soc. 59, 1040-1045, (2011)
3) A.J. Koning *et al.*, Proc. ND-2007, 22-27 (2007).



Excitation functions of the ^{209}Bi(n,xn) (x=4,5,6,7) reactions.

Results

・Comparison of RRs

Reaction rates (RRs)

	This work [/nucleus/proton]	C/E for JENDL/HE	C/E for TALYS
(n,4n)	(1.64 ± 0.05)x10^{-34}	0.880 ± 0.036	1.10 ± 0.04
(n,5n)	(1.07 ± 0.03)x10^{-34}	1.03 ± 0.04	1.11 ± 0.04
(n,6n)	(7.46 ± 0.93)x10^{-35}	0.674 ± 0.087	0.992 ± 0.127
(n,7n)	(4.67 ± 0.25)x10^{-35}	0.849 ± 0.054	0.975 ± 0.061

・C/E values
C/E (JENDL/HE) < C/E (TALYS)
$\because \sigma_{JENDL} < \sigma_{TALYS}$ at the peak region
C/E (JENDL/HE) < 1
$\because \sigma_{JENDL} < \sigma_{Exp.}$ at the peak region

・Reproducibility

X_i: C/E for each reaction

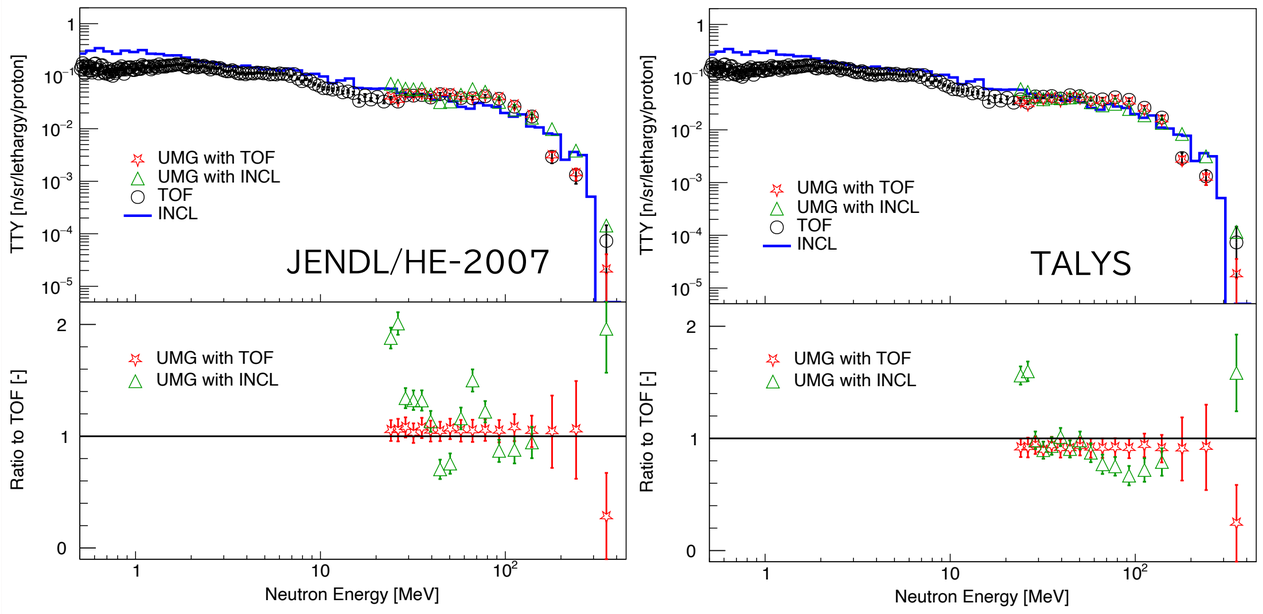
$$\delta_{C/E} = \sqrt{\sum_{i=1}^{4}(X_i - 1)^2/4}$$

$\delta_{C/E}$ values

	$\delta_{C/E}$
JENDL/HE	0.19
TALYS	0.075

・Unfolding with UMG[4)]
Initial guess (IG): TOF or INCL
Response function (RF): JENDL/HE or TALYS

4) M. Reginatto, (2003)



Comparison among the results of UMG, TOF, and INCL (above). Ratios to TOF are also shown (below).

・IG: TOF
UMG(RF: TALYS) < UMG(RF: JENDL/HE)
$\because \sigma_{JENDL} < \sigma_{TALYS}$
UMG equals to be TOF within uncertainty.

・IG: INCL
Worse reproducibility than UMG(IG: TOF)
UMG with INCL agreed with TOF results about 40%.

Conclusion

・Measurement and comparison of RRs
RRs of the ^{209}Bi(n,xn) reactions (x=4,5,6,7) were compared with the RRs by TOF data and cross sections of TALYS and JENDL/HE. Reproducibility of TALYS ($\delta_{C/E}$ = 0.075) was better than that of JENDL/HE ($\delta_{C/E}$ = 0.19).

・Unfolding with UMG code
When TOF data was used as IG, UMG reproduced the TOF data within uncertainty. When INCL was used as IG, discrepancy about 40% between UMG(RF: TALYS) and TOF was seen. Following the large/small relation of σ_{JENDL} and $\sigma_{Exp.}$, ratios of UMG(RF: JENDL/HE) to TOF were fluctuated.