DETERMINATION OF BRANCHING RATIO FOR THE RADIOISOTOPES OF ALPHA EMITTERS IN THORIUM DECAY SERIES EVENTS

Chaw Su Myint[1], Aye Moh Moh Myo[2], Khin Than Tint[3]

Abstract

The purpose of this research is to identify the decay branching ratios of five radioisotopes in thorium decay chain from their measured ranges and kinetic energies. Totally 50 thorium decay series events which were detected in nuclear emulsion of plate #5, Module #26 in J-PARC E07 experiment were analyzed. The type of radioisotopes of alpha emitters were identified with measured range and the range in emulsion obtained from empirical formula and Barkas' literature. Moreover, branching ratio for the radioisotopes of alpha emitters in thorium decay series events were obtained from their measured ranges and corresponding kinetic energies. The results are consistent with the results in Barka's literature.

Keywords: alpha particles tracks, thorium series, nuclear emulsion, range, kinetic energy

Introduction

Nuclear emulsion is the key detector for the detection of three-dimensional trajectory of charged particles. Nuclear emulsions gel are composed by seven elements (hydrogen, carbon, nitrogen, oxygen, bromine, silver, iodine) with different densities. Nuclear emulsion plates are fabricated by drying after pouring gel on both sides of base polystyrene film. When a charged particle passing through nuclear emulsion, silver ions (Ag+) contained in AgBr crystal became silver atom (Ag) by the reduction reaction of silver. And then form a small cluster of metallic silver atoms called a latent image which is an invisible image. After development process, the latent image changes into visible image. Fuji GIF emulsion gel was used for E07 emulsion plate detectors production [Hayakawa. S, (2019)], .

Among the three naturally occurring decay series, thorium and uranium decay series can be detected in nuclear emulsion of emulsion-counter hybrid experiment (J-PARC E07 experiment). Since, the time for pouring and development of nuclear emulsion plates took about two years for that experiment, the five alpha particles tracks were observed as the decay chain of thorium series in both sides of emulsion plates. This event can occur if the successive nuclides found are of short life. Five alpha tracks are emitted from ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po and ^{212}Po (or ^{212}Bi) nuclides [Barkas. W. H, (1963)]. The thorium decay series events, totally 50 events, in nuclear emulsion plate of #5 and Mod#26 of E 07 experiment are described in Figure 1.

Materials and Methods

Firstly, Q value and kinetic energy of alpha particles emitted from all decay modes in Thorium Series were calculated by using the following equations (1) and (2).

$$Q = \Delta m \times 931 \text{ MeV} \quad (1)$$

In above equation, $m_{p,}$ m_d and m_α are the masses of parent nuclide, daughter nuclide and alpha particle, respectively. From the conservation of energy and momentum, the kinetic energy

[1] Department of Physics, Mandalay Technological University

[2] Department of Physics, Mandalay University of Distance Education

[3] Department of Physics, University of Mandalay

of emitted alpha particles related to Q value and the mass number A of the original nucleus is calculated by using the following equation.

$$KE_\alpha = \frac{A-4}{A}\ Q \tag{2}$$

Secondly, the range of alpha particles moving in nuclear emulsion for the kinetic energies were deduced from the following equations (equations 3 to 6). For alpha particles, the range in air at normal temperature and pressure is

$$R(mm, air) = exp\left[1.61\sqrt{T(MeV)}\right]\ for\ 1 < T\ \leq 4\ MeV \tag{3}$$

$$R(mm, air)[0.05\ T\ (MeV) + 2.85]\ T^{\frac{3}{2}}(MeV), for\ \ 4 < T \leq 15 \tag{4}$$

Where T = kinetic energy of the particle in MeV.

If the range is known for one material, it can be determined for any other by applying the *Bragg-Kleeman* rule.

$$\frac{R_1}{R_2} = \frac{\rho_2}{\rho_1}\sqrt{\frac{A_1}{A_2}} \tag{5}$$

Where ρ_i and A_i are density and atomic weight of material i. Since, nuclear emulsion gel is composed of eight kinds of element, an effective molecular weight was obtained from the equation

$$\sqrt{A_{ef}} = \left(\sum_{i=1}^{l}\frac{w_i}{\sqrt{A_i}}\right)^{-1} \tag{6}$$

On the other hand, range of alpha particles for corresponding kinetic energies are also obtained from traditionally range-energy formula in emulsion of a particle with charge of Z and mass of *M* in units of the proton mass is expressed as

$$\text{Range } R_{obs} - R_c = \rho\left[\frac{M}{Z^2}\cdot\lambda(\beta) + R_{ext}\right] \tag{7}$$

The range-energy relation in emulsion was written in Fortran code by Prof. Nakazawa, Gifu University, Japan.

The ranges of α-tracks in decay chain were measured with Graphical User Interface tool (GUI) and identified the radioactive isotope by comparing the range of α-tracks obtained by empirical formula and range energy relation based on W.H. Barkas' literature [Chaw Su Myint and Khin Than Tint, (2024)]. Finally, branching ratios were determined.

Results and Discussion

In nuclear emulsion, a member of an alpha-active series as several tracks may be found emerging from a common point. This event can occur if the successive nuclides found are short life. Five alpha tracks are emitted from ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po and ^{212}Po nuclides.

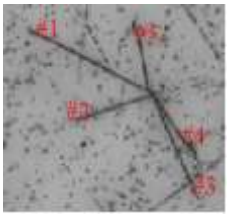
Ranges of α-tracks in thorium decay chain according to their kinetic energies were calculated by using equations 3 to 6 and range energy relation in emulsion based on Barkas' literature (equation 7) are expressed in Table 1.

Table 1. Calculated range of alpha particles in Thorium Decay Series

Decay Mode	Kinetic Energy of Alpha Particle (MeV)	Range of Alpha Particles (μm)	
		Obtained from Empirical Formula	Obtained from Range - Energy Relation (Barkas' literature)
$^{228}_{90}Th \rightarrow {}^{224}_{88}Ra + \alpha$	5.340	23.65	23.48
	5.423	24.68	24.0
$^{224}_{88}Ra \rightarrow {}^{220}_{86}Rn + \alpha$	5.448	24.86	24.17
	5.685	26.60	25.70
$^{220}_{86}Rn \rightarrow {}^{216}_{84}Po + \alpha$	5.747	27.67	26.11
	6.288	31.20	29.79
$^{216}_{84}Po \rightarrow {}^{212}_{82}Pb + \alpha$	5.985	28.88	27.71
	6.778	35.24	33.30
$^{212}_{84}Po \rightarrow {}^{208}_{82}Pb + \alpha$	8.784	50.63	49.37

The image processing (GUI tool) with personal computer and slice pictures taken by microscope was used to measure the range of alpha particles in thorium decay series events. Identifying radioisotopes of alpha emitters in thorium decay series event (one of the fifty events) by comparing measured range and calculated range in emulsion is presented in the following Table 2. Similarly, the other 49 events of thorium decay series events were analyzed as the same manner. The measured ranges of alpha tracks of events were consistent with the range of alpha track obtained from range-energy relation by Barkas.

Table 2. Identifying radioisotopes of alpha emitters in thorium decay series event by comparing measured range and calculated range in emulsion

Event #	Track #	Range of measured alpha tracks (μm) our result	Calculated Range(μm) [Equations 3 to 6]	Range of alpha tracks (μm) [Range-Energy Relation, Barkas]	Identified Radioactive Isotope for sample event
 20190328T141648	1	49.91± 0.24	50.63	49.37	^{212}Po
	2	29.64 ± 0.28	29.67	29.79	^{216}Po
	3	32.64 ± 0.23	33.24	33.30	^{220}Rn
	4	24.30± 0.10	24.68	24.00	^{224}Ra
	5	25.73 ± 0.20	26.60	25.70	^{228}Th

The range of alpha particle tracks emitted form five radioactive isotope were grouped according to their kinetic energies. The results for the obtaining alpha decay branching ratios for five alpha particle tracks in thorium decay series from their ranges are described in Table 3. The summarized branching ratios for radioisotopes of alpha emitters in thorium decay events and results from Barkas' literature are presented in Table 4.

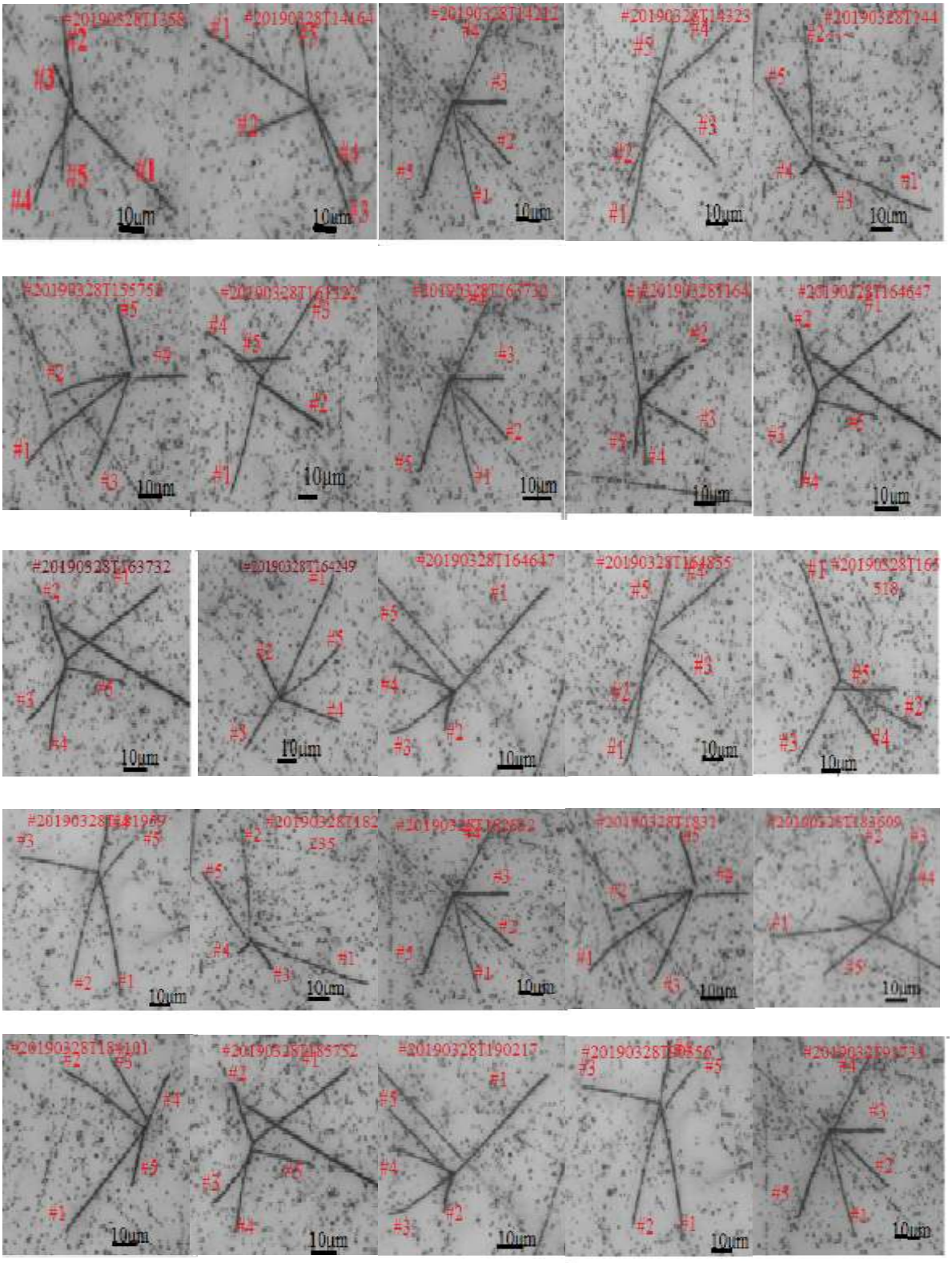


Figure 1. Thorium decay series events in nuclear emulsion plate of E07 experiment

Table 3 Alpha decay branching ratio

Sr No.	Event #	Radioisotopes of alpha emitters and measured range alpha tracks in micro meter								
		^{228}Th		^{224}Ra		^{220}Rn		^{216}Po		^{212}Po
1.	#20190328T135838	23.72± 0.11	-	-	25.92 ± 0.22	27.01 ± 0.90	-	-	32.69± 0.13	48.66± 0.87
2.	#20190328T141648	-	24.30 ± 0.11	-	25.74 ± 0.36	-	29.13± 0.27	-	31.81± 0.59	48.71± 0.89
3.	#20190328T142122	23.71± 0.10	-	24.52 ± 0.10	-	-	29.64± 0.28	-	31.85± 0.57	49.59± 0.82
4.	#20190328T143203	23.75± 0.13	-	24.5 ± 0.12	-	-	28.21± 0.86	-	31.94± 0.85	48.44± 0.33
5.	#20190328T144802	23.78± 0.36	-	-	25.76 ± 0.36	-	29.19± 0.67	-	33.22± 0.67	49.16± 0.68
6.	#20190328T155752	23.86± 0.23	-	24.50 ± 0.11	-	-	28.21± 0.84	-	31.92± 0.83	48.47± 0.35
7.	#20190328T161322	-	24.33 ± 0.36	-	25.75 ± 0.35	-	29.1± 0.39	-	33.22± 0.67	49.16± 0.68
8.	#20190328T163732	-	24.21 ± 0.20	-	25.74 ± 0.33	-	28.12± 0.85	-	32.78 ± 0.22	48.82± 0.44
9.	#20190328T164249	-	23.68 ± 0.69		25.61 ± 0.56	-	28.17± 0.29		32.11± 0.73	48.66± 0.47
10.	#20190328T164647		24.36 ± 0.12		25.67 ± 0.26		28.19± 0.54		32.01± 0.35	49.33± 0.76
11.	#20190328T164855		24.35 ± 0.11		25.61 ± 0.25		28.21± 0.44		32.09 ± 0.34	49.23± 0.77
12.	#20190328T165518		24.36 ± 0.12		25.12 ± 0.68		28.1± 0.90		32.6± 0.96	49.56 ± 0.35
13.	#20190328T180507		24.20 ± 0.13		25.58 ± 0.38		29.45± 0.14		32.17± 0.75	49.11± 0.54
14.	#20190328T180722		24.21 ± 0.13		25.57 ± 0.34		28.25± 0.90		32.20± 0.72	48.58± 0.82
15.	#20190328T181310		24.25 ± 0.12		25.83 ± 0.67		28.81± 0.12		33.01± 0.96	49.1 ± 0.92
16.	#20190328T181959		24.35 ± 0.11		25.81 ± 0.66		29.83± 0.36		32.25 ± 0.61	49.48± 0.64
17.	#20190328T182235	23.67± 0.12			25.71 ± 0.21		29.71 ± 0.26		32.69± 0.78	49.91± 0.24
18.	#20190328T182812		24.20 ± 0.12		25.73 ± 0.20		29.67± 0.31		32.98± 0.63	48.81± 0.68
19.	#20190328T183113	23.70 ± 0.21	-	-	25.74 ± 0.22	-	29.75± 0.29	-	32.78± 0.78	49.86± 0.22
20.	#20190328T183609	23.71 ± 0.11	-		25.13 ± 0.64	-	28.22± 0.83	-	32.68± 0.65	48.77± 0.52
21.	#20190328T184101	-	24.27 ± 0.11	-	25.14 ± 0.56	-	28.83 ± 0.36	-	32.77 ± 0.70	49.82± 0.64

Sr No.	Event #	**Radioisotopes of alpha emitters and measured range alpha tracks in micro meter**								
		^{228}Th		**^{224}Ra**		**^{220}Rn**		**^{216}Po**		**^{212}Po**
22.	#20190328T185752	23.63 ± 0.22	-	-	25.71 ± 0.25	-	29.64± 0.28	-	32.66± 0.68	49.91± 0.27
23.	#20190328T190217	-	24.34 ± 0.13		25.73 ± 0.20	-	29.71± 0.31	-	32.54± 0.48	49.58± 0.18
24.	#20190328T90356	-	24.21 ± 0.22	-	25.74 ± 0.22	-	29.74± 0.38	-	32.51± 0.57	49.85± 0.12
25.	#2019032T191733	23.64 ±0.23	-	-	25.15 ± 0.59	-	28.22± 0.53	-	32.27± 0.21	49.73± 0.24
26.	#20190328T175558		24.30 ± 0.14	-	25.83 ± 0.67	-	28.75± 0.24	-	32.16 ± 0.21	49.48± 0.64
27.	#20190328T180007	23.73 ± 0.11	-	-	25.70 ± 0.23	-	29.53± 0.38	-	32.4± 0.71	49.73± 0.22
28.	#20190328T180152	23.71 ± 0.21	-	-	25.73 ± 0.20	-	29.64± 0.27	-	32.2± 0.24	49.59± 0.37
29.	#20190328T180832	-	24.32 ± 0.17	-	25.74 ± 0.22	-	29.51± 0.38	-	32.27 ± 0.17	49.84± 0.41
30.	#20190328T181058	23.68 ± 0.24	-	-	25.12 ± 0.76	-	28.23± 0.81	-	32.66± 0.68	49.57± 0.24
31.	#20190328T182328		24.18 ± 0.16	-	25.83 ± 0.67	-	28.54± 0.31	-	32.16± 0.21	49.48± 0.64
32.	#20190328T15047	23.85 ± 0.23	-	-	25.68 ± 0.27	-	29.64± 0.29	-	32.41± 0.84	49.57± 0.31
33.	#20190328T182948	-	24.30 ± 0.10	-	25.73 ± 0.14	-	29.53± 0.21	-	32.54± 0.14	49.62± 0.30
34.	#20190328T183324	-	24.21 ± 0.11	-	25.74 ± 0.22	-	29.64± 0.29	-	32.63± 0.68	49.24± 0.51
35.	#20190328T183616	-	24.27 ± 0.12	-	25.81 ± 0.27	-	28.22± 0.83	-	32.71± 0.47	49.84± 0.24
36.	#20190328185502	-	24.27 ± 0.13	-	25.83 ± 0.67	-	28.71± 0.29	-	32.16± 0.23	49.48 ± 0.64
37.	#20190328T190323	23.77± 0.17	-	-	25.71 ± 0.21	-	29.64± 0.30	-	32.60± 0.78	49.69± 0.24
38.	#20190328T190804	-	24.30 ± 0.10	-	25.73 ± 0.20	-	29.71± 0.89	-	32.71±0 . 66	49.71± 0.69
39.	#20190328T191430	-	24.18 ± 0.15	-	25.74 ± 0.22	-	29.64± 0.28	-	32.56± 0.68	49.74± 0.96
40.	#20190328T191740	-	24.21 ± 0.21		25.82 ± 0.28	-	28.22± 0.83	-	32.41 ± 0.42	49.87± 0.24
41.	#20190328T192622	-	24.25 ± 0.22	-	25.83 ± 0.67	-	27.60± 0.25	-	32.16± 0.21	49.48± 0.15
42.	#20190328T193401	-	24.19 ± 0.23	-	25.71 ± 0.21	-	29.64± 0.38	-	32.66± 0.68	49.78± 0.27
43.	#20190328T193858	-	24.27		25.73	-	29.65±	-	32.57±	49.85±

Sr No.	Event #	Radioisotopes of alpha emitters and measured range alpha tracks in micro meter								
		^{228}Th		**^{224}Ra**		**^{220}Rn**		**^{216}Po**		**^{212}Po**
			± 0.10		± 0.20		0.29		0.63	0.24
44.	#20190328T194332	-	24.28 ± 0.11	-	25.74 ± 0.22	-	29.61± 0.28	-	32.66± 0.68	49.65± 0.53
45.	#20190328T194842	-	24.20 ± 0.21	-	25.52 ± 0.68	-	28.22± 0.83	-	32.27± 0.75	49.93± 0.62
46.	#20190328T195025	-	24.17 ± 0.22	23.72 ± 0.11		-	29.83± 0.36	-	32.16± 0.21	49.48± 0.64
47.	#20190328T195657	-	24.20 ± 0.17	-	25.65 ± 0.27	-	29.64± 0.27	-	32.27 ± 0.81	49.69± 0.53
48.	#20190328T200222		24.19 ± 0.22	-	25.73 ± 0.20	-	28.61 ± 0.68	-	32.63± 0.68	49.78± 0.24
49.	#20190328T1204352	-	24.25 ± 0.12	-	25.74 ± 0.22	-	29.28± 0.31	-	32.42± 0.48	49.76± 0.55
50.	#20190328T1205123	-	24.23 ± 0.21	-	25.81 ± 0.27	-	28.22± 0.83	-	32.91± 0.47	49.64± 0.24
	Total events for each range and kinetic energy	15	35	5	45	**1**	**49**	-	**50**	**50**

Table 4 The branching ratios of five radioisotopes in thorium decay series

Radioactive isotopes (Parent)	Half-Life	Kinetic Energy of Emitted Alpha Particles (MeV)	Branching Ratio (%) our result	Branching Ratio(%) Barakas' Literature
^{228}Th	1.910yr	5.340	30	28
		5.423	70	71
^{224}Ra	3.64day	5.448	10	5
		5.685	90	95
^{220}Rn	51.5sec	5.747	2	-
		6.288	98	99+
^{216}Po	0.158sec	5.958	-	-
		6.778	100	100
^{212}Po	3.04×10^{-7}sec	8.784	100	99+

Conclusion

The measured range of alpha particle tracks in each thorium decay series events in nuclear emulsion of plate #5, Mod#26 of E07 experiment are comparable with the ranges obtained from range energy relation in emulsion based on Barkas' literature. The calculated ranges of alpha particles by using empirical formula are a little longer than the measured range. From the measured range of alphas; the types of radioactive isotopes are identified. Moreover, the decay branching ratio of each decay mode is also identified. The branching ratios for the radioisotopes of alpha emitters in thorium decay series events in nuclear emulsion of E07 experiment are quite consistent with the results in Barkas' literature.

Acknowledgement

We wish to express our warmest thanks to Prof. Dr Tin Tun, Rector, University of Mandalay and Pro-Rectors, University of Mandalay for their kind permission for this research work. The author would like to acknowledge Prof. Dr Nyeint Wint Lwin, Head of Department and Prof. Dr San Yu Swe, Department of Physics, University of Mandalay for their kind permission and encourage to carry out this research work. I would like to express my special thanks to Prof. Dr Khin Than Tint, University of Mandalay, for her close supervision and permission to perform this research.

References

Barkas. W. H, (1963), *Nuclear Research Emulsions,* Academic Press, New York and London.

Barkas. W. H., *et.a*l, (1958) "Range-Energy Relation in Emulsion", Nuovo Cimento, vol 8, pp,185-200.

Chaw Su Myint and Khin Than Tint (2024) "Identification of Type of Radioisotopes from Thorium Decay Series Events in Nuclear Emulsion" Mandalay Technological University Journal, vol 10 (accepted).

Hayakawa. S, (2019) "Study of Ξ^- nucleus interaction by measurement of twin hypernuclei with hybrid emulsion method", D. Sc Thesis, Department of Physics, Osaka University (unpublished).

Heckman et.al, 1960, "Range and Energy-Loss Process of Heavy Ions in Emulsion", Phys. Rev. vol 117, pp .544-556

Ito.H, *et al*, (2015) "Mass production of the large-sized nuclear plate for J-PARC E07", JPS Conf. Proc. 2nd Int.

Symp on Sci. at J. PARC, vol 8**,** pp 021007-1-6.

Khin ThanTint, (2015), "Study on Thorium and Uranium Decay Series in Nuclear Emulsion", MDC Research Journal, *vol 6*. pp 62-70.

Takahashi H., (2003), "Study of Double-Hypernuclei with Hybrid-Emulsion Method", D. Sc Thesis, Department of Physics, Kyoto University