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Graduate School of Biomedical Science and Engineering

Activation cross section measurements for ^{7}Li-induced monitor reactions

December 4, 2024

AIKAWA Masayuki

Faculty of Science/
Graduate School of Biomedical Science and Engineering,
Hokkaido University

Introduction

- Many radionuclides are used for diagnosis and therapy.
  - Diagnosis
    - positron emitters for PET
    - gamma emitters for SPECT
  - Therapy
    - beta, alpha, and Auger electron emitters

Chemical Reviews Review

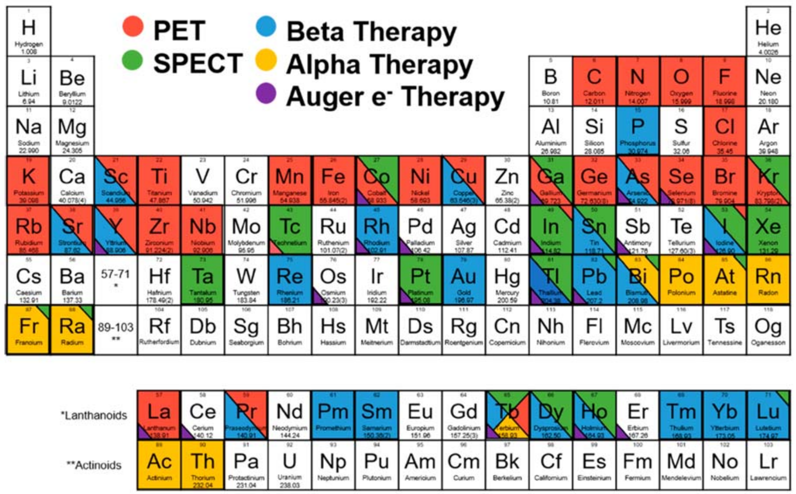


Figure 1. Color-coded periodic table with current or potential applications of each element in diagnostic and/or therapeutic radiopharmaceuticals.[2−14] Periodic table reproduced by permission of International Union of Pure and Applied Chemistry. Copyright © 2018 International Union of Pure and Applied Chemistry.

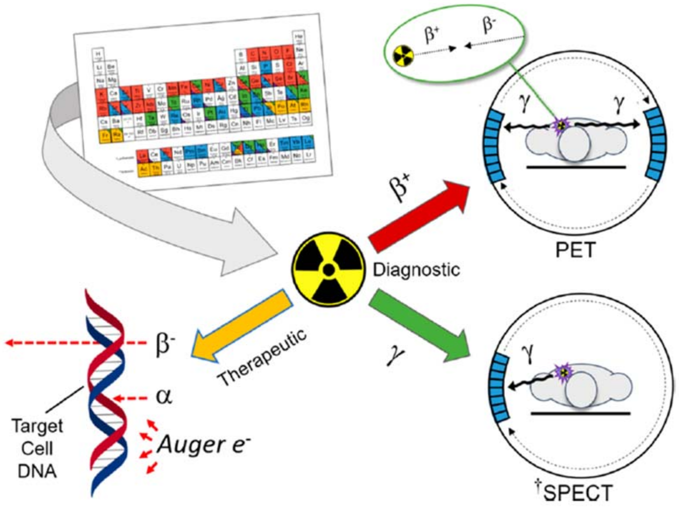
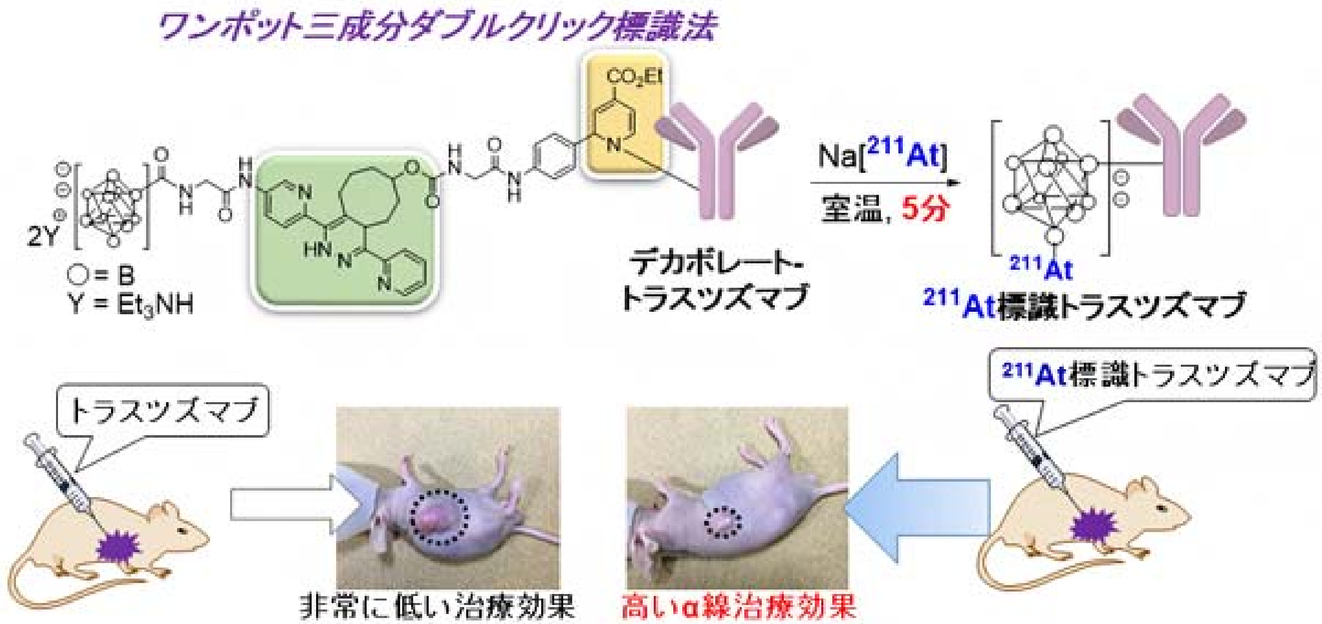


Figure 3. Radiometal decay types and their corresponding applications in nuclear medicine. †Indicates that degree of rotation, number of detectors, and orbital path may vary depending on instrument.

T.I. Kostelnik et al., Chem. Rev. 119 (2019) 902

Medical application of Astatine-211

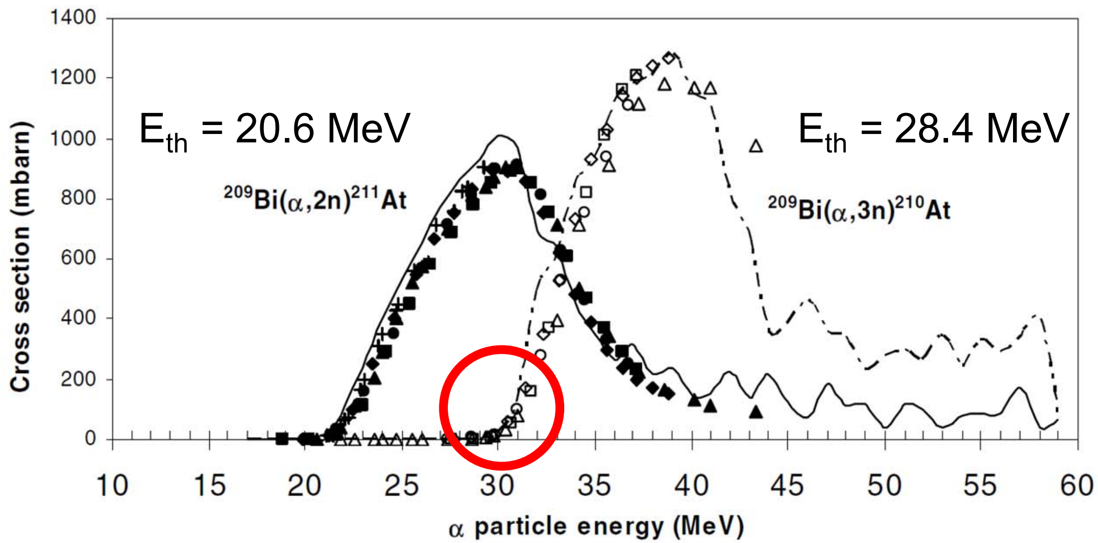
- Astatine-211 ($T_{1/2}$ = 7.22 h) is an alpha emitter and attracts many researchers because of effectiveness in therapy.



アスタチン-211の実用的な標識法の開発, RIKEN
https://www.riken.jp/press/2019/20190118_3/index.html

Production of ^{211}At

- Cross sections for ^{211}At ($T_{1/2}$ = 7.22 h) production via the $^{209}Bi(\alpha,2n)^{211}At$ reaction were measured by several groups.
- The incident energy should be less than 29 MeV to avoid production of ^{210}At ($T_{1/2}$ = 8.1 h, $\varepsilon+\beta^+$: 99.825%, $\rightarrow ^{210}Po$ ($T_{1/2}$ = 138 d)).



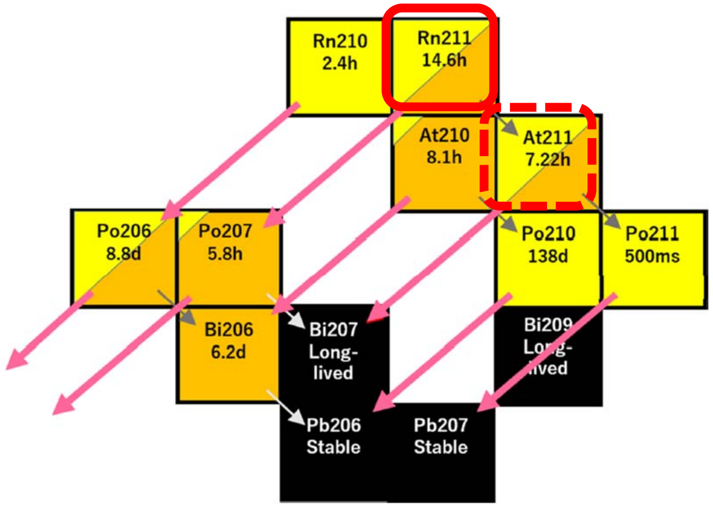
Alfarano et al., J. Phys.: Conf. Ser. 41 (2006) 115.

Production of ^{211}Rn via the ^{209}Bi+^{7}Li reaction

- Unfortunately, the half-life of ^{211}At ($T_{1/2}$ = 7.22 h) is too short to deliver.
- ^{211}Rn ($T_{1/2}$ = 14.6 h) is expected to be a generator.
- One possible production reaction, the ^{209}Bi(^{7}Li,5n)^{211}Rn reaction, was investigated.

922 Journal of Radioanalytical and Nuclear Chemistry (2020) 323:921–926

Fig. 1 Nuclear chart and decay processes relating to ^{211}Rn production



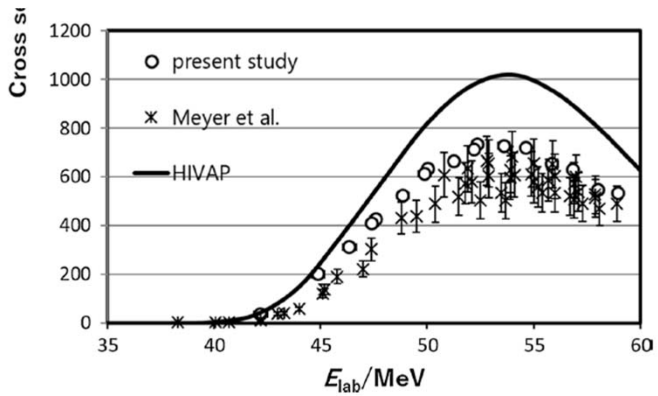
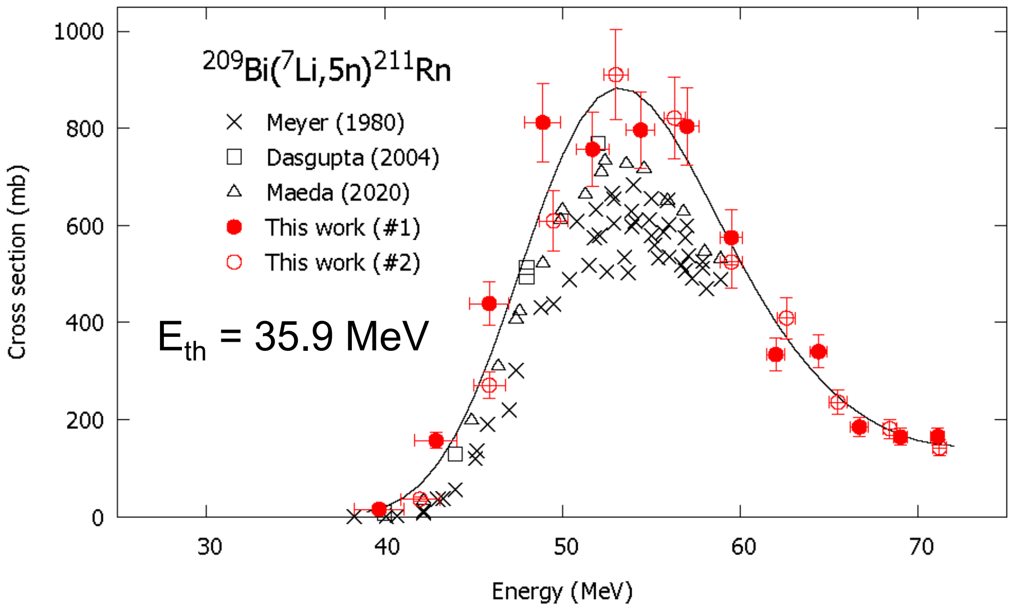


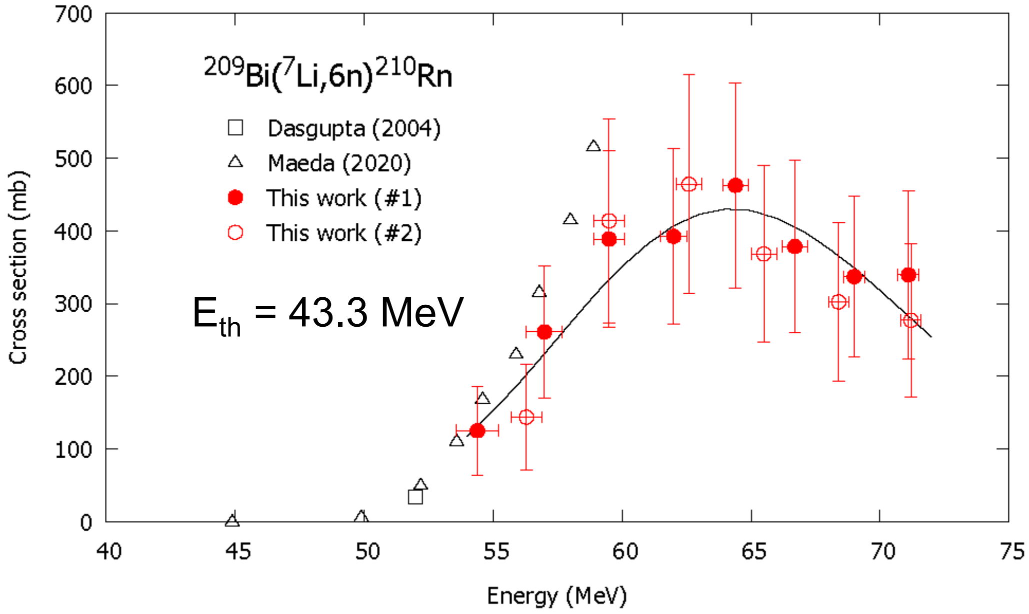
Fig. 3 Excitation function of the ^{209}Bi(^{7}Li, 5n)^{211}Rn reaction. Circle marks indicate results from the present study, whereas crosses are results from [6]. Data are compared with a solid line calculated with the use of the HIVAP code in logarithmic scale in the upper figure and in linear scale in the bottom figure

Maeda et al., J. Radioanal. Nucl. Chem. 323 (2020) 921.

Production cross sections of ^{211}Rn and ^{210}Rn

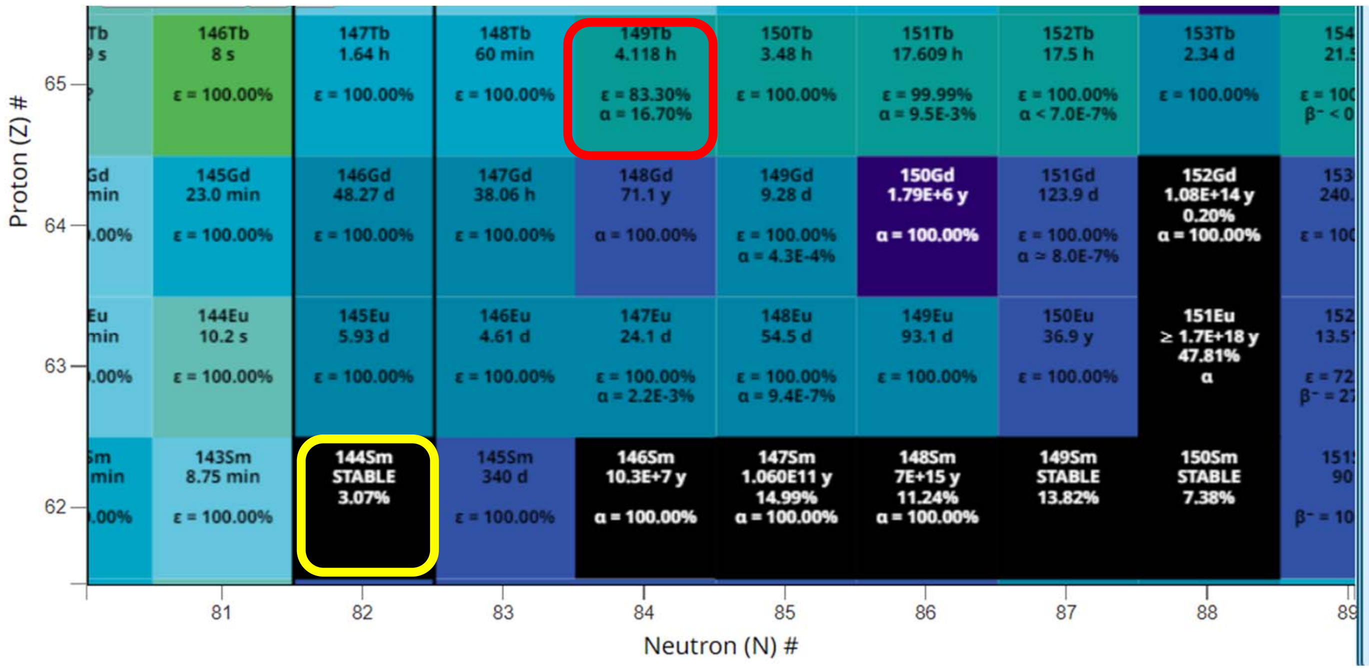
- Production cross sections of ^{211}Rn and ^{210}Rn were determined.
- The measured cross sections are slightly deviated from those of previous studies.





Another alpha emitter: ^{149}Tb ($T_{1/2}$ = 4.1 h, I_{α} = 16.7%)

- Is ^{144}Sm(^{7}Li,2n)^{149}Tb reaction available for production?



Ground and isomeric state information for $^{149}_{65}$Tb

E(level) (MeV)	Jπ	Mass Excess (keV)	$T_{1/2}$	Decay Modes
0.0	1/2+	-71489 *4*	4.118 h *25*	ε = 83.30% α = 16.70%
0.0358	11/2-	-71453 *4*	4.16 min *4*	ε = 99.98% α = 0.02%

NuDat 3.0, https://www.nndc.bnl.gov/nudat3/

Monitor reactions

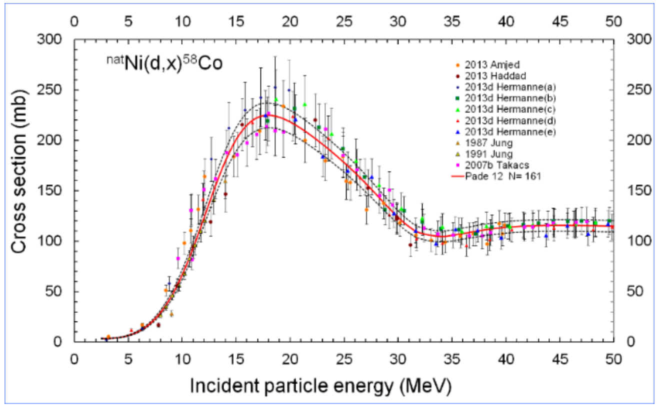
- Monitor reactions play an important role to determine projectile energy to produce required amounts of RI of interest under constraints to minimize impurities.

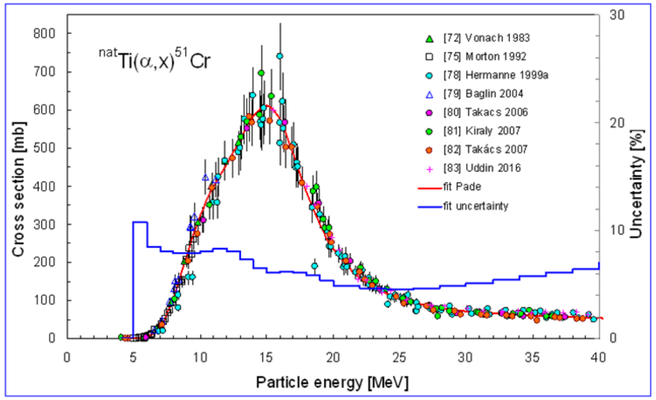
Monitor Reactions 2017

A. Hermanne et al., Nucl. Data Sheets 148 (2018) 338-382

Protons	Deuterons	^{3}He-particles	Alpha-particles
$^{27}Al(p,x)^{22}Na$	$^{27}Al(d,x)^{22}Na$	$^{27}Al(^{3}He,x)^{22}Na$	$^{27}Al(\alpha,x)^{22}Na$
$^{27}Al(p,x)^{24}Na$	$^{27}Al(d,x)^{24}Na$	$^{27}Al(^{3}He,x)^{24}Na$	$^{27}Al(\alpha,x)^{24}Na$
$^{nat}Ti(p,x)^{48}V$	$^{nat}Ti(d,x)^{48}V$	$^{nat}Ti(^{3}He,x)^{48}V$	$^{nat}Ti(\alpha,x)^{51}Cr$
$^{nat}Ti(p,x)^{46}Sc$	$^{nat}Ti(d,x)^{46}Sc$	$^{nat}Cu(^{3}He,x)^{66}Ga$	$^{nat}Cu(\alpha,x)^{66}Ga$
$^{nat}Ni(p,x)^{57}Ni$	$^{nat}Fe(d,x)^{56}Co$	$^{nat}Cu(^{3}He,x)^{63}Zn$	$^{nat}Cu(\alpha,x)^{67}Ga$
$^{nat}Cu(p,x)^{62}Zn$	$^{nat}Ni(d,x)^{61}Cu$	$^{nat}Cu(^{3}He,x)^{65}Zn$	$^{nat}Cu(\alpha,x)^{65}Zn$
$^{nat}Cu(p,x)^{63}Zn$	$^{nat}Ni(d,x)^{56}Co$		
$^{nat}Cu(p,x)^{65}Zn$	$^{nat}Ni(d,x)^{58}Co$		
$^{nat}Cu(p,x)^{56}Co$	$^{nat}Cu(d,x)^{62}Zn$		
$^{nat}Cu(p,x)^{58}Co$	$^{nat}Cu(d,x)^{63}Zn$		
$^{nat}Mo(p,x)^{96m+g}Tc$	$^{nat}Cu(d,x)^{65}Zn$		

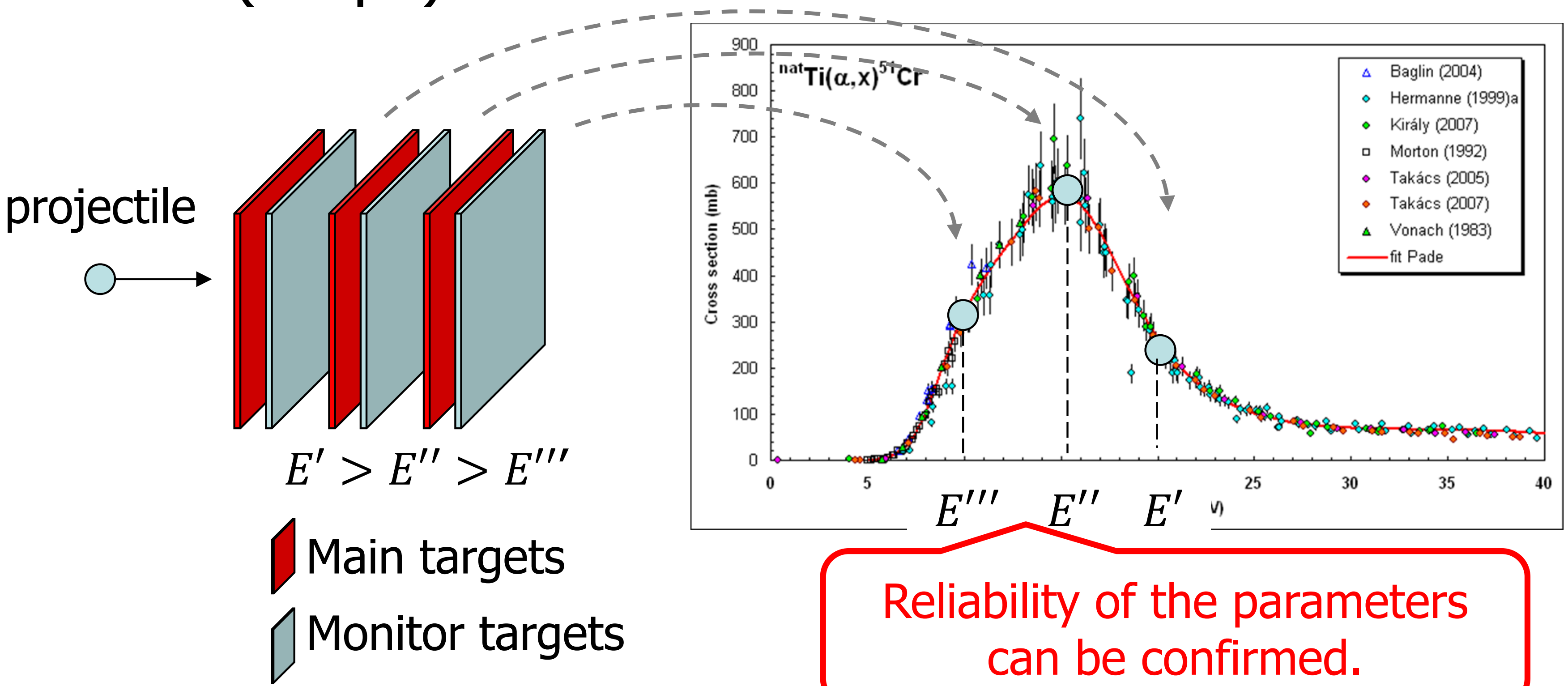
Monitor Reactions 2017,
https://www-nds.iaea.org/medical/monitor_reactions.html





Monitor reactions

- Cross section values recommended by IAEA are used to assess experimental parameters, such as beam intensity (amplitude), projectile energy (peak position) and target thicknesses (shape).



Reliability of the parameters can be confirmed.

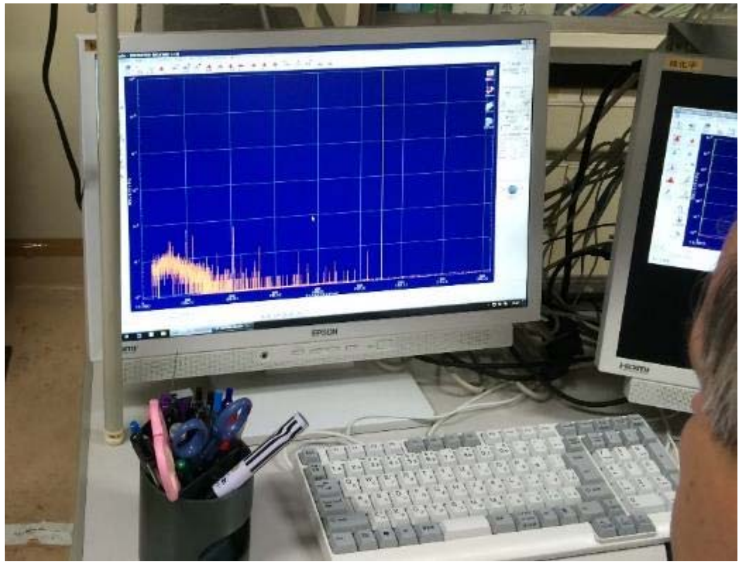
Purpose

- There are no monitor reactions for lithium-induced reactions.
- We performed cross section measurements of ^{7}Li-induced reactions on ^{nat}Cu and ^{nat}Ti.

Monitor reactions published by IAEA		
Proton	Deuteron	Alpha
$^{27}Al(p,x)^{22,24}Na$ $^{nat}Ti(p,x)^{48}V,^{46}Sc$ $^{nat}Ni(p,x)^{57}Ni$ $^{nat}Cu(p,x)^{62,63,65}Zn,^{56,58}Co$ $^{nat}Mo(p,x)^{96m+g}Tc$	$^{27}Al(d,x)^{22,24}Na$ $^{nat}Ti(d,x)^{48}V,^{46}Sc$ $^{nat}Fe(d,x)^{56}Co$ $^{nat}Ni(d,x)^{61}Cu,^{56,58}Co$ $^{nat}Cu(d,x)^{62,63,65}Zn$	$^{27}Al(\alpha,x)^{22,24}Na$ $^{nat}Ti(\alpha,x)^{51}Cr$ $^{nat}Cu(\alpha,x)^{66,67}Ga,^{65}Zn$

Method

- We performed cross section measurements using the following well-established methods at RIKEN.
  - Stacked-foil activation technique
  - γ-ray spectrometry



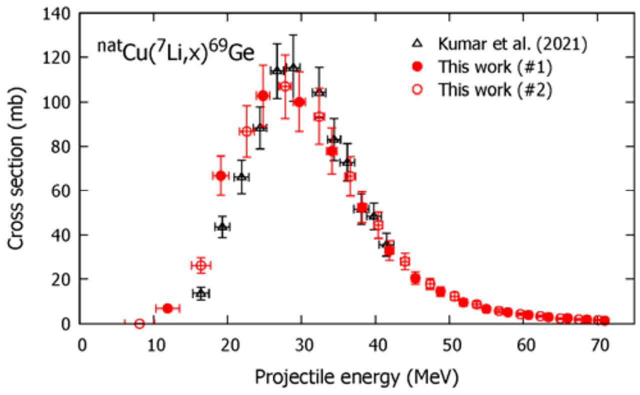

Experiments of Cu targets

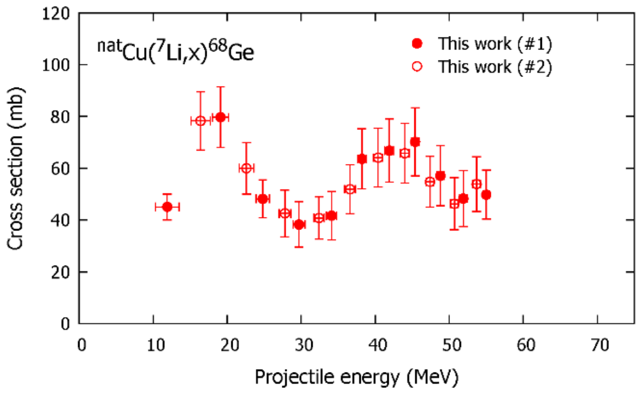
- Experiments were conducted at the RIKEN AVF cyclotron
- Three stacked targets were irradiated with 71.6-MeV ^{7}Li beams.

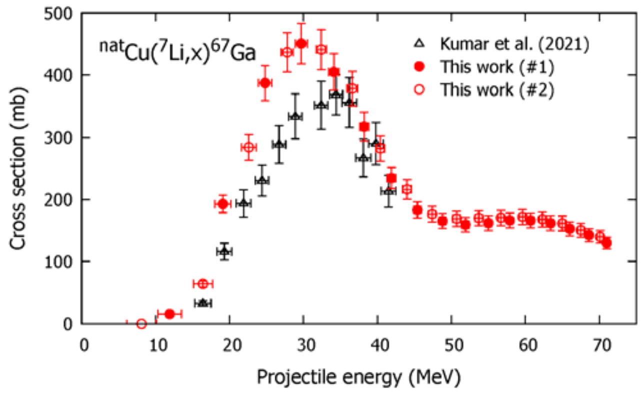
	#1 (σ)	#2 (σ)	#3 (TTY)
Energy	71.6 ± 0.4 MeV		
Intensity	314 ± 16 nA	321 ± 16 nA	309 ± 15 nA
Period	3600 s	3600 s	1800 s
Target	17 sets of Cu-Al-Ti-Al foils	17 sets of Ti-Al-Cu-Al foils	8 Cu foils
^{nat}Cu	4.49 ± 0.04 mg/cm^2		21.5 ± 0.2 mg/cm^2
^{nat}Ti	2.34 ± 0.02 mg/cm^2		
^{27}Al	1.21 ± 0.01 mg/cm^2		

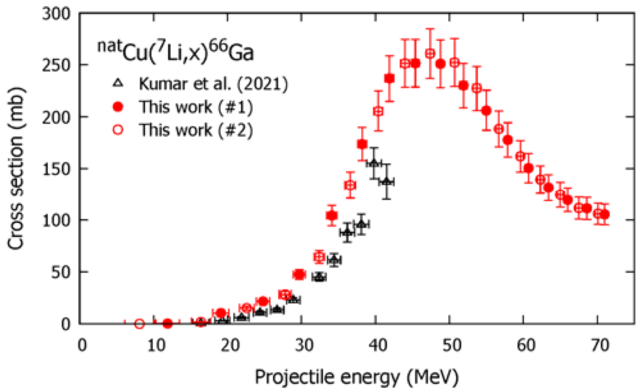
Activation cross sections

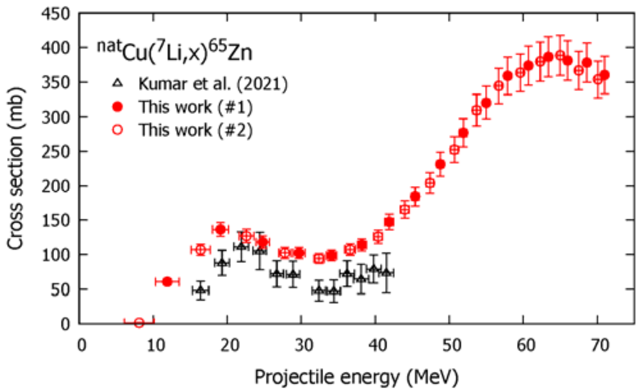
- Cross sections to form $^{69,68}Ge$, $^{67,66}Ga$, and $^{69m,65}Zn$ derived from the two experiments are consistent.

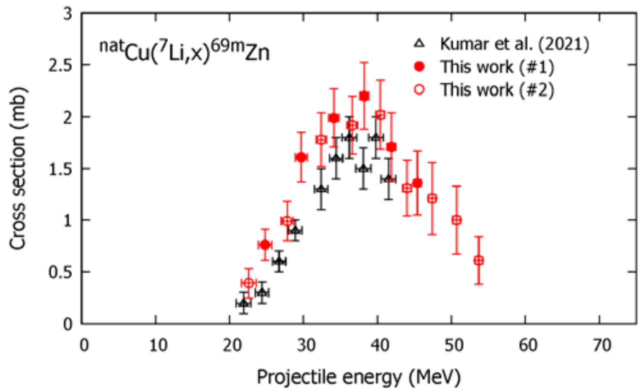






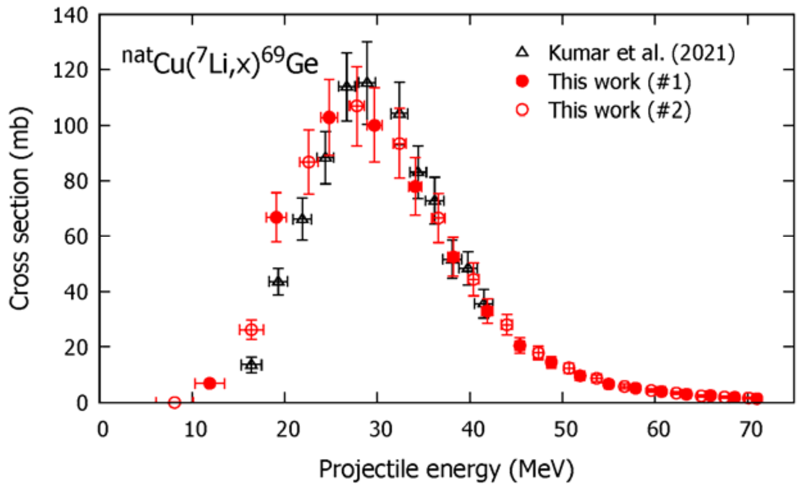


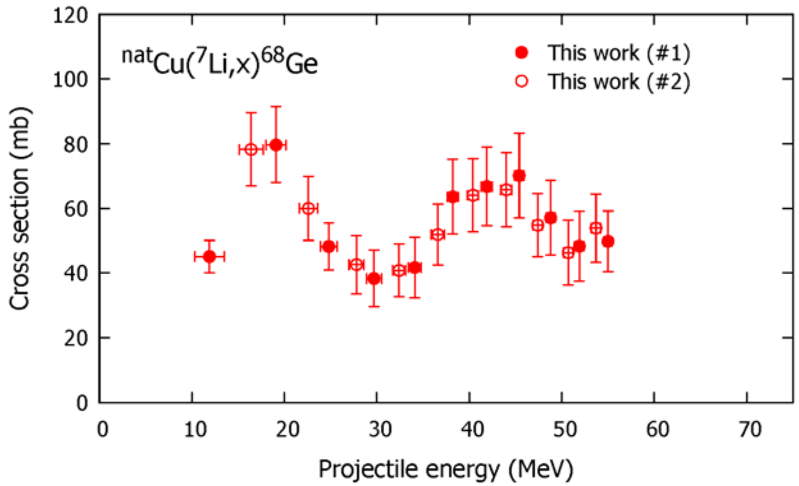


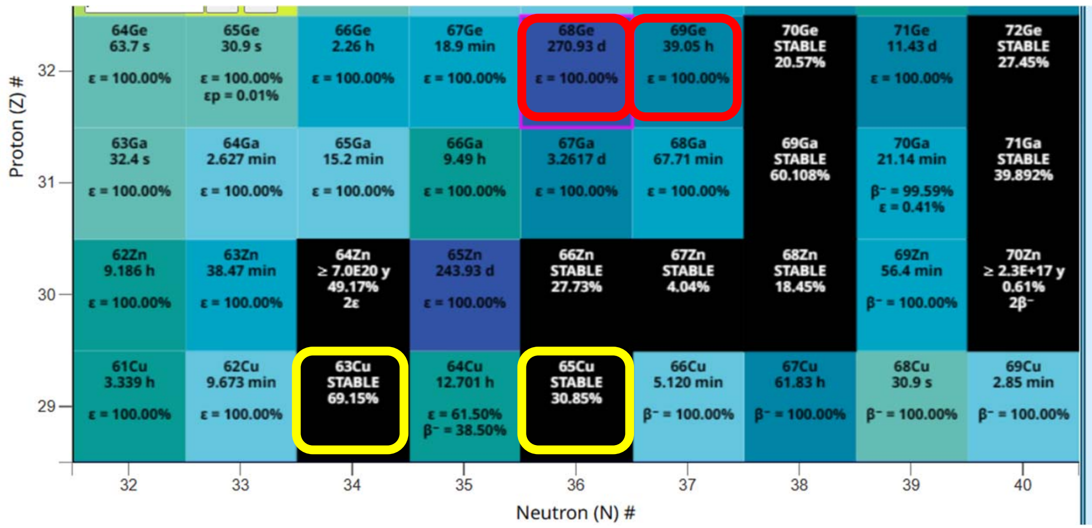


Result: Ge radioisotopes

- Production cross sections of ^{69,68}Ga were derived.







Problems

^{69}Ge: Large I_γ uncertainty (36(4)%)

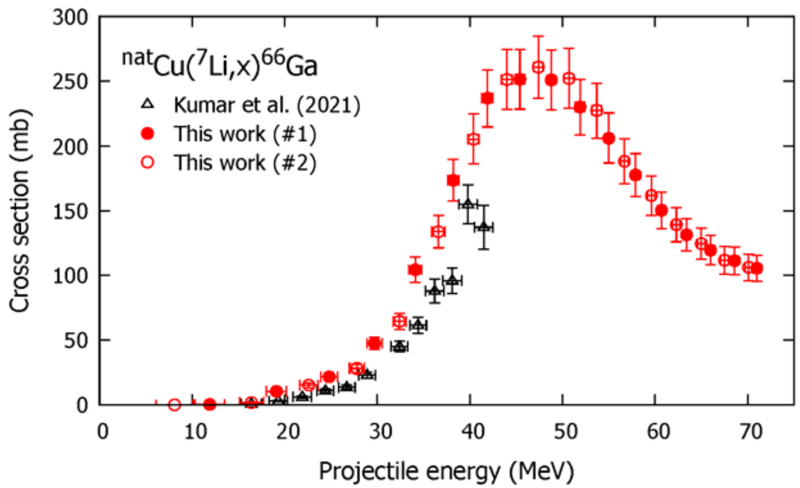
^{68}Ge: Low statistics

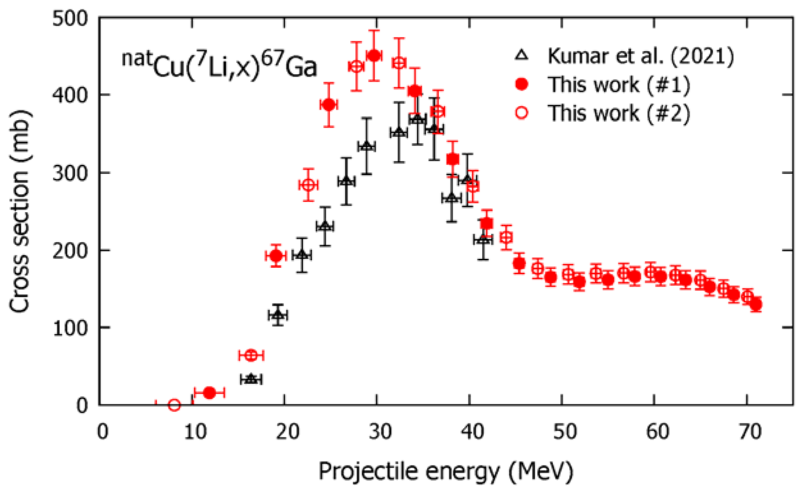
($T_{1/2}$ = 271 d, I_γ = 3.22(3)%)

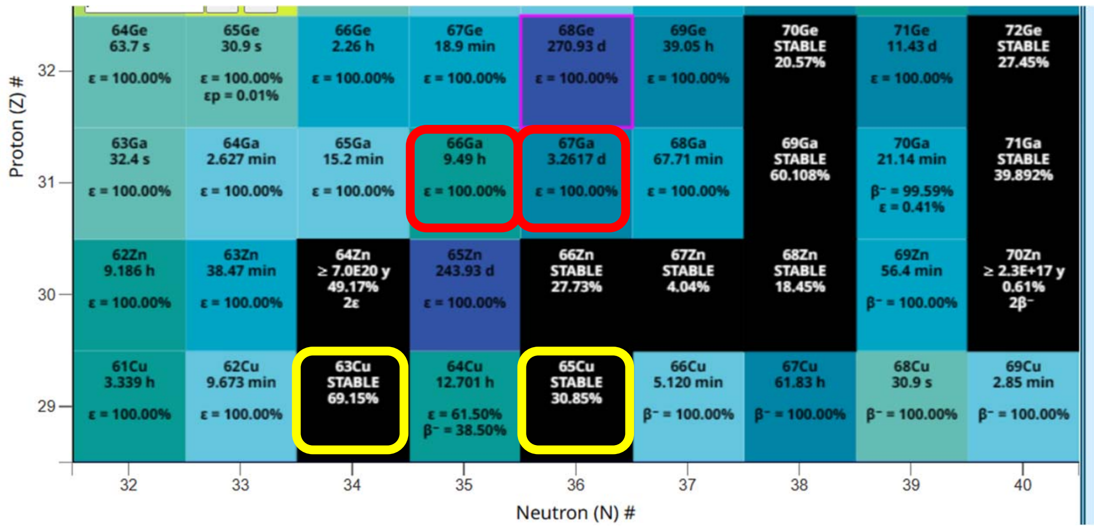
NuDat 3.0

Result: Ga radioisotopes

- Production cross sections of ^{67,66}Ga were derived.



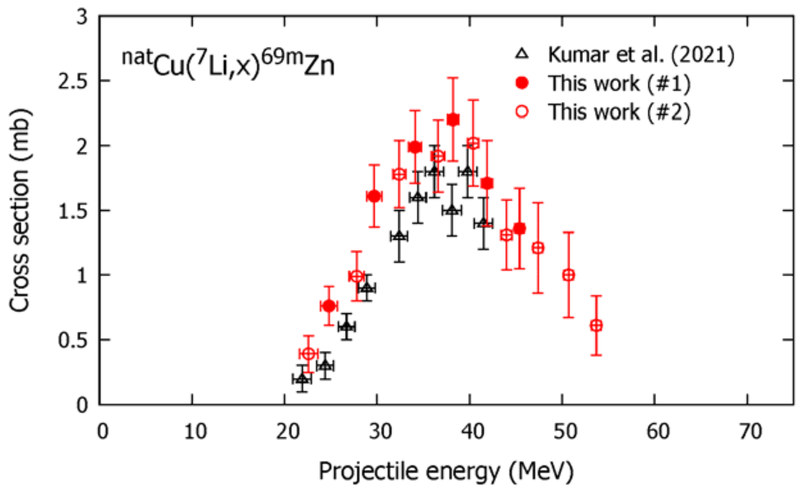


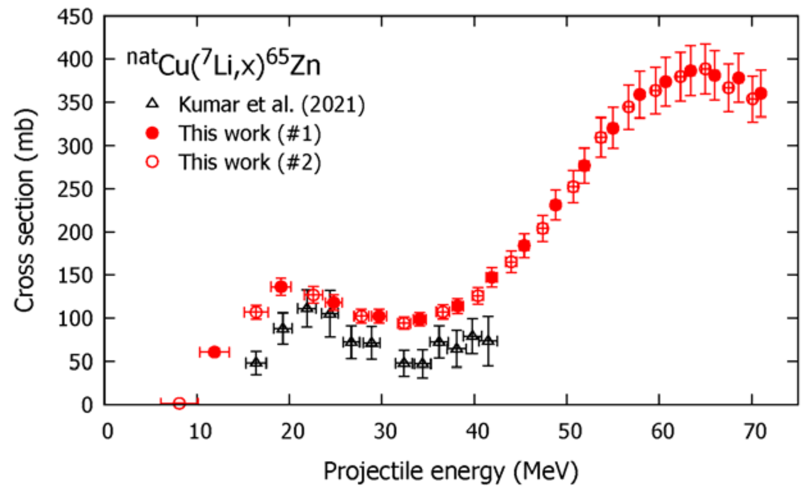


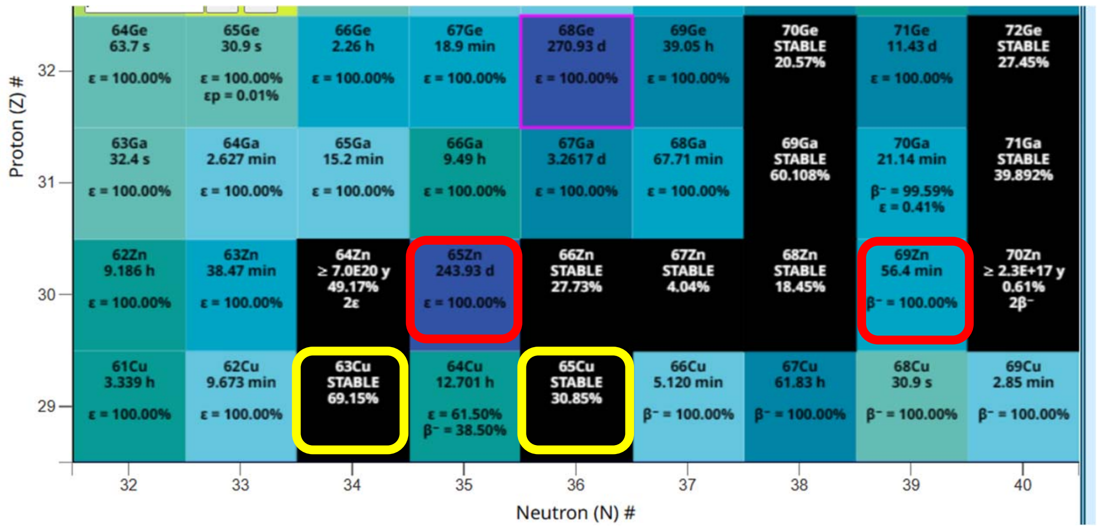
NuDat 3.0

Result: Zn radioisotopes

- Production cross sections of $^{69m,65}Zn$ were derived.







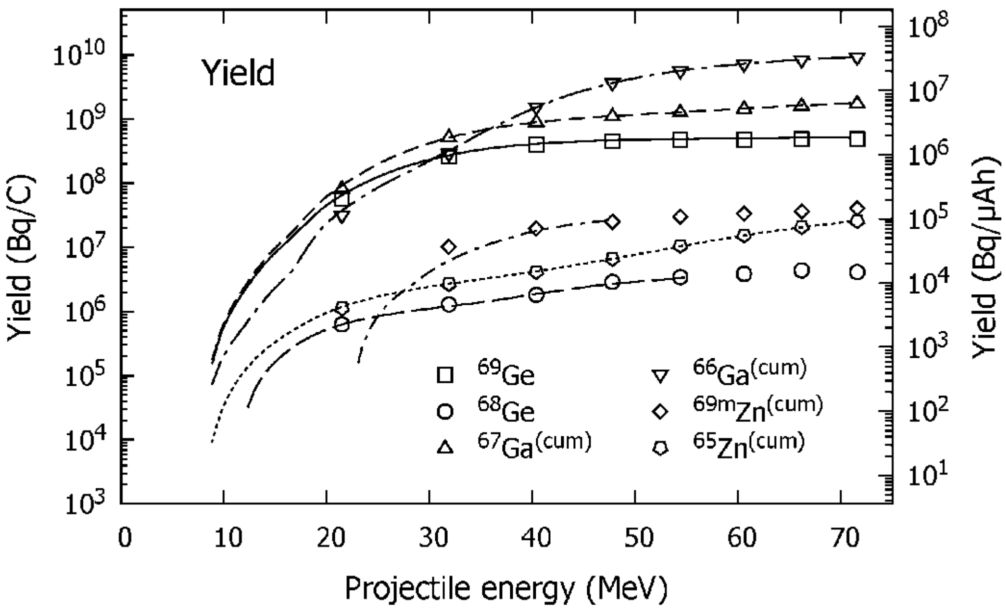
Problems

^{69m}Zn: Low σ

NuDat 3.0

Comparison of thick target yields

- Experimental physical thick target yields of $^{69,68}Ge$, $^{67,66}Ga$ and $^{69m,65}Zn$ were determined and compared with the calculated ones using the measured cross sections.
- The consistencies could be found.



$$Y^{\mathrm{exp}} = \frac{\lambda}{Ze} \frac{N_{E_\gamma} \lambda}{\varepsilon_{E_\gamma} I_{E_\gamma} \varepsilon_t n_b (1 - e^{-\lambda t_b}) e^{-\lambda t_c} (1 - e^{-\lambda t_m})} \quad (2)$$

$$Y^{\mathrm{calc}} = \frac{\lambda}{Ze} \int_0^{E_{\mathrm{in}}} \frac{\sigma(E)}{S(E)} dE \quad (3)$$

where Z is the atomic number of the projectile, e is the elementary charge (C), E_{in} is the incident energy of the projectile (MeV), $S(E)$ is the stopping power per areal number density of the target (MeV cm^2).

Possible monitor reactions with Cu targets

- The three reactions, $^{nat}Cu(^{7}Li,x)^{66,67}Ga$, ^{65}Zn, may be appropriate for the monitor reactions.
- Another reaction, $^{nat}Cu(^{7}Li,x)^{69}Ge$, can be added.

Monitor reactions published by IAEA			Suggestion
Proton	Deuteron	Alpha	^{7}Li
$^{27}Al(p,x)^{22,24}Na$ $^{nat}Ti(p,x)^{48}V,^{46}Sc$ $^{nat}Ni(p,x)^{57}Ni$ $^{nat}Cu(p,x)^{62,63,}$**^{65}Zn**$,^{56,58}Co$ $^{nat}Mo(p,x)^{96m+g}Tc$	$^{27}Al(d,x)^{22,24}Na$ $^{nat}Ti(d,x)^{48}V,^{46}Sc$ $^{nat}Fe(d,x)^{56}Co$ $^{nat}Ni(d,x)^{61}Cu,^{56,58}Co$ $^{nat}Cu(d,x)^{62,63,}$**^{65}Zn**	$^{27}Al(\alpha,x)^{22,24}Na$ $^{nat}Ti(\alpha,x)^{51}Cr$ $^{nat}Cu(\alpha,x)$**^{66,67}Ga,^{65}Zn**	$^{nat}Cu(^{7}Li,x)$**^{66,67}Ga,^{65}Zn**

Compilation to EXFOR E2785

Nuclear Instruments and Methods in Physics Research B 554 (2024) 165441

Contents lists available at ScienceDirect

ELSEVIER

Nuclear Inst. and Methods in Physics Research, B

journal homepage: www.elsevier.com/locate/nimb

BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Full Length Article

Activation cross sections of ^{7}Li-induced reactions on ^{nat}Cu for monitor reactions

Masayuki Aikawa [a,b,c,*], Saki Goto [c], Damdinsuren Gantumur [c], Dagvadorj Ichinkhorloo [d], Naoyuki Ukon [e], Naohiko Otuka [f], Sándor Takács [g], Hiromitsu Haba [h]

[a] Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan
[b] Global Center for Biomedical Science and Engineering, Faculty of Medicine, Hokkaido University, Sapporo 060-8648, Japan
[c] Graduate School of Biomedical Science and Engineering, Hokkaido University, Sapporo 060-8638, Japan
[d] Nuclear Research Center, National University of Mongolia, Ulaanbaatar 13330, Mongolia
[e] Advanced Clinical Research Center, Fukushima Medical University, Fukushima 960-1295, Japan
[f] Nuclear Data Section, International Atomic Energy Agency, A-1400 Wien, Austria
[g] HUN-REN Institute for Nuclear Research, ATOMKI, Debrecen 4026, Hungary
[h] Nishina Center for Accelerator-Based Science, RIKEN, Wako 351-0198, Japan

ARTICLE INFO

Keywords:
^{7}Li induced reaction on ^{nat}Cu
Monitor reaction
Production cross section of ^{69,68}Ge, ^{67,66}Ga, ^{69m,65}Zn
Excitation function

ABSTRACT

Activation cross sections of ^{7}Li-induced reactions on ^{nat}Cu were measured in order to investigate suitability of some reactions for monitoring experimental parameters. Cross sections producing ^{69,68}Ge, ^{67,66}Ga and ^{69m,65}Zn were determined. Physical thick target yields were experimentally measured and compared with those calculated using the measured cross sections. The measured cross sections were verified by the agreements between the directly measured thick target yields and the thick target yields deduced from the measured cross sections. The ^{7}Li-induced reactions on ^{nat}Cu for the production of ^{67,66}Ga and ^{65}Zn are suggested as monitor reactions.

1. Introduction

Charged-particle-induced reactions are used for radionuclide production for different applications, such as imaging and therapy in nuclear medicine. One attractive radionuclide for nuclear medicine is ^{211}At, which has a half-life of 7.214 h and is promising radionuclide for targeted α-particle therapy [1–3]. Its longer-lived parent nucleus ^{211}Rn ($T_{1/2}$ = 14.6 h) can be employed in the ^{211}Rn/^{211}At generator [4,5]. One potential production route of the ^{211}Rn radionuclide is through ^{6}Li- and ^{7}Li-induced reactions on a ^{209}Bi target. In order to maximize the production of ^{211}Rn under the constraint to minimize the unnecessary by-products, monitor reactions play an important role to determine and monitor the optimal beam parameters. As there are no established monitor reactions for both stable lithium isotopes, ^{6}Li and ^{7}Li, as projectiles, we started a systematic study to select target materials for possible monitor reactions.

Copper is a target material of monitor reactions for proton-, deuteron-, ^{3}He- and α-particle-induced reactions [6,7]. As a ^{7}Li beam is more frequently used than the beam of ^{6}Li we focused on ^{7}Li-induced reactions on ^{nat}Cu. In the literature survey based on the latest version of EXFOR library [8], only one experimental study was found below 100 MeV [9]. We performed experiments at the 72-MeV ^{7}Li energy to measure activation cross sections of the reactions in which longer-lived reaction products are formed. The reaction cross sections for formation of ^{69,68}Ge, ^{67,66}Ga, and ^{69m,65}Zn on ^{nat}Cu targets bombarded by ^{7}Li projectiles were determined. In order to verify the experimentally measured cross sections physical thick target yields were also determined experimentally and were compared with calculated ones based on the measured cross sections.

2. Experimental details and data analysis

We conducted three experiments; two experiments were dedicated for measurements of excitation functions and one for determination of thick target yields of selected reactions. Beams of ^{7}Li particles at 72 MeV were used for irradiation at the AVF cyclotron in RIKEN. The stacked-foil activation technique was applied. In order to identify the radioactive products γ-ray spectrometry was used in all experiments.

Three separate targets were prepared for the three experiments. Targets #1 and #2 served for excitation function measurements and

* Corresponding author at: Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan.
E-mail address: aikawa@sci.hokudai.ac.jp (M. Aikawa).

https://doi.org/10.1016/j.nimb.2024.165441
Received 12 March 2024; Received in revised form 4 June 2024; Accepted 12 June 2024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ENTRY            E2785   20240722                                 E278500000001
SUBENT        E2785001   20240722                                 E278500100001
BIB                 12         25                                 E278500100002
TITLE      Activation cross sections of 7Li-induced reactions on  E278500100003
           natCu for monitor reactions                            E278500100004
AUTHOR     (M.Aikawa, S.Goto, D.Gantumur, D.Ichinkhorloo, N.Ukon, E278500100005
            N.Otuka, S.Takacs, H.Haba)                            E278500100006
INSTITUTE  (2JPNHOK,3MGLNUM,2JPNFMU,3ZZZIAE,3HUNDEB,2JPNIPC)      E278500100007
REFERENCE  (J,NIM/B,554,165441,2024)                              E278500100008
INC-SOURCE Beam intensity: 314 and 321 nA for cross sections and  E278500100009
           309 nA for thick target yields                         E278500100010
SAMPLE     - Chemical-form of target is element.                  E278500100011
           - Physical-form of target is solid.                    E278500100012
           - Target-thickness: 4.49 mg/cm2 for cross sections and E278500100013
             21.5 mg/cm2 for thick target yields                  E278500100014
METHOD     (ACTIV) Irradiated for 60 min for cross sections and   E278500100015
                   30 min for thick target yields                 E278500100016
           (GSPEC)                                                E278500100017
FACILITY   (ISOCY,2JPNIPC)                                        E278500100018
DETECTOR   (HPGE)                                                 E278500100019
ERR-ANALYS (ERR-1) beam intensity                                 E278500100020
           (ERR-2,0.1,11.) gamma ray intensity (0.1-11%)          E278500100021
           (ERR-3) detector efficiency                            E278500100022
           (ERR-4) target thickness                               E278500100023
           (ERR-S,0.5,37.) counting statistics (0.5-37%)          E278500100024
FLAG       (1.) Result using stacked target no. 1                 E278500100025
           (2.) Result using stacked target no. 2                 E278500100026
HISTORY    (20240623C) MA                                         E278500100027
ENDBIB              25          0                                 E278500100028
COMMON               3          3                                 E278500100029
ERR-1      ERR-3      ERR-4                                       E278500100030
PER-CENT   PER-CENT   PER-CENT                                    E278500100031
 5.         5.         1.                                         E278500100032
ENDCOMMON            3          0                                 E278500100033
ENDSUBENT           32          0                                 E278500199999
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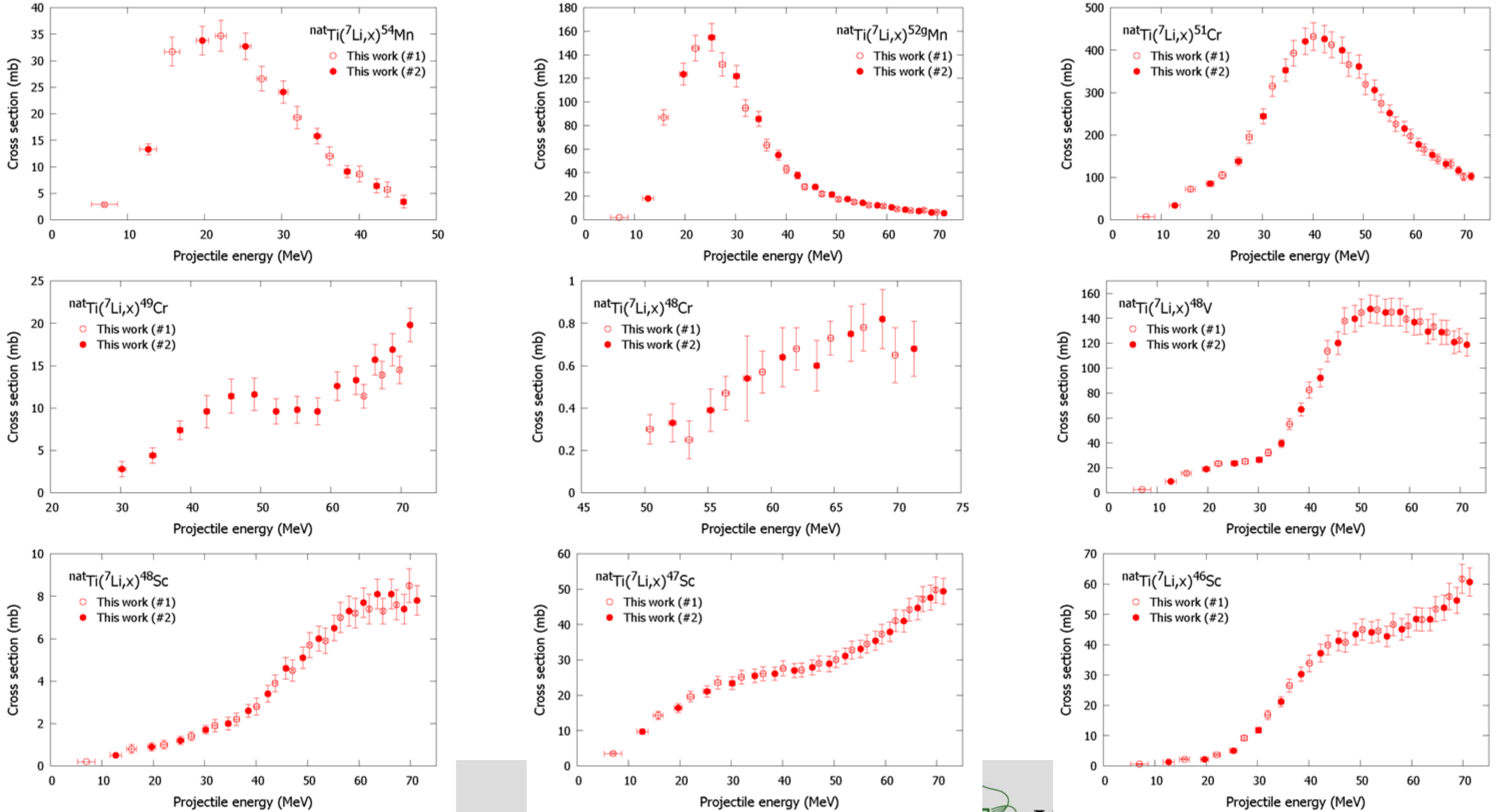
Experiments of Ti targets

- Experiments were conducted at the RIKEN AVF cyclotron
- Three stacked targets were irradiated with 71.6-MeV ^{7}Li beams.

	#1 (σ)	#2 (σ)	#3 (TTY)
Energy	71.6 ± 0.4 MeV		
Intensity	314 ± 16 nA	321 ± 16 nA	309 ± 15 nA
Period	3600 s	3600 s	1800 s
Target	17 sets of Cu-Al-Ti-Al foils	17 sets of Ti-Al-Cu-Al foils	7 Ti foils
^{nat}Ti	2.34 ± 0.02 mg/cm^{2}		22.7 ± 0.2 mg/cm^{2}
^{nat}Cu	4.49 ± 0.04 mg/cm^{2}		
^{27}Al	1.21 ± 0.01 mg/cm^{2}		

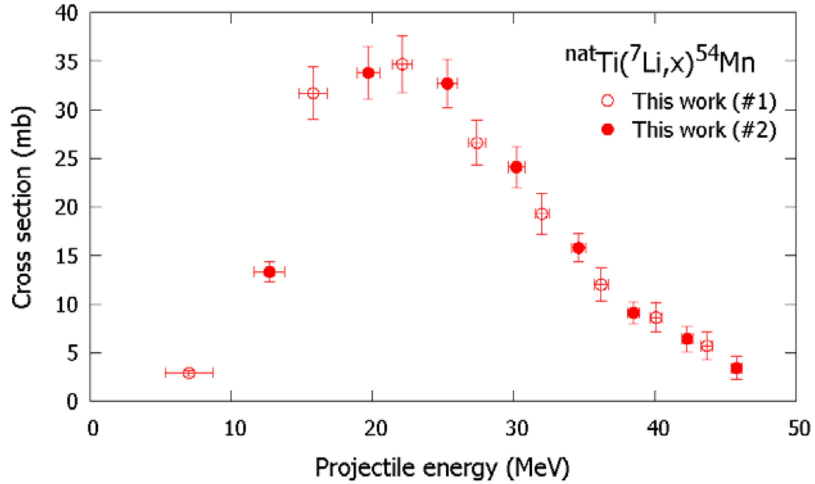
Activation cross sections

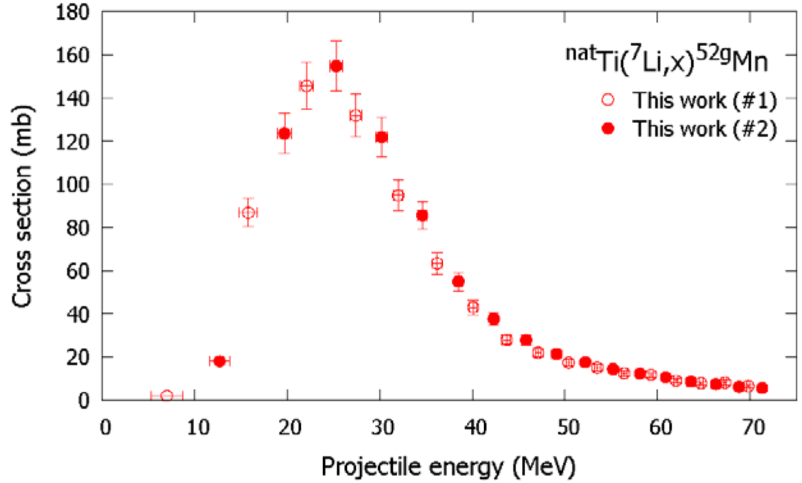
- Cross sections to form $^{54,52g}Mn$, $^{51,49,48}Cr$, ^{48}V, and $^{48,47,46}Sc$ derived from the two experiment are consistent.

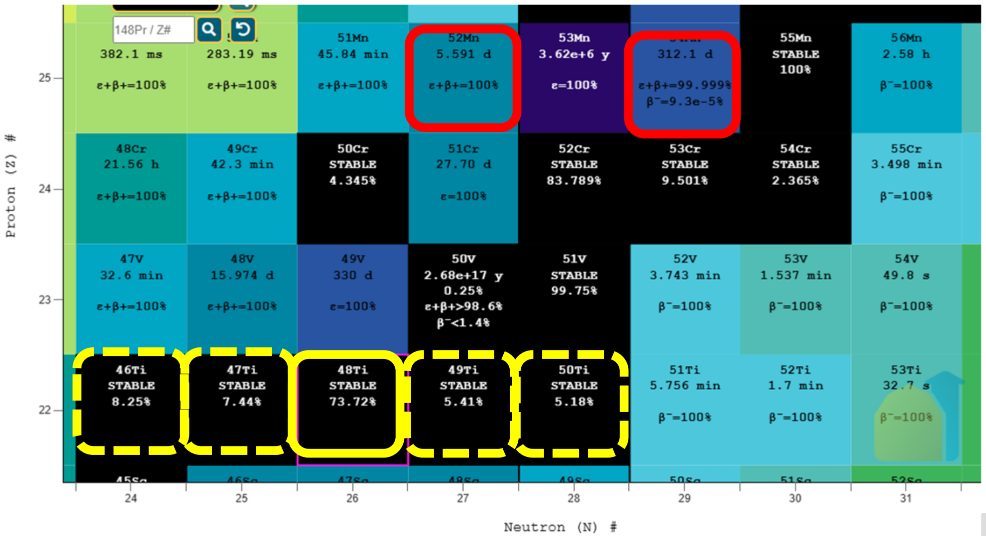


Result: Mn radioisotopes

- Production cross sections of $^{54,52g}Mn$ were derived.



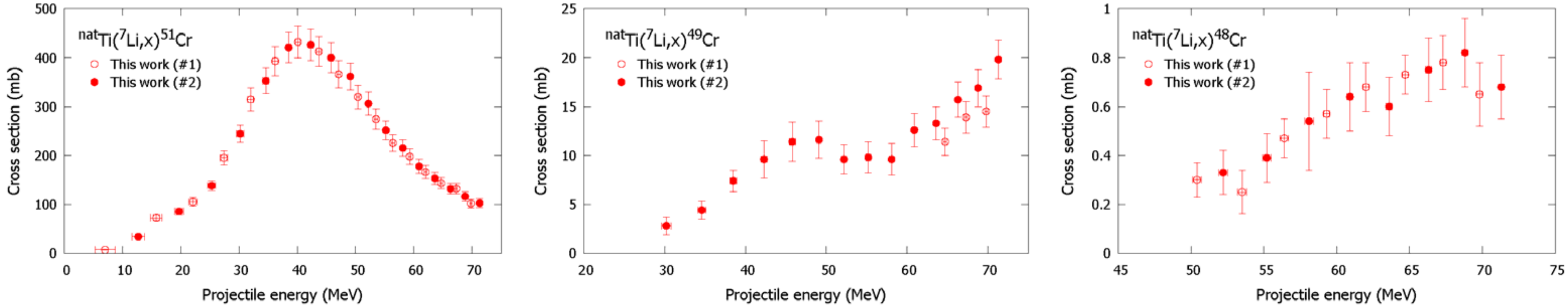


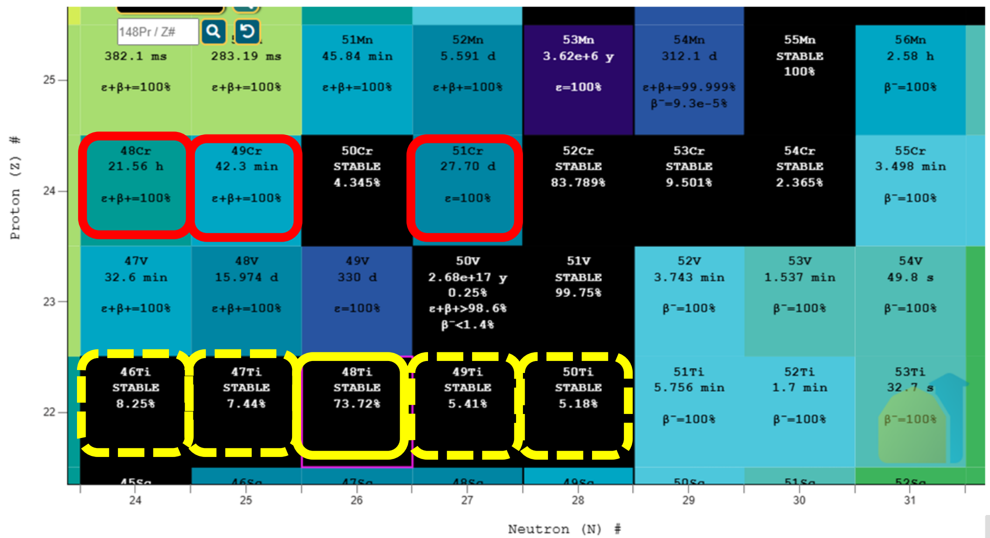


NuDat 3.0

Result: Cr radioisotopes

- Production cross sections of $^{51,49,48}Cr$ were derived.





Problems

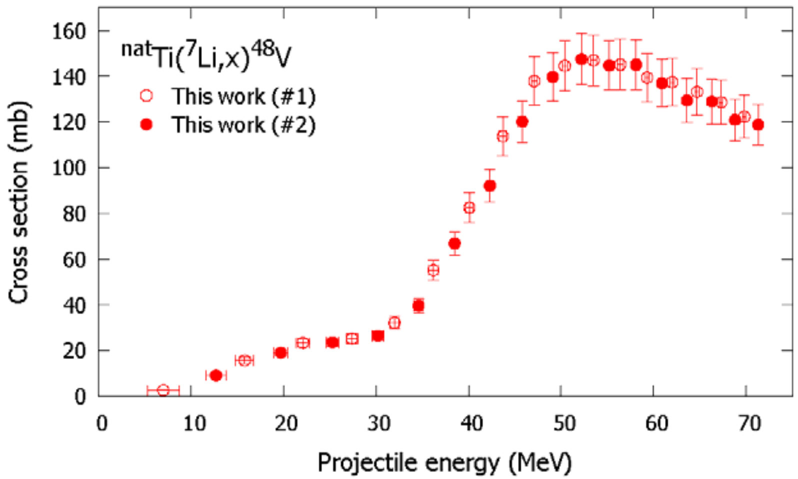
^{49}Cr: Low σ and short $T_{1/2}$ (42.3 min)

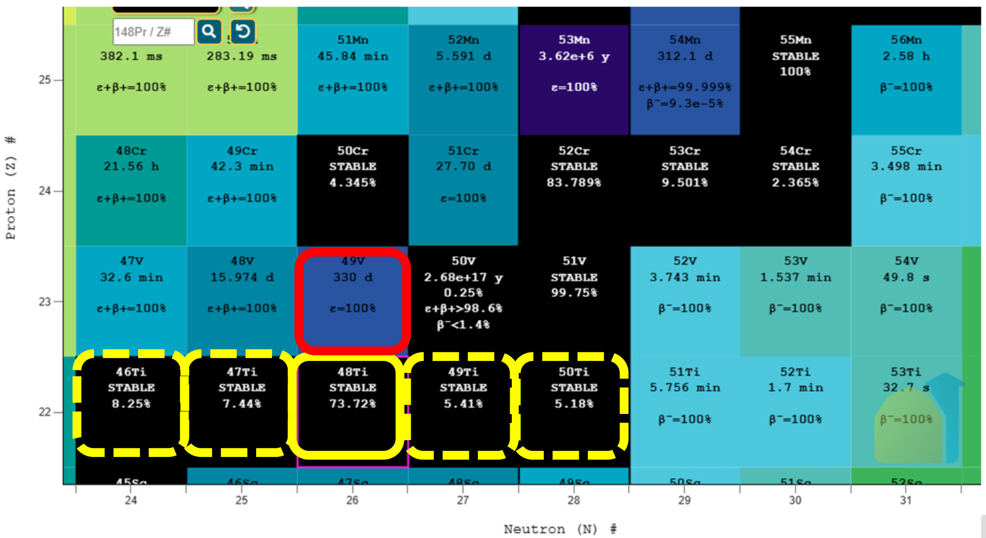
^{48}Cr: Low σ

NuDat 3.0

Result: V radioisotopes

- Production cross sections of ^{48}V were derived.





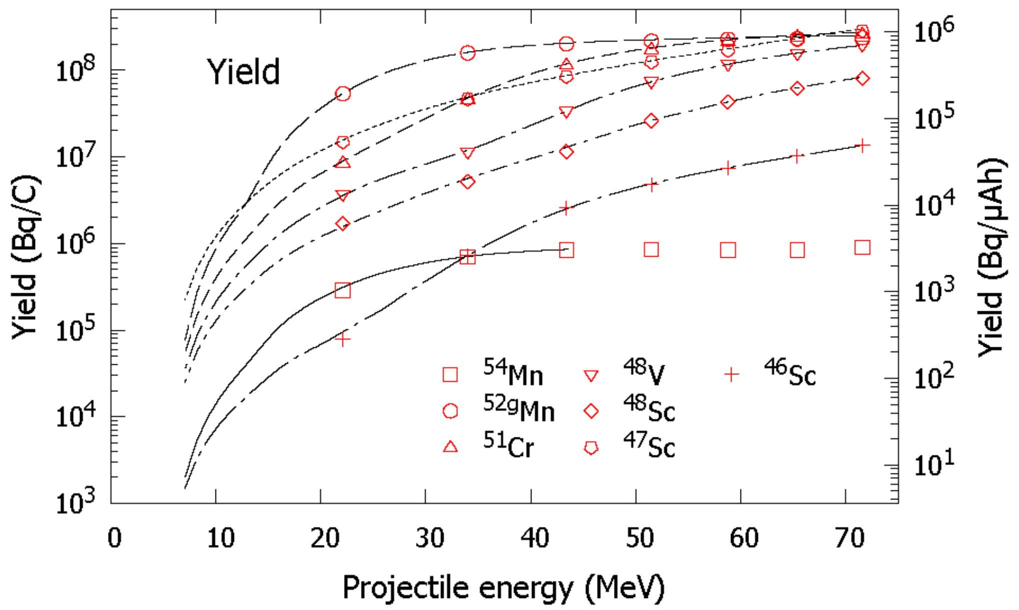
Problems

^{48}V: Unknown effect of secondary particles at low energy region

NuDat 3.0

Comparison of thick target yields

- Experimental physical thick target yields of $^{54,52g}Mn$, ^{51}Cr, ^{48}V, and $^{48,47,46}Sc$ were determined and compared with the calculated ones using the measured cross sections.
- The consistencies could be found.



Possible monitor reactions with Ti targets

- The three reaction, $^{nat}Ti(^{7}Li,x)^{54,52g}Mn$, ^{51}Cr, may be appropriate for the monitor reactions.

Monitor reactions published by IAEA			Suggestion
Proton	Deuteron	Alpha	^{7}Li
$^{27}Al(p,x)^{22,24}Na$ $^{nat}Ti(p,x)^{48}V,^{46}Sc$ $^{nat}Ni(p,x)^{57}Ni$ $^{nat}Cu(p,x)^{62,63,}\mathbf{^{65}Zn},^{56,58}Co$ $^{nat}Mo(p,x)^{96m+g}Tc$	$^{27}Al(d,x)^{22,24}Na$ $^{nat}Ti(d,x)^{48}V,^{46}Sc$ $^{nat}Fe(d,x)^{56}Co$ $^{nat}Ni(d,x)^{61}Cu,^{56,58}Co$ $^{nat}Cu(d,x)^{62,63,}\mathbf{^{65}Zn}$	$^{27}Al(\alpha,x)^{22,24}Na$ $^{nat}Ti(\alpha,x)\mathbf{^{51}Cr}$ $^{nat}Cu(\alpha,x)\mathbf{^{66,67}Ga,^{65}Zn}$	$^{nat}Ti(^{7}Li,x)\mathbf{^{54,52g}Mn,^{51}Cr}$ $^{nat}Cu(^{7}Li,x)\mathbf{^{66,67}Ga,^{65}Zn}$

Compilation to EXFOR E2798 (Prelim.E151)

Nuclear Instruments and Methods in Physics Research B 559 (2025) 165579

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, B

journal homepage: www.elsevier.com/locate/nimb

Activation cross sections of ^{7}Li-induced reactions on ^{nat}Ti: Implications for monitor reactions

Masayuki Aikawa [a,b,c,*], Saki Goto [c], Damdinsuren Gantumur [c], Dagvadorj Ichinkhorloo [d], Naoyuki Ukon [e], Naohiko Otuka [f], Sándor Takács [g], Hiromitsu Haba [h]

[a] Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan
[b] Global Center for Biomedical Science and Engineering, Faculty of Medicine, Hokkaido University, Sapporo 060-8648, Japan
[c] Graduate School of Biomedical Science and Engineering, Hokkaido University, Sapporo 060-8638, Japan
[d] Nuclear Research Center, National University of Mongolia, Ulaanbaatar 13330, Mongolia
[e] Advanced Clinical Research Center, Fukushima Medical University, Fukushima 960-1295, Japan
[f] Nuclear Data Section, International Atomic Energy Agency, A-1400 Wien, Austria
[g] HUN-REN Institute for Nuclear Research, ATOMKI, Debrecen 4026, Hungary
[h] Nishina Center for Accelerator-Based Science, RIKEN, Wako 351-0198, Japan

ARTICLE INFO

Keywords:
^{7}Li induced reaction on ^{nat}Ti
Monitor reaction
Production cross section of $^{54,52g}Mn$ $^{51,49,48}Cr$ ^{48}V and $^{48,47,46}Sc$
Excitation function

ABSTRACT

Activation cross sections for ^{7}Li-induced reactions on ^{nat}Ti were measured to discuss the suitability of selected reactions as monitor ones. The cross sections for the production of $^{54,52g}Mn$, $^{51,49,48}Cr$, ^{48}V, and $^{48,47,46}Sc$ were determined for the first time. Additionally, the thick target yields of $^{54,52g}Mn$, ^{51}Cr, ^{48}V, and $^{48,47,46}Sc$ were experimentally measured and compared with the yields calculated from the measured cross sections. The agreement between the experimental and calculated thick target yields validates the reliability of the experimental data measured in this work. The ^{7}Li-induced reactions on ^{nat}Ti for the production of $^{54,52g}Mn$, and ^{51}Cr are recommended as monitor reactions.

1. Introduction

Radionuclides produced in charged-particle-induced reactions are useful for different applications, such as imaging and therapy in nuclear medicine, radio-tracing, thin layer activation and so on. One possible projectile is ^{7}Li, which can generate a medically important radioisotope ^{211}Rn ($T_{1/2}$ – 14.6 h) [1–3] for the $^{211}Rn/^{211}At$ generator via the $^{209}Bi(^{7}Li,5n)^{211}Rn$ reaction [4,5]. The production of ^{211}Rn for practical use needs to be maximized, while minimizing the generation of unnecessary by-products. To determine and optimize the target thickness and the beam parameters, monitor reactions are essential. However, no suitable monitor reactions have been identified yet for ^{7}Li-induced reactions. We have initiated a systematic study to identify potential monitor reactions induced by the ^{7}Li projectiles. Among possible target materials, we investigated ^{nat}Cu and identified several reactions that may serve as potential monitor ones [6]. In this paper, we focus on ^{nat}Ti as a target material.

Titanium is widely used as target material for monitor reactions induced by protons, deuterons, ^{3}He, and α particles [7–9]. It is also expected to serve as a target for ^{7}Li-induced monitor reactions. A literature survey using the EXFOR library [10] revealed no experimental studies on the cross sections of these reactions. Therefore, we conducted experiments using ^{7}Li beams. The production cross sections of $^{54,52g}Mn$, $^{51,49,48}Cr$, ^{48}V, and $^{48,47,46}Sc$ and the physical thick target yields of $^{54,52g}Mn$, ^{51}Cr, ^{48}V, and $^{48,47,46}Sc$ were measured. The experimental yields were compared with values calculated from the cross sections to validate the obtained results. The reactions are discussed from the perspective of their suitability for monitoring ^{7}Li beam parameters. They should have sufficiently large cross sections in a wide energy range and the excitation functions should be smooth with a few clear maxima. These characteristics are essential for comparison with measured data and for fine-tuning parameters.

2. Experimental details and data analysis

We conducted three experiments: two to determine excitation functions and one to determine thick target yields of ^{7}Li-induced reactions. The experiments were implemented using 72-MeV ^{7}Li beams

* Corresponding author.
E-mail address: aikawa@sci.hokudai.ac.jp (M. Aikawa).

https://doi.org/10.1016/j.nimb.2024.165579
Received 19 September 2024; Received in revised form 26 October 2024; Accepted 10 November 2024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BIB                 12         22                             E279800100002
TITLE      Activation cross sections of 7Li-induced reactions on E279800100003
           natTi: Implications for monitor reactions          E279800100004
AUTHOR     (M.Aikawa, S.Goto, D.Gantumur, D.Ichinkhorloo, N.Ukon, E279800100005
            N.Otuka, S.Takacs, H.Haba)                        E279800100006
INSTITUTE  (2JPNHOK,3MGLNUM,2JPNFMU,3ZZZIAE,3HUNDEB,2JPNIPC)  E279800100007
REFERENCE  (J,NIM/B,559,165579,2025)                          E279800100008
INC-SOURCE Beam intensity: 314, 321, and 309 nA, respectively. E279800100009
SAMPLE     - Chemical-form of target is element.              E279800100010
           - Physical-form of target is solid.                E279800100011
           - Target-thickness is 2.34 mg/cm2.                 E279800100012
METHOD     (ACTIV) Irradiated for 60, 60, and 30 min.,        E279800100013
                   respectively.                              E279800100014
           (GSPEC)                                            E279800100015
FACILITY   (ISOCY,2JPNIPC) AVF cyclotron                      E279800100016
DETECTOR   (HPGE)                                             E279800100017
ERR-ANALYS (ERR-1) target thickness                           E279800100018
           (ERR-2) detector efficiency                        E279800100019
           (ERR-3) current integration by Faraday cups        E279800100020
           (ERR-4,,3.6) gamma-ray intensity (<3.6%)           E279800100021
FLAG       (1.) Result using stacked target no. 1             E279800100022
           (2.) Result using stacked target no. 2             E279800100023
HISTORY    (20241124C) MA                                     E279800100024
ENDBIB              22          0                             E279800100025
COMMON               3          3                             E279800100026
ERR-1      ERR-2      ERR-3                                   E279800100027
PER-CENT   PER-CENT   PER-CENT                                E279800100028
 1.          5.          5.                                   E279800100029
ENDCOMMON            3          0                             E279800100030
ENDSUBENT           29          0                             E279800199999
SUBENT        E2798002   20241125                             E279800200001
BIB                  4          4                             E279800200002
REACTION   (22-TI-0(3-LI-7,X)25-MN-54,,SIG)                   E279800200003
DECAY-DATA (25-MN-54,312.20D,DG,834.8,0.999760)               E279800200004
ERR-ANALYS (ERR-T) Total uncertainty                          E279800200005
STATUS     (TABLE,,M.Aikawa+,J,NIM/B,559,165579,2025) Tables 4-5 E279800200006
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Summary

- There are no monitor reactions for lithium-induced reactions.
- We performed to measure cross sections of ^{7}Li-induced reactions on ^{nat}Cu and ^{nat}Ti to discuss possible monitor reactions.
- We found several possible reactions,
  - ^{nat}Ti(7Li,x)^{54,52g}Mn,^{51}Cr
  - ^{nat}Cu(7Li,x)^{66,67}Ga,^{65}Zn
- We will accumulate their data and study other possible targets, e.g., ^{27}Al, ^{nat}Ni, and ^{nat}Fe.

Collaborators

- Saki Goto (Hokkaido U.)
- Damdinsuren Gantumur (Hokkaido U.)
- Dagvadorj Ichinkhorloo (NUM)
- Naoyuki Ukon (FMU)
- Naohiko Otuka (IAEA)
- Sándor Takács (ATOMKI)
- Hiromitsu Haba (RIKEN)