Proceedings of the Fifth International Symposium on Radiation Education ISRE2016

第５回放射線教育に関する国際シンポジウム
論文集

December 16-19, 2016
Koriyama Chamber of Commerce and Industry
Koriyama, Fukushima, Japan

July 2017
NPO Radiation Education Forum

主催
NPO 法人放射線教育フォーラム

後援
福島県、福島県教育委員会
郡山市、郡山市教育委員会
郡山商工会議所、郡山コンベンションビューロー
福島民報社、福島民友新聞社

ISRE2016 Schedule

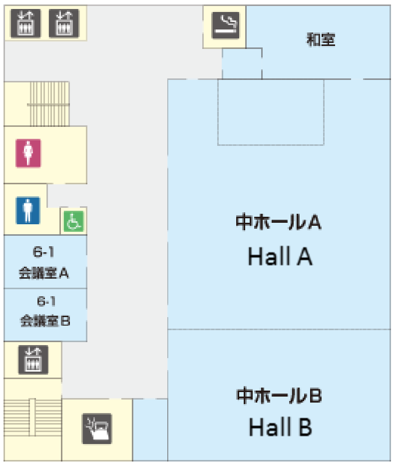
	Morning	Afternoon	Night
Friday, December 16, 2016	11:00- Registration	14:00-14:10 Opening Address 14:10-17:00 Keynote Lectures	17:00-17:10 Group Photo 17:10-18:10 Welcome Reception
Saturday, December 17, 2016	8:30-11:50 Plenary Session	13:00-15:50 Plenary Session	16:00-17:30 Poster Session
Sunday, December 18, 2016	9:00-12:40 Tour: Fukushima Environmental Creative Center	13:00-16:40 Public Session 13:00-14:20 Keynote Lecture 14:30-16:40 Plenary Session	17:00-19:00 Symposium Dinner 19:00-19:10 Closing Address
Monday, December 19, 2016	9:00-18:00 Excursion: Fukushima Daini Nuclear Power Plant		

Venue: Koriyama Chamber of Commerce and Industry (KCCI)

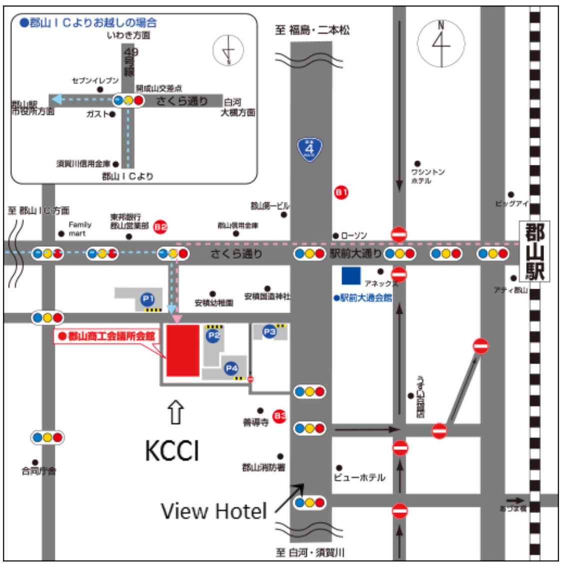
Organizing Committee

K. Hasegawa Chairperson
K. Horiuchi
Y. Hosobuchi
H. Kudo Vice-chairperson
K. Kudo Vice-chairperson
T. Nozaki
S. Ohmori
S. Ohno
S. Shibata
R. Tanaka Secretary
M. Tsuji
(Members of NPO Radiation Education Forum)

Koriyama Chamber of
Commerce and Industry (KCCI)



Hall A, 6th Floor



Fukushima ⇧

⇦ Koriyama station

⇩ Tokyo

Map to KCCI

Preface

Radiation is an essential means to promote basic science research. In particular, radiation detectors and radiation research have made significant progress in the past century. Furthermore, research and application of radiation in the medical field have greatly developed in term of industry. X-ray applications in medicine, especially diagnostic CT scans are currently very common in hospitals. Some citizens do not recognize the role of radiation and radioactivity and there are not a few who are afraid of them, but others are taking risks of excessive exposure to X-rays. We wish people to understand the nature and usefulness of radiation, and the dangers of its handling. It is our duty as scientists and engineers to talk to citizens about how to use radiation and radioactivity safely in everyday life.

The 4th International Symposium on Radiation Education (ISRE2008) was held in Hsinchu City, Taiwan 8 years ago, and this Symposium (ISRE2016) was held in Koriyama City, Fukushima Prefecture. This symposium has been devoted to the radiation education for pupils and general citizens. Six major topics in this symposium were discussed: (1) upbringing of human resources and securing the field of radiation science、(2) radiation education, energy education and environmental education for schools and the general public, (3) effects of low-dose radiation on the human body, method of protecting the human body, (4) risks associated with the application science and technology, (5) natural radiation, (6) radiation literacy after the Fukushima nuclear accident. There were 17 participants from Thailand and Taiwan, 4 keynote speakers, 14 oral presenters and 14 poster presenters, and a total of 95 participants in this symposium. Thank you for letting us know about this unique experience.

The organizing committee of this symposium is very knowledgeable about the purpose of this symposium and many companies, prominent lecturers and participants cooperated in various ways to fruitful discussions. We sincerely welcome organizations and individuals

Kunihiko Hasegawa
Chairperson of the Organizing Committee, The Fifth International Symposium on Radiation Education (ISRE2016), and President of NPO Radiation Education Forum

Contents

III. Poster Presentation

Appendix

Necessity of Education on Radiation and Radioactivity in Japan

日本における放射線教育の必要性

Akito ARIMA
有馬朗人
President, Japan Radioisotope Association
日本アイソトープ協会会長

2011 年 3 月 11 日、東日本大震災・大津波によって東京電力福島第一原子力発電所の事故が発生した。津波によって外部電源も、非常用発電機も破壊され、原子炉の冷却が不可能になり、水素爆発が起きた。その結果福島第一原子力発電所より放射能物質が放出され、周辺の地帯が放射能に汚染され、多くの住民が疎開せざると得なくなった。

この事故によって福島県を始め日本全般に放射能・放射線への恐怖心が高まった。また福島県の農産物や海産物への不買運動が発生した。その恐怖心の中には正しいものも勿論あるが、必要以上に恐れるという面もある。そのような事態の発生した原因の一つに、日本において放射能・放射線教育が充分に行われていなかったことがある。

ここで日本の過去の放射能・放射線教育の問題を検討し、その現状を分析し、望ましい姿についての私の見解を以下の３項目に分けて述べたい。

１．日本の小中高生の理科力と成人の科学知識
２．日本の初中教育における放射能・放射線教育
３．放射能・放射線教育で教えて欲しいこと

１．日本の小中高生の理科力と成人の科学知識

小中高生の数学（算数）・理科の学力の国際的調査 TIMSS によると、日本の生徒の学力は高いことが分ります。そのうち理科の成績を表 1 に示しておきます。日本のみでなくシンガポール、中国、韓国などアジアの国々の生徒も理科や数学などの学力が高いことが分ります。それに反してアメリカやヨーロッパの生徒の理科力が低いこと（表 2）をよく見ておいて下さい。

高等学校の生徒の理科力はどうでしょうか。15 歳の人々に対する一般のリタラシーや数学、科学のリタラシーについての国際比較（PISA）が OECD で 2000 年以降数回行われています。そのうち科学についての成績を見てみましょう。（表 3、図 1）ここでも日本の高校生の科学力が高いことが分ります。そしてまたやはりアジア諸国の高校生の科学力も高いことが示されました。

1991 年 OECD によって国民の科学知識についての調査が共通問題を用いて行われました。私は、日本人は知識力が高いと思っていたのですが、その結果にがく然としました。日本人は 13 番目でした（表 4）。小中学生の時には日本よりずっと下の理科の学力であった国々、例えばイタリアなどがずっと上でした。ギリシアやスペインよりも下です。そこでもう一度やってみようということで 2001 年に行ったのですが、どうでしょう（表 5）。ギリシアより

は上になりました。でも依然として上から数えると 13 番目。しかも EU 諸国の平均値より下でした。これは何を意味しているのでしょうか。子供のうちは理科好きであったのが、大人になると理科離れどころか、理科ぎらいになる傾向にあることを示しています。

表1　Grade4　Science

	TIMSS1995		TIMSS2003		TIMSS2007		TIMSS2011		TIMSS2015	
1	Korea	597	Singapore	565	Singapore	587	Korea, Rep. of	587	Singapore	590
2	Japan	574	Chinese Taipei	551	Chinese Taipei	557	Singapore	583	Korea, Rep. of	589
3	United States	565	Japan	543	Hong Kong SAR	554	Finland	570	Japan	569
4	Austria	565	Hong Kong, SAR	542	Japan	548	Japan	559	Russian Federation	567
5	Australia	562	England	540	Russian Federation	546	Russian Federation	552	Hong Kong SAR	557
6	Netherlands	557	United States	536	Latvia	542	Chinese Taipei	552	Chinese Taipei	555
7	Czech Republic	557	Latvia	532	England	542	United States	544	Finland	554
8	England	551	Hungary	530	United States	539	Czech Republic	536	Kazakhstan	550
9	Canada	549	Russian Federation	526	Hungary	536	Hong Kong SAR	535	Poland	547
10	Singapore	547	Netherlands	525	Italy	535	Hungary	534	United States	546
11	Slovenia	546	Australia	521	Kazakhstan	533	Sweden	533	Slovenia	543
12	Ireland	539	New Zealand	520	Germany	528	Slovak Republic	532	Hungary	542
13	Scotland	536	Belgium (Flemish)	518	Australia	527	Austria	532	Sweden	540
14	Hong Kong	533	Italy	516	Slovak Republic	526	Netherlands	531	Norway (5)	538
15	Hungary	532	Lithuania	512	Austria	526	England	529	England	536
16	New Zealand	531	Scotland	502	Sweden	525	Denmark	528	Bulgaria	536
17	Norway	530	Moldova, Rep. of	496	Netherlands	523	Germany	528	Czech Republic	534
18	Latvia (LSS)	512	Slovenia	490	Slovenia	518	Italy	524	Croatia	533
19	Israel	505	Cyprus	480	Denmark	517	Portugal	522	Ireland	529
20	Iceland	505	Norway	466	Czech Republic	515	Slovenia	520	Germany	528
21	Greece	497	Armenia	437	Lithuania	514	Northern Ireland	517	Lithuania	528
22	Portugal	480	Iran, Islamic Rep. of	414	New Zealand	504	Ireland	516	Denmark	527

作成：千々布(国立教育政策研究所) 2012.12

表2 Grade8　Science

	TIMSS1995		TIMSS1999		TIMSS2003		TIMSS2007		TIMSS2011		TIMSS2015	
1	Singapore	607	Chinese Taipei	569	Singapore	578	Singapore	567	Singapore	590	Singapore	597
2	Czech Republic	574	Singapore	568	Chinese Taipei	571	Chinese Taipei	561	Chinese Taipei	564	Japan	571
3	Japan	571	Hungary	552	Korea, Rep. of	558	Japan	554	Korea, Rep. of	560	Chinese Taipei	569
4	Korea	565	Japan	550	Hong Kong, SAR	556	Korea, Rep. of	553	Japan	558	Korea, Rep. of	556
5	Bulgaria	565	Korea, Rep. of	549	Estonia	552	England	542	Finland	552	Slovenia	551
6	Netherlands	560	Netherlands	545	Japan	552	Hungary	539	Slovenia	543	Hong Kong SAR	546
7	Slovenia	560	Australia	540	Hungary	543	Czech Republic	539	Russian Federation	542	Russian Federation	544
8	Austria	558	Czech Republic	539	Netherlands	536	Slovenia	538	Hong Kong SAR	535	England	537
9	Hungary	554	England	538	United States	527	Hong Kong SAR	530	England	533	Kazakhstan	533
10	England	552	Finland	535	Australia	527	Russian Federation	530	United States	525	Ireland	530
11	Belgium (Fl)	550	Slovak Republic	535	Sweden	524	United States	520	Hungary	522	United States	530
12	Australia	545	Belgium (Flemish)	535	Slovenia	520	Lithuania	519	Australia	519	Hungary	527
13	Slovak Republic	544	Slovenia	533	New Zealand	520	Australia	515	Israel	516	Canada	526
14	Russian Federation	538	Canada	533	Lithuania	519	Sweden	511	Lithuania	514	Sweden	522
15	Ireland	538	Hong Kong, SAR	530	Slovak Republic	517	Scotland	496	New Zealand	512	Lithuania	519
16	Sweden	535	Russian Federation	529	Belgium (Flemish)	516	Italy	495	Sweden	509	New Zealand	513
17	United States	534	Bulgaria	518	Russian Federation	514	Armenia	488	Italy	501	Australia	512
18	Germany	531	United States	515	Latvia	512	Norway	487	Ukraine	501	Norway (9)	509
19	Canada	531	New Zealand	510	Scotland	512	Ukraine	485	Norway	494	Israel	507
20	Norway	527	Latvia (LSS)	503	Malaysia	510	Jordan	482	Kazakhstan	490	Italy	499
21	New Zealand	525	Italy	493	Norway	494	Malaysia	471	Turkey	483	Turkey	493
22	Thailand	525	Malaysia	492	Italy	491	Thailand	471	Iran, Islamic Rep. of	474	Malta	481

表3　PISA Scientific literacy

	PISA2000		PISA2003		PISA2006		PISA2009		PISA2012		PISA2015	
1	Korea	552	Finland	548	Finland	563	shanghai-China	575	Shanghai-China	580	Singapore	556
2	Japan	550	Japan	548	Hong Kong-China	542	Finland	554	Hong Kong-China	555	Japan	538
3	Finland	538	Hong Kong-China	539	Canada	534	Hong Kong-China	549	Singapore	551	Estonia	534
4	United Kingdom	532	Korea	538	Chinese Taipei	532	singapore	542	Japan	547	Chinese Taipei	532
5	Canada	529	Liechtenstein	525	Estonia	531	Japan	539	Finland	545	Finland	531
6	New Zealand	528	Australia	525	Japan	531	Korea	538	Estonia	541	Macao(China)	529
7	Australia	528	Macao-China	525	New Zealand	530	New Zealand	532	Korea	538	Canada	528
8	Austria	519	Netherlands	524	Australia	527	Canada	529	Viet Nam	528	Viet Nam	525
9	Ireland	513	Czech Republic	523	Netherlands	525	Estonia	528	Poland	526	Hong Kong-China	523
10	Sweden	512	New Zealand	521	Liechtenstein	522	Australia	527	Canada	525	B-S-J-G(China)	518
11	Czech Republic	511	Canada	519	Korea	522	Netherlands	522	Liechtenstein	525	Korea	516
12	France	500	Switzerland	513	Slovenia	519	Chinese taipei	520	Germany	524	New Zealand	513
13	Norway	500	France	511	Germany	516	Germany	520	Chinese Taipei	523	Slovenia	513
14	United States	499	Belgium	509	United Kingdom	515	Liechtenstein	520	Netherlands	522	Australia	510
15	Hungary	496	Sweden	506	Czech	513	Switzerland	517	Ireland	522	United Kingdom	509
16	Iceland	496	Ireland	505	Switzerland	512	United Kingdom	514	Australia	521	Germany	509
17	Belgium	496	Hungary	503	Macao-China	511	Slovenia	512	Macao-China	521	Netherlands	509
18	Switzerland	496	Germany	502	Austria	511	macao-China	511	New Zealand	516	Switzerland	506
19	Spain	491	Poland	498	Belgium	510	Poland	508	Switzerland	515	Ireland	503
20	Germany	487	Slovak	495	Ireland	508	Ireland	508	Slovenia	514	Belgium	502
21	Poland	483	Iceland	495	Hungary	504	Belgium	507	United Kingdom	514	Denmark	502
22	Denmark	481	United States	491	Sweden	503	Hungary	503	Czech Republic	508	Poland	501

図1 PISA Average Score and Ranking, 2000 through 2015

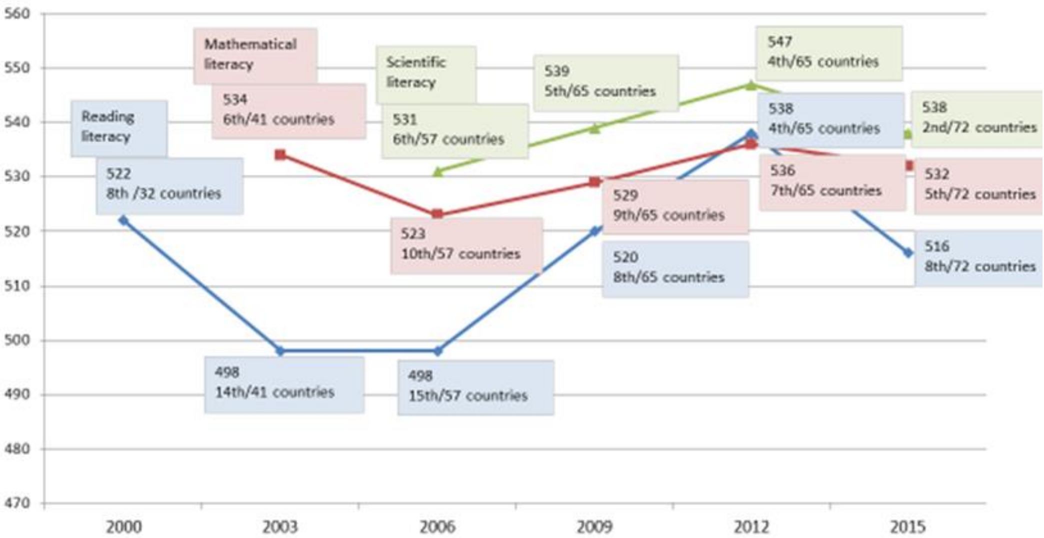


表4　Understanding and Interest of Science and Technology in the World Today

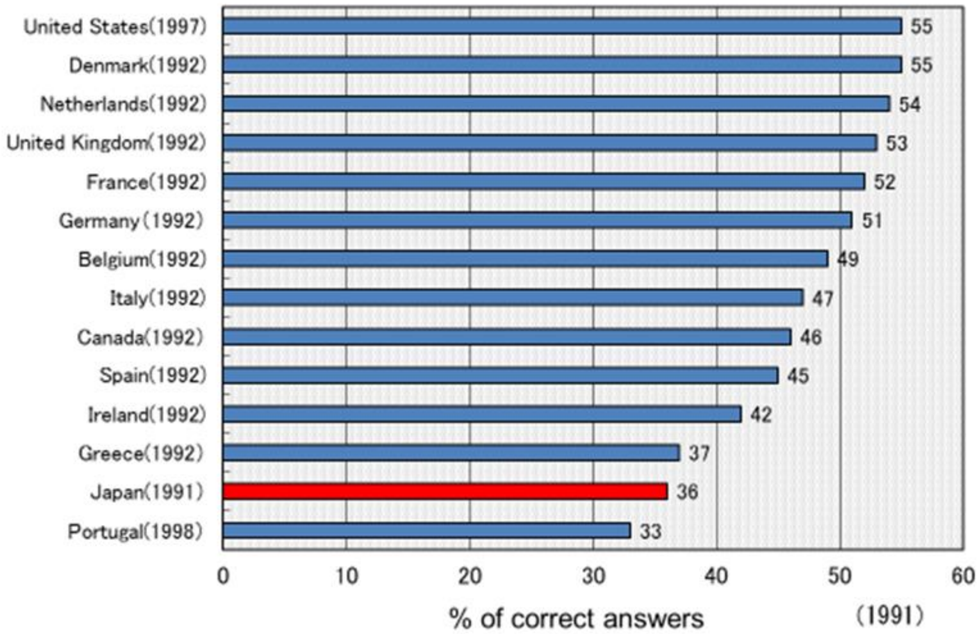
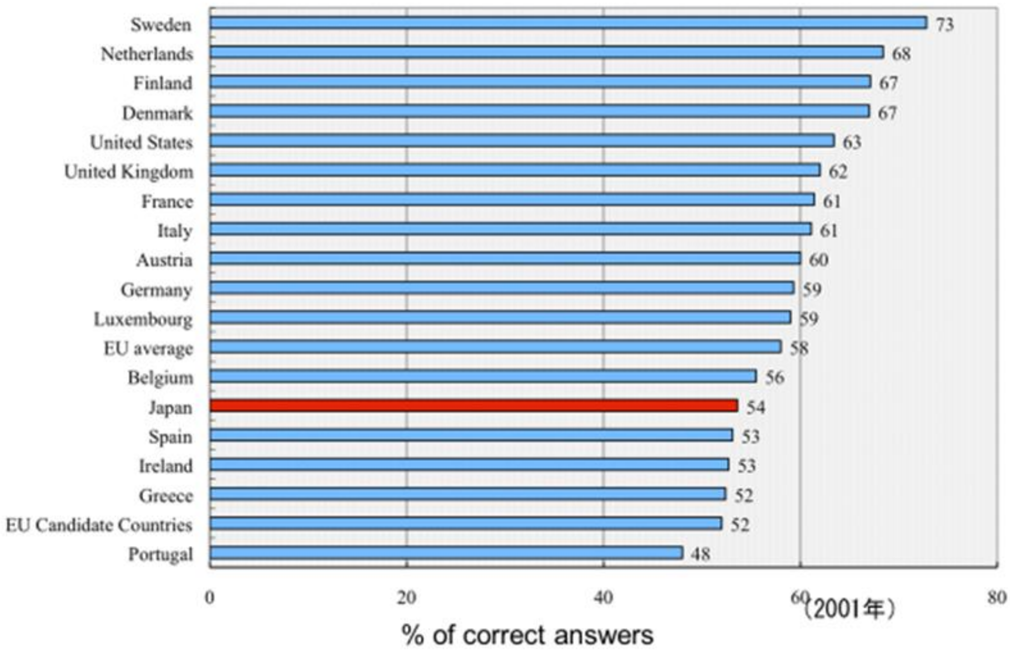


表5　Understanding and Interest of Science and Technology in the World Today



２．日本における放射能・放射線教育

OECD による成人の科学知識の調査における共通問題の一つが「放射能には人工のものがありますか、天然のものはどうですか」です。日本人がこの問題に正しく答えなかった可能性があります。即ち日本の大人は科学知識が弱い。そして放射線・放射能の教育を充分に受けていないのです。

1989 年（平成元年）以降 2010 年迄、日本の中学校では放射線・放射能について教えませんでした。そもそも放射線・放射能の教育と言うと、原子力推進のためだと反対する人が昔から多く、2010 年に復活したときもそのような反対がありました。

原子力の利用に賛成反対どちらでも、医学などで放射線・放射能が使われていますし、ジャガイモの芽をガンマ線で処理して何時でもジャガイモが食べられるようにするなどで、放射線が利用されています。

アメリカなどでは牛肉なども放射線で処理してあります。それで腸管出血性大腸菌感染症を引き起す病原菌 O-157 の心配がありません。日本では時々生肉を食べて O-157 のため死亡することが良くありますから日本でも放射線で処理しておくと良いと思いますが、放射線利用に反対の人が多く実施されていません。また福島の原子炉の事故などの際、放射線・放射能に対してどう対応すべきかなど正しく判断できるように、きちっとした知識を持っていなければなりません。

しかし先程申しましたように、1989 年以来長年日本では中学における放射線・放射能教育が行われませんでした。高等学校では物理や化学を学べばそこで放射線・放射能について教育を受けることができますが、物理や化学は選択ですので、学ばない人が多いのです。理系でもそうですから、文系の人は大部分が物理や化学をとらず、従って放射能・放射線をきちっと学ぶことがなかったのです。

日本において義務教育段階の中学校で放射線・放射能をしっかりと教育すべきです。

３．放射能・放射線教育はいかにあるべきか

先ず放射能は何かを教えるべきです。歴史的には、フランスの物理学者ベクレルが 1896 年ウラン鉱からの放射線を発見しました。1895 年ドイツのレントゲンが X 線を発見したことに刺激されて、蛍光の研究などをしていたベクレルは、偶然ウラン鉱を置いた写真乾板を現像したらば、その鉱物の影のような不思議な像がうつっていたのです。その後ベクレルの弟子のピエール・キューリーとマリー・キューリーの 2 人がウラン鉱の放射能を追求しましたトリウムからも同じような放射能を発見し、その後ピッチブレンド中の放射能を追跡して、1898 年更に新しい放射性元素ポロニウムとラジウムを発見したのです。

2 つの新しい放射性元素の一方はマリー・キューリーの母国ポーランドにちなんで、ポロニウムと名づけられたのです。

このポロニウムをキューリーからもらってイギリスのアーネスト・ラザフォードは、ポロニウムからの放射線に磁場を加えてみたところ、真直ぐに進むもの、かなり重い粒子らしい少し曲がるもの、かなり軽い粒子らしいもので大きく曲るものの 3 種類あることを発見しました。真直ぐ進む軽いものは γ 線、ちょっと曲る放射線を α 線、大きく曲るものを β 線と名付けました。また曲り方からその電荷や、質量を測定し、α 線は正電荷のヘリウム He、β 線は負電荷の電子であることをつきつめました。協同して研究したのは、ソディです。この

γ 線は X 線や紫外線、可視光、赤外線、短波、長波などおなじみの光線の仲間で波長が最も短いものであることが分りました（図 2)。

光波も粒子、フォトンであり、そのエネルギーεは振動数νに比例します。νは波長λの逆数で$\lambda\nu=c$であり、$\varepsilon=h\nu=\frac{hc}{\lambda}$ですから、波長$\lambda$が短い程大きなエネルギーを持ちます。ですから紫外線や X 線そして γ 線はエネルギーが大きく、X 線や γ 線は人体に与える影響、場合によっては危険性が大きいのです。ですから X 線もあび過ぎると危険ですので注意しなければなりません。現在は医師達も X 線で診断する時に極めて慎重なのはそのためです。

放射線の量を表わす単位に 2 種類あります。

照射線量、X 線や γ 線の放射線としての強さで単位はレントゲン。

吸収線量　物質 1 キログラム当りの吸収される放射線のエネルギー量、単位としてはグレイ（Gy）またはその 100 分の 1 のラド（rad)。グレイは物質 1 キログラム当り 1 ジュール吸収される放射線量、1 ラドはその 100 分の 1 です。

人間にとってもっとも重要なことは放射能が及ぼす影響です。放射線の生体吸収量の単位としてシーベルトが用いられます。1 Sv は 1 Gy（グレイ）の γ 線と生物学的効果がほぼ同等の線量として定義されています。1 Sv はあまりにも大きいので通常は 1 Sv の 1000 分の 1 のミリシーベルト mSv が用いられます。1 mSv は生体組織 1 g あたり 10 erg の γ 線のエネルギー吸収に相当します。

地球上の人間は大地からの放射線、宇宙からの放射線、食物を採取することによる体内からの放射線、そして呼吸によってすい込む空気が持ち込むことによる放射線などがあります。

世界平均で人間は毎年宇宙から 0.39 mSv、大地から 0.48 mSv、食物から 0.29 mSv、呼吸から 1.26 mSv 自然放射能によって被爆しています。
です。平均して 1 年間に日本人は 1.5 mSv、世界平均は 2.4 mSv です。

自然放射能による被爆量は大地からの放射能は日本では 0.43 mSv/年、大きい所は、図 3 の示すようにイランのラムサール 10.2 mSv/年、中国の陽江は 3.5 mSv/年です。

飛行機に乗ったり、医療などでどのくらいの放射線量をあびるかを示したのが　図 4 です。パイロットなどは飛行機に乗り過ぎないようにしなければなりません。

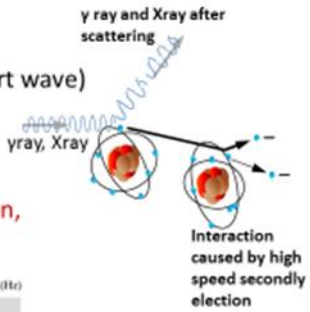
それでは放射線をどのくらい浴びれば、どんな病気が発生するか　図 5 に示しておきましょう。詳しくは山下先生がおられますので、山下先生など医学の専門家に聞いて下さい。

さて東電の福島第一原子力発電所の事故に伴う放射能汚染による放射線量を 1 mSv 以下にするという方針がありますが、これは以上述べた自然放射線量によるものに比べて、明らかに原子力発電所事故によって増加した線量の部分を取り除くことを意味しているのです。もともとの宇宙線によるものとか、大地からのものは除きようはないのです。

図2 Kinds of Radiation (Radiation without charge)

γray (gamma ray), Xray:

- Light with high energy
  (kinds of electromagnetic waves with extremely short wave)
- No charge -> big penetration capability



γray : to be emitted from nucleus, elementary particles
Xray: to be emitted by bremsstrahlung of orbital electron, charged particles

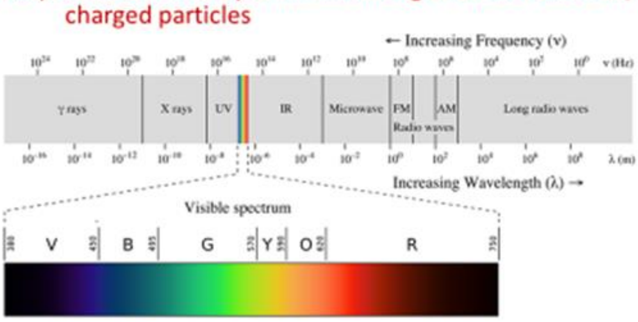
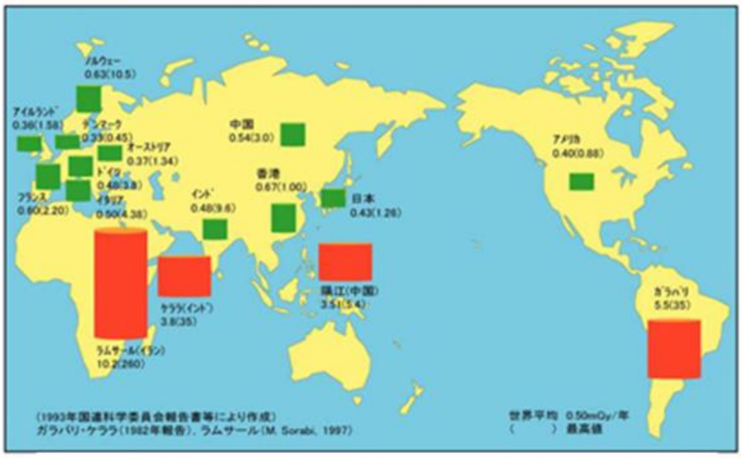


図3 Natural radiation dose per year from earth in the world



Natural radiation dose from at highly dose area in the world(mSv/y)

Area	Average	Max. Rate
Ramsar (Iran)	10.2	260.0
Guarapari (Brasil)	5.5	35.0
Kerala (India)	3.8	35.0
Yang Jion (China)	3.5	5.4
Hong Kong (China)	0.67	1.0

図4　Radiation in daily life

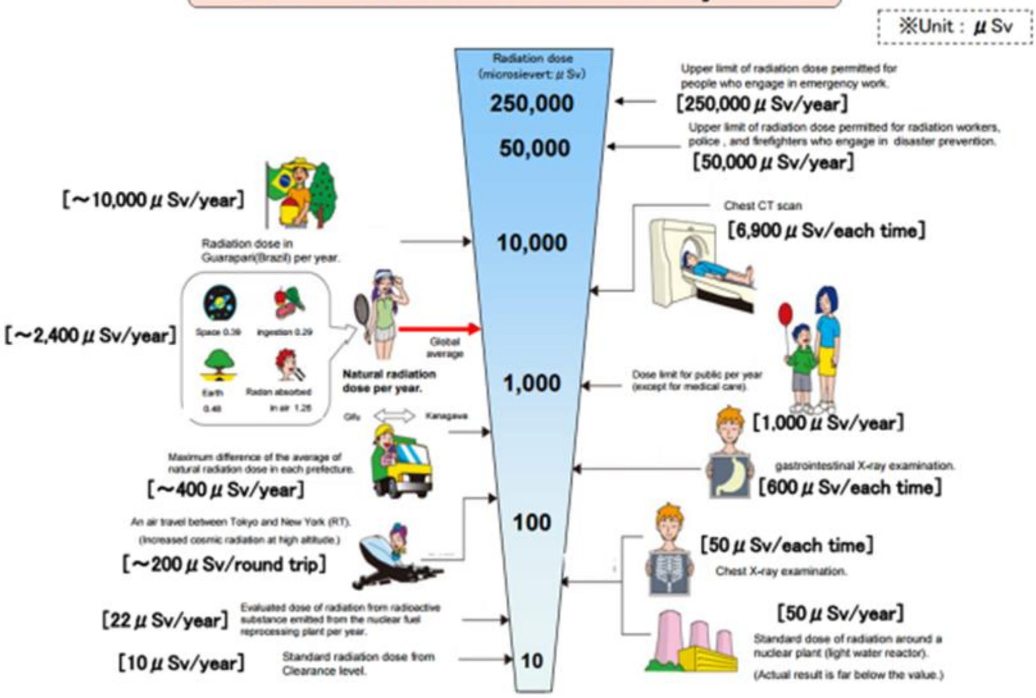
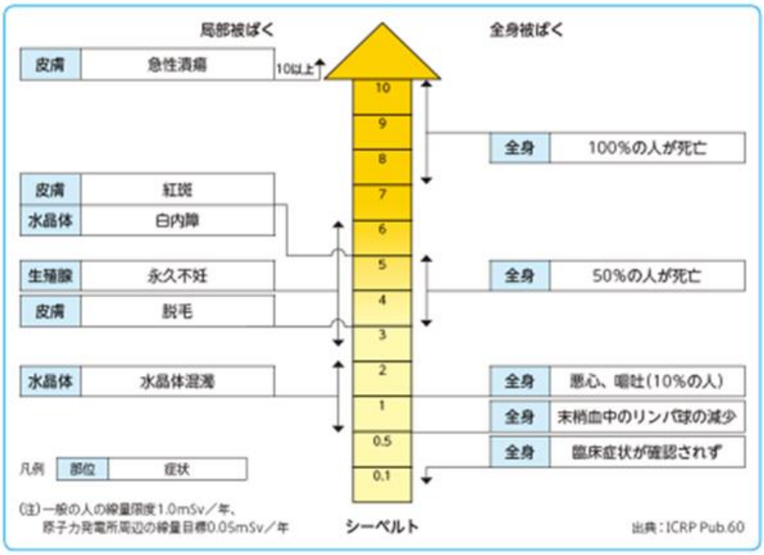


図5　放射線の人体影響



消防庁「スタート！ＲＩ　119～消防職員のための放射性物質事故対応の基礎知識～」より

結論

国民が正しい放射線・放射能の知識を持つべきです。正しく医療を受け、食料の殺菌などを理解するためです。更に原子炉事故等に伴う放射能汚染について正しく判断し、風聞に左右されないようにすべきです。そのためこういう客観的科学的知識をきちんと教育すべきでしょう。その上で恐れ過ぎず適切に行動すべきです。

御清聴有難う御座いました。

ISRE2016 (2017) 10-14

How to Explain Radiation Health Risk to The General Public: Lessons Learned from Chernobyl and Fukushima Nuclear Power Plant Accidents

Shunichi YAMASHITA, MD, PhD
Nagasaki University/Fukushima Medical University

Abstract

I have passed through many challenges and had a chance to actually realize the significance of responsibilities from the nuclear power plant accidents in Chernobyl and Fukushima on accurate evaluation of radiation risk and radiation health effects when communicating with the public. The public has similar negative feelings about terror, tragedy of the atomic bombings and nuclear accidents, frustration about the widely spread illusion of nuclear safety before the accidents. We thus face many continuous difficulties when we have to perform crisis and post-crisis radiation risk communications.

At first, we should realize that there are two types of radiation health effects: an acute radiation syndrome, the so-called deterministic effect (tissue reaction) due to a high dose radiation exposure, and chronic radiation damages and possible genetic consequences, which underlie the stochastic effects caused by the lower doses or low dose-rate radiation exposure. It is important to understand that health effects of radiation may be very different depending on the level of the dose received. Clearly, we naturally are surrounded by radiation exposures and radiological materials, even from inside our body. Therefore, we should learn comprehensively the effects of low dose and low dose-rate radiation exposure at the standpoint of daily life and consider other health risk factors.

Introduction

I was one of the medical experts and advisors on radiation health risk management to command the emergency radiation medicine in Fukushima just after the accident. At first, we tried to mitigate and block the radiation risk, especially overall health risk to the population in Fukushima in order to calm down exaggerated anxiety and mental stress immediately after the forced evacuation and later spontaneous evacuation. At present, we are meeting more challenges at the frontline of the individual risk management far beyond the principal and conventional approach to radiation protection. When we see people's feelings and difficulties of the daily lives of evacuation, we surely understand their deep damages and all negative consequences. If people could admit that "It is no use crying over spilt milk", it would be possible to forward positively radiation risk communication. However, many still suffer from post-traumatic stresses, social discrimination and inequality, and from disruption of local communities and dramatic changes of daily lifestyle; they sometimes could not avoid individual self-stigmatization. We should keep in mind when we implement a sound radiation education that the negative delayed impact of radiation exposure always influences not only physical, but also psychosocial part of life.

In this presentation, on a basis of our knowledge and own experience of Chernobyl+30 and Fukushima+5, an accurate and well-balanced way of education in radiation health risk, focusing on thyroid problems, will be introduced.

Lessons learned from Chernobyl

Chernobyl nuclear power plant accident was of outstanding importance for the issues arising after the Fukushima accident. The two accidents were different in terms of magnitude, with Fukushima's 10% of the radioactive materials released from Chernobyl. Large-scale releases of radioactive materials including short-lived iodine-131 were widely diffused around Chernobyl and even in the Northern Hemisphere around Europe. In particular, the critical problems for local residents have been that iodine-131 was found in milk from cows that had grazed on contaminated grass in areas close to Chernobyl. Because of a lack of radiation protection and insufficient food safety control, many people including infants and children were likely ingesting iodine-131 in large amounts. Iodine itself has the property to be selectively taken up by the thyroid gland and this also fully applies to iodine-131. In addition, Chernobyl is an inland area poor in natural iodine, a factor which contributed to exacerbating internal exposure of thyroids of children who were consuming iodine-131 contaminated milk. These children were exposed to an estimated dose from tens to several thousand milliSievert of thyroidal radiation. As a result, infant and thyroid cancer incidence increased rapidly in those who were children at the time of the accident. Eventually, the number of thyroid cancers continues to increase even 30 years after the accident, and has amounted to ~6,000 as of 2005, and there may be additional 16,000 cases due to radiation in European countries by 2065.

Physical half-life of iodine-131 is around 8 days so it decays quickly, but radioactive cesium remains in the environment. Physical half-lives of Cs-134 and Cs-137 are around 2 years and 30 years, respectively. Therefore, around Chernobyl, radioactive cesium was highly prevalent in animals and plants in the forest as the food chains was polluted with it. Together with vigorous efforts how to avoid internal exposure by contaminated food chain, the dose control under the safety level is always challengeable. So far, besides thyroid cancer, the incidence of other malignant tumors, leukemia and other radiation-associated diseases did not increase in the population as a result of radiation exposure. Furthermore, there were no differences in congenital abnormalities rate between cesium-contaminated and non-contaminated areas; however, the greatest health problems were the mental and psychosocial issues due to the accident itself.

The difficulties we faced around Chernobyl were how to communicate radiation health risk to the public and how to encourage their recovery from the accident given a problem of thyroid cancer. It is of a big problem for us to encourage people overcome radiophobia as well as to help them realize the accuracy of radiation health effects and risk estimates. We can explain the results of the past epidemiological studies logically and comprehensibly describe the principles of radiation protection, but far beyond from such approaches it takes time to reach the common and mutual understanding of radiation health risks.

Therefore, one of the lessons learned from Chernobyl is that beyond the emotional reaction on the event which is already in the past, we, especially experts in radiation protection, should honestly, patiently and positively support and assist the public in gaining objective perception of radiation risk. This needs to be done through the direct dialogue and various education materials because public risk perception is easily influenced by other sources of information such as the unreliable mass media and groundless rumors. Secondly, during the recovery and rehabilitation period after the Chernobyl accident, the unnecessary threat of radiation as well as over- and under-estimation of radiation risk among the residents of affected areas should be avoided. The community-based recovery together with individual-based approach would be desirable for raising the radiation protection culture in radio-contaminated areas of Chernobyl in addition to the governmental support.

Lessons learned from Fukushima

Five years have passed since the Fukushima nuclear power plant accident, a multidimensional disaster that combined to destroy, giving a serious impact to the world. Owing to the timely emergency response and prompt countermeasures that included evacuation, sheltering and control of food production and supply, the risk of radiation-associated physical consequences for residents in Fukushima is quite different from that in Chernobyl. It is considerably lower or undetectable based on the estimates of radiation doses the individuals received during the accident.

In contrast, however, there are striking similarities in the social, psychological and economic impacts between the two accidents. For example, maternal concern is a very serious and important consideration, especially for children's health and future. Wrong and misleading information of the second coming of Chernobyl evoked a profound mental damage, such as a radiophobia. Therefore, in order to support people's recovery, careful explaining radiation health risk in Fukushima is one of the key issues to be solved. Indeed, it is difficult to understand the linear non-threshold (LNT) cancer risk model used for radiation protection purposes, which does not reflect the real individual health risk. Namely, the meaningfulness of the LNT model for and biological effects of low dose radiation exposure are insufficiently understood indicative of shortcomings in relevant scientific knowledge or of even possibly erroneous conception.

To overcome an endemic of fear of radiation, several concrete actions are now taking place in Fukushima. These are a collaboration model in Kawauchi village, a series of dialogue seminars organized by the International Commission for Radiological Protection (ICRP) and a courteous explanation of the aims and results of the thyroid ultrasound examination (TUE) program to the affected population by Fukushima Medical University.

Here is one example how to improve the TUE program. After the Fukushima accident, the government established a wide-reaching health management survey in Fukushima in order to promote residents' health for a long time. Strictly speaking, surveys are not primarily scientific studies. Health and wellbeing is affected by a very large number of factors and to attribute any health effect to a particular cause, careful scientific studies that involve control groups and take into account various confounding factors are required, such as e.g. epidemiological investigations. However, explaining the difference between surveys and scientific studies to the general public is not easy, particularly explanation about the TUE, which involves highly sophisticated and technologically advanced screening method.

In Fukushima, the results of TUE clearly indicate a high detection rate of childhood, adolescent and young adult thyroid cancer, which Fukushima residents sometimes tend to associate with their radiation exposure. Accumulated health examination data, and repetitive examinations using highly sensitive equipment and standardized diagnostic protocol result in the detection of increasing number of thyroid cancer in young people. More than 140 papillary thyroid carcinomas were operated among the cohort of about 300,000 individuals aged less than 18 years at the time of the accident in Fukushima. Although the thyroid doses from potential exposure to radioactive iodines after the accident were very low compared to those around Chernobyl, misunderstanding and rumors suggesting a scenario similar to Chernobyl have evoked distress and anxiety about a rapid increase of thyroid cancer in Fukushima. This has led to an epidemic of fear that exaggerates wrong interpretation of an increase of thyroid cancer in Fukushima attributing it to radiation. Therefore, it is important for physicians and public health workers to correctly understand the reasons of the increased detection rate of thyroid cancer in Fukushima area. This is exactly due to mass screening. To avoid misreading of the results of the TUE program, there is an urgent need to quantify the magnitude of the “screening effect” as well as the risk of potential overdiagnosis in young patients.

In addition, even though the Fukushima accident is likely to result in no discernible health effects from radiation, our risk communication strategy and policy should be reconsidered and involve various stakeholders. Especially during the post-crisis period, a common knowledge about radiation protection and radiation health effects is essentially needed.

Summary

When we, medical and health care experts, challenge to tackle the difficulties, trying to find the ways how to explain radiation health risk to the public, it is essential for all of us to clearly and mutually understand that expected radiation-associated health consequences in Fukushima are quite different from Chernobyl. The risk is drastically lower or undetectable based on radiation dose estimates. This is very fortunate; it gives us a strong confidence and encouraging background how to communicate with local residents during the recovery phase. However, there are similarities between the two accidents in the social, psychological and economic impacts. Therefore, the continuation of the Fukushima Health Management Survey is essential to monitor health condition of the residents. It is also an important component of all recovery efforts to train and bring up the specialists who can take responsibility for long-term risk management regarding health effect of radiation. Our goals include overcoming and reforming the difficult and disordered situation to transform Fukushima in the future into the “Number one prefecture of longevity in Japan” based on our common human spirit of “a happiness of lending a helping hand”. Academic responses to Fukushima accident are now vital and in great demand to match the request for well-balanced radiation risk communication from the public.

References

1) Cardis E, Krewski D, Boniol M et al.: Estimates of the cancer burden in Europe from radioactive fallout from the Chernobyl accident. ***Int J Cancer*** 119(6), 1224–1235, 2006
Saenko V, Thomas GA, Yamashita S. Meeting report: the 5th International expert symposium in Fukushima on radiation and health. ***Environ Health*** 16(1): 3, 2017
2) Yasui K, Kimura Y, Kamiya K et al.: Academic responses to Fukushima disaster: three new radiation disaster curricula. ***Asia Pacific J Pub Health*** 29(2S): 99S-109S, 2017
3) Nagataki S: Minimizing the health effects of the nuclear accident in Fukushima on thyroid. ***Eur Thyroid J*** 5(4): 219-223, 2016
4) Takamura N, Taira Y, Yosida K et al.: Communicating radiation risk to the population of Fukushima. Rad Prot Dosimetry 171 (1): 23-26, 2016
5) Yamashita S, Takamura N: Post-crisis efforts towards recovery and resilience after the Fukushima Daiichi Nuclear Power Plant accident. ***Jpn J Clin Oncol*** 45(8): 700-707, 2015
6) Ohtsuru A, Tanigawa K, Kumagai A et al.: Nuclear disasters and health: lessons learned, challenges, and proposals. ***Lancet*** 386(9992): 489-497, 2015
7) Yamashita S: Tenth Warren k. Sinclair keynote address-the Fukushima nuclear power plant accident and comprehensive health risk management. ***Health Phys*** 106(2): 166-180, 2014

Correspondence: Shunichi Yamashita
Atomic Bomb Disease Institute, Nagasaki University
1-12-4 Sakamoto, Nagasaki 8528523 Japan

The contents of this manuscript were presented in part at the Fifth International Symposium on Radiation Education in Koriyama, on December 18, 2016.

The Nuclear Energy Education in Taiwan

Keh-Shih CHUANG
Department of Biomedical Engineering and Environmental Sciences
National Tsing-Hua University, Taiwan

Abstract

Tsing-Hua Open-pool Reactor (THOR), the first nuclear reactor built in Taiwan, reached its state of criticality in 1961. THOR is a reactor dedicated for research and education in Nuclear Energy. Since 1961, both College of Nuclear Science (CNS), National Tsing-Hua University (NTHU) and Atomic Energy Council (AEC) assumed the responsibility in the Nuclear Energy Education in Taiwan. While CNS offers formal education and degree to the students in nuclear engineering and science, AEC provides the general public information on atomic energy, nuclear power and radiation safety. Today, there are three commercial nuclear power plants commissioned: Chin-Shan Nuclear Power Plant (1978, 636 MWe), Kuo-Sheng Nuclear Power Plant (1981, 985 MWe), and Ma-An-Shan Nuclear Power Plant (1984, 951 MWe). The fourth nuclear power plant, Long-Men, was licensed to build in 1999 but was deferral in 2015. During these years, the public opinion on nuclear energy in Taiwan is similar to the riding of roller coaster. The society favored nuclear energy during the global energy crisis but turned to downside due to the nuclear accident and the problem in handling the nuclear waste. The Fukushima disaster in 2011 caused a significant impact on the nuclear energy policy in Taiwan. The new government proposes a nuclear-free homeland at 2025, i.e. to phase out all the nuclear power plants. The college of Nuclear Science also adjusts its structure to meet the rise and fall of the society favorite on nuclear energy. The original mission of AEC was to foster peaceful applications of atomic energy, and to coordinate international cooperation on nuclear energy. However, due to the non-nuclear policy AEC's goal also changed. In this talk, we will address the evolution of both Atomic Energy Council and College of Nuclear Science, National Tsing-Hua University, Taiwan.

Introduction

College of Nuclear Science (CNS), National Tsing-Hua University (NTHU) and Atomic Energy Council (AEC) are the two organizations responsible for Nuclear Energy Education in Taiwan. CNS is mainly for the professional education in nuclear sciences. Tsing-Hua Open-pool Reactor (THOR) (Fig. 1), the first nuclear reactor built in Taiwan and also in Asia, reached its state of criticality in 1961. THOR is a reactor dedicated for research and education in Nuclear Energy. It provided reactor operation training for Asia countries (supported by IAEA) during its early years. It also undertook medical applications of nuclear reactor such as blackfoot disease in detecting the levels of arsenic in hair and produced I-131, Na-24, and K-42 for medical examinations. Recently THOR is under evaluation of Boron Neutron Capture Therapy (BNCT) in treatment of patients with head and neck cancer and gaining great successes.

The main task of AEC is to monitor environmental radiation induced by nuclear reactor and regulate the radiation dose by the radiation equipment for medical usage. It also provides the general public information on atomic energy, nuclear power and radiation safety through internet, flyers, advertisements, publications, press conferences, exhibitions, and media.

Nuclear Reactors in Taiwan

Today, there are three commercial nuclear power plants commissioned: Chin-Shan nuclear power plant (1978, 636 MWe), Kuo-Sheng nuclear power plant (1981, 985 MWe), and Ma-An-Shan nuclear power plant (1984, 951 MWe). The fourth nuclear power plant, Long-Men, was licensed to build in 1999 but was deferral in 2015.

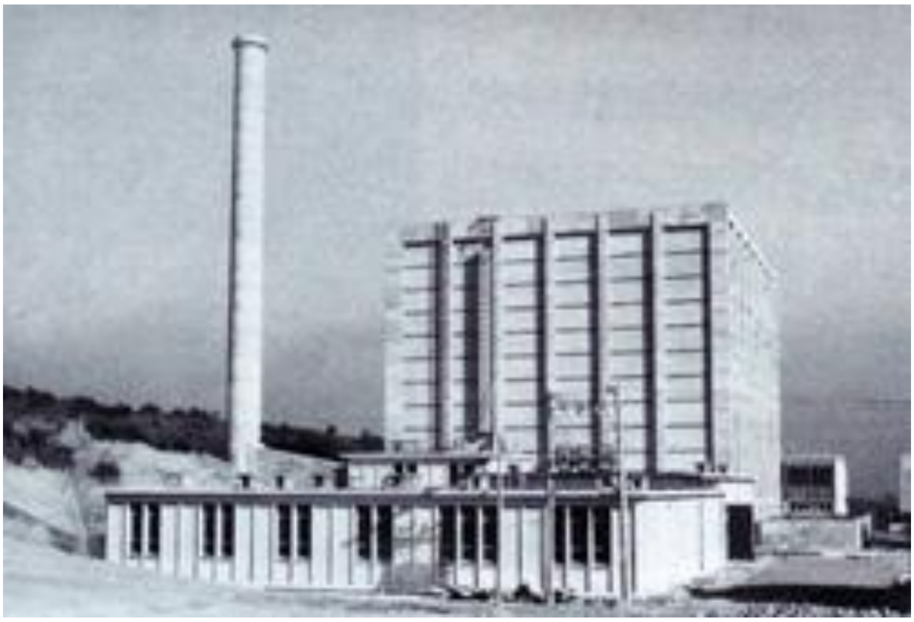


Fig. 1. THOR is the first nuclear reactor in Asia. THOR is a 2 MW, light water moderated and cooled reactor of the TRIGA conversion type. License renewed in 2011.

Evolution

The society favored nuclear energy during the periods of global energy crisis and then turned to downside due to the nuclear reactor accident and the problem in handling the nuclear waste. The Fukushima disaster in 2011 caused a significant impact on the nuclear energy policy in Taiwan. The newly elected government (2016) proposes a nuclear-free homeland at 2025 policy: (1) suspension of construction of the fourth nuclear power plant; (2) phasing out nuclear power plants; (3) searching for suitable site for the disposal of nuclear waste (3,575 tonnes of spent nuclear fuel); (4) promoting renewable energy; (5) improving power generation efficiency; (6) saving energy; (7) industrial structure adjustment; and (8) electricity liberalization.

During these years, the public opinion on nuclear energy in Taiwan is similar to the riding of roller coaster. The College of Nuclear Science also adjusts its structure to meet the rise and fall of the society attitude toward nuclear energy. In the following, we address the evolution of both Atomic Energy Council and College of Nuclear Science.

College of Nuclear Sciences, National Tsing-Hua University

The evolution of College of Nuclear Science (CNS), NTHU can be classified into 5 periods:

(1) Incubation (1956-1974)

During the Incubation period, the Institute of Nuclear Science (master program), the Department of Nuclear Engineering (undergraduate), and the Institute of Nuclear Engineering were founded in 1956, 1964, and 1970, respectively and the College of Nuclear Science was established in 1974. In these years, several professors from Japan visited CNS and contributed their knowledge to enrich the field of Nuclear Science in Taiwan. They were: 河野 宗治，原島 鮮，佐藤 德意，影山 誠三郎，小谷 正雄，濱口 博，齋藤 一夫，真田 順平，神原 富尚，菊池 千尋，赤石 準，田中 重男，and 古田 悠. In the meantime, several faculties from CNS (楊末雄，朱鐵吉，許俊男，王傳鍈) went to Japan and acquired their degrees. The frequent exchange of scholars between Japan and Taiwan is not seen today as the Japanese in Taiwan is not so popular as before. The younger generation is more fluent in English now and United States is their first choice for study.

(2) Development (1975-1994)

In the Development stage, the college continues to expand. During this time, the Institute of Radiation Biology (Master Program), PhD program in the Institute of Nuclear Engineering, and the Department of Nuclear Science (undergraduate program) were added to CNS and undergraduate program of NE Department expanded doubly.

(3) Paradigm Shift (1995-2006)

In these years, because of the anti-nuclear environment the Departments changed name to avoid "nuclear" in order to attract students. During the Paradigm Shift period, NE Department was first renamed as Department of Nuclear Engineering and Engineering Physics at 1995 and then to Department of Engineering and System Science (ESS) in 1997. Nuclear Engineering became one of the programs in the ESS Department. In 1998, Institute of Radiation Biology was combined with the Department of Life Science and became part of the College Life Science. In 2006, Department of Nuclear Science renamed to Department of Biomedical Engineering and Environmental Sciences

(4) Nuclear Renaissance (2007-2011)

Between the years 2007 to 2011, due to the Greenhouse effect (0.6^{o}C temperature increasing and caused sea level rising last century), Kyoto Protocol came into force, and rise in fossil fuel prices, USA, England, Russia, Japan, and other industrial countries supported nuclear power stations. Nuclear Renaissance term had been used to refer to a possible nuclear power industry revival. In these years, the College continued to grow: re-establishment of Institute of Nuclear Engineering and Science (master and doctoral program), establishment of Advanced Photo Source Program (with the corporation of Synchrotron Radiation Research Center), and establishment of

Interdisciplinary Undergraduate Program of Nuclear Science.

(5) After Fukushima (2011~)

In March 2011, the nuclear disaster at Japan's Fukushima I Nuclear Power Plant raised questions over the future of the nuclear energy. The nuclear-free homeland policy declared the end of nuclear energy in Taiwan. The fourth nuclear power plant was in deferral state. It can be predicted that the program of Nuclear Engineering will dwindle in the coming years. The research focus of the College gradually shifts from reactor design to nuclear waste disposal and medical applications. The Department of Biomedical Engineering and Environmental Science is considering change name to the Department of Biomedical Engineering and Medical Physics.

Atomic Energy Council

The Atomic Energy Council (AEC) was founded in 1955 at the ministerial level. Its original missions during its initial establishment were: (1) to formulate the Atomic Energy Law; (2) to foster peaceful applications of atomic energy; (3) to coordinate international cooperation on nuclear energy; and (4) to help Tsing-Hua University in the construction of THOR.

After the construction of nuclear power plants, its missions became: (1) reactor safety regulation; (2) radiation protection; (3) radwaste administration; (4) environmental radiation monitoring; (5) R&D for technology development; and (6) other civilian nuclear applications.

After Fukushima Daiichi Nuclear Disaster, due to the non-nuclear policy AEC will undergo reconstruction. Firstly, AEC will be included in the ministry of science and technology (MOST). Then INER will be renamed as Institute of Energy Research (without nuclear) and moved to under Ministry of Economic and Energy. Missions of AEC will be changed and be focused on: (1) ensuring safety during "nuclear power phase-out"; (2) regulating nuclear power plant decommissioning; and (3) radioactive waste management.

Conclusion

The evolution of the nuclear education in Taiwan reflects the society attitude toward the nuclear energy. The mission of College of Nuclear Science is to train professionals for nuclear power plant when the society is for the nuclear energy. But when the society is against nuclear energy, the focuses of the college researches switch to nuclear waste management, green energy, and medical applications. Similarly, the mission of Atomic Energy Council switches from promoting of nuclear energy to the safe decommission of nuclear power plants.

Patient-Specific Radiopharmaceutical Time Activity Curve Estimation Using External Thermoluminescent Dosimeters

Hsin-Hon LIN[1], Cheng-Chang LU[2], Shang-Lung DONG[2], Yu-Ching NI[3,4], Meei-Ling JAN[1], and Keh-Shih CHUANG[3]

[1]Medical Physics Research Center, Institute for Radiological Research, Chang Gung University/Chang Gung Memorial Hospital, Linkou, Taoyuan, Taiwan
[2]Department of Medical Imaging and Radiological Sciences, Chung-Shan Medical University, Taiwan
[3]Department of Biomedical Engineering and Environmental Sciences, National Tsing-Hua University, Taiwan
[4]Health Physics Division, Institute of Nuclear Energy Research, Atomic Energy Council, Taiwan

Abstract

In this work, we proposed a novel method to estimate time activity curve in nuclear medicine examination using serial timely measurements of thermoluminescent dosimeters (TLDs). The approach is based on the combination of the measurement of surface dose using TLDs and Monte Carlo simulations to estimate the patient-specific time activity data. Since the surface dose is connected to the cumulated activities of source organs through the radiation transport from the human body which can be pre-calculated with the Monte Carlo simulations by inputting the patient CT images, the organ cumulated activities can be estimated by solving the dose-activity equations. Therefore, the activity of each organ at the time of measurement can be simply the cumulative activity divided by the time span between measurements. Serial sets of TLDs to be read in a sequential manner were employed and each TLD set measured a fraction of cumulative activity in each organ. By connecting these timely fractional cumulative activities, the TAC can be constructed for each source organ. Preliminary results indicate that it is an effective, robust, and simple method to assess the TAC. The proposed method holds great potential for a range of applications in areas such as targeted radionuclide therapy, pharmaceutical research, or patient specific dose estimation.

1. Introduction

The biodistribution of radioactive isotopes within the patient's body is particularly useful for calculating the cumulative activities and estimating the absorbed doses in the different organs of the patient[1, 2]. Such information can be acquired by measuring the time–activity curve (TAC), a plot of activity over time of a region of interest (ROI) drawn over a tissue. Biochemical or physiological models can be fitted to the time-activity curve (TAC) to produce parametric images and convey more information than just the distribution of radioactivity in an organ[3]. However, the measurement of TAC usually requires several repetitive scans by planar scintigraphy, positron emission tomography (PET) or single-photon emission computed tomography (SPECT) at different time points. These repetitive procedures are usually time-consuming and not cost-effective. To this end, an alternative method to estimate TAC information by using external thermoluminescence dosimetry (TLD) measurements is proposed in this work.

2. Methodology

Previously works[4-6] suggested the uses of external TLD to measure organ dose. Let $S_{j \leftarrow i}$ be the dose to target j with the radiation from source i per unit cumulated activity. The total dose to an organ is the summation of the dose delivered from all source organs. Their relation is characterized by the following dose-activity equation:

$$D_j = \sum_{i=1}^{N} \tilde{A}_i S(j \leftarrow i) \tag{1}$$

where $\tilde{A}_i$ is the cumulated activity occurred within the source organ i during the time interval of study and D_j is the total dose delivered to target organ j. The S value representing the target–source organ pair[7] that can be obtained from the Monte Carlo (MC) simulation beforehand. In this study, the MC simulation was based on our house-made patient-specific dosimetry system, namely SimDOSE[8, 9]. Assuming N source organs distributed within the patient, as many as N TLDs placed on the surface around the subject should be sufficient to estimate the N source organ activities. The N unknown cumulated activities of each organ can be calculated by solving the equation (1) using the Jacobi method. Fig. 1 demonstrates the procedure example of estimating the

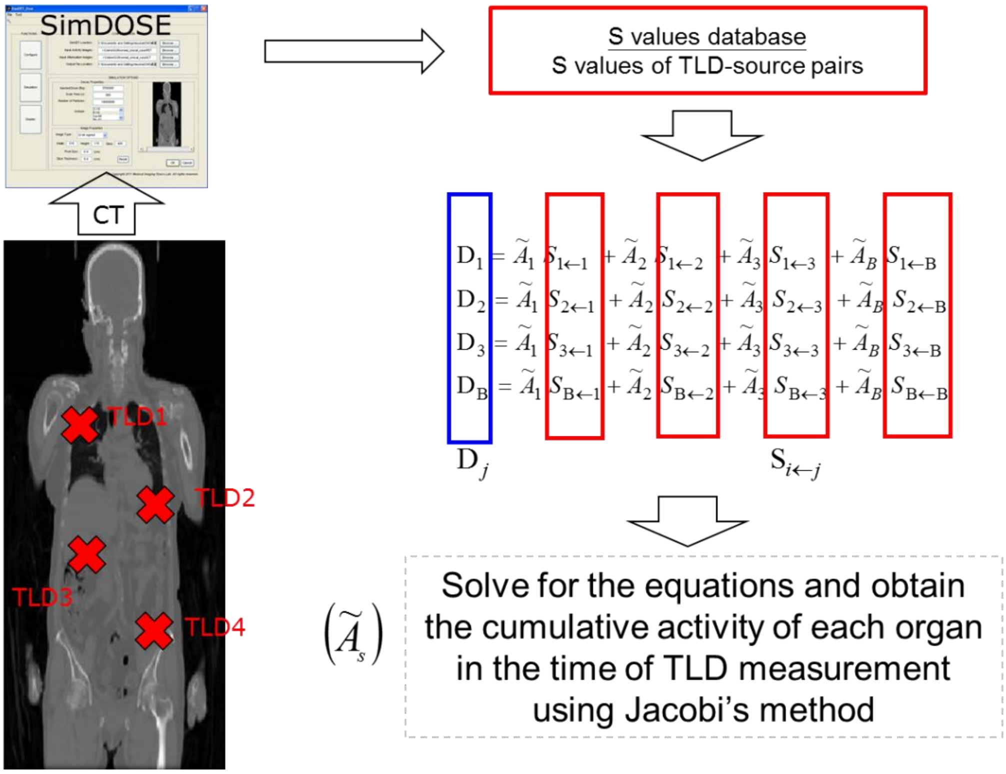
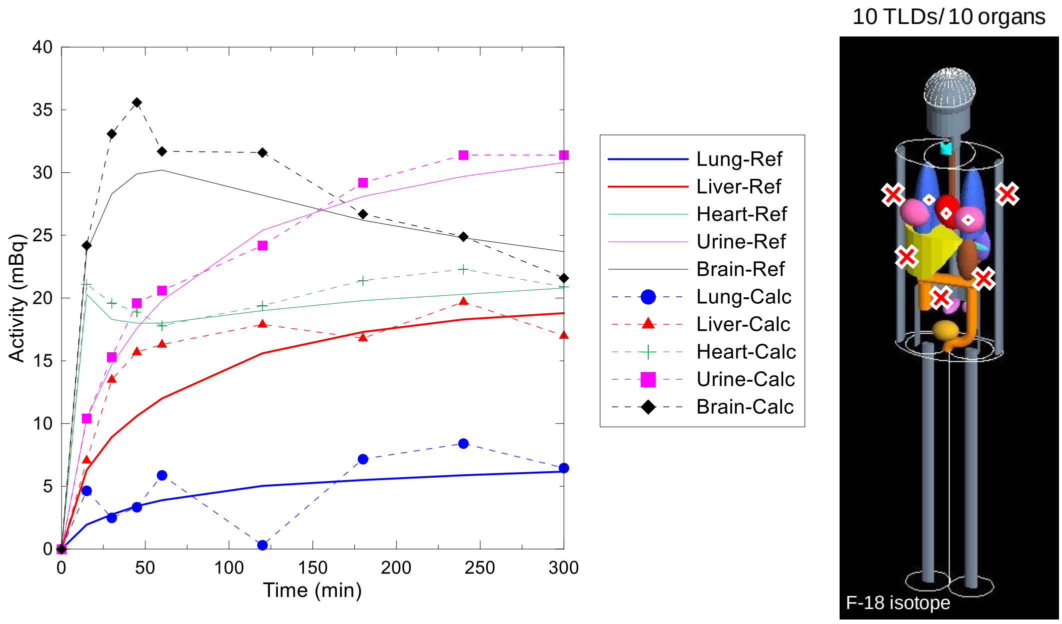


Fig. 1. The procedure of estimating the cumulative activities of each organ through the external TLD measurement and Monte Carlo simulations.

cumulative activity of each organ using the combination of TLD measurements and MC simulations. For obtaining the organ activity at different time points, one can leave the TLDs untouched for a period of time. The cumulative activity in each organ during the period of time can be calculated by performing the procedure in Fig. 1. Finally, the TAC of each source organ can be constructed by connecting these timely fractional cumulative activities.

3. Results

The effectiveness of this method was studied using a Monte Carlo simulation based on an ORNL mathematical phantom[10] with TAC in six organs (lung, heart, urine, liver, head, and whole body) during an ^{18}F-FDG study. Numerous TLDs were placed on different locations of the surface and were repeatedly read and replaced as shown in Fig. 2 (b). The TACs presented in MIRD 19 report used as input in ^{18}F-FDG uptake simulation. Note that only lung, heart, urine, liver, head, and whole body were selected as source organs and all the others (kidneys, pancreas, spleen, red marrow, etc.) were grouped together with the whole body as one homogeneous background due to their small activities from MIRD 19 report[11]. Simulations of dose measurements by using TLDs on the ORNL phantom were performed at eight temporal frames (15, 30, 45, 60, 120, 180, 240, and 300 min) after the intravenous administration of 370 MBq ^{18}F-FDG. Fig. 2(a) compares the reference TAC (solid lines) adapted from MIRD report 19 and calculated TAC (dash lines) using the proposed method for decay-corrected FDG activity in the normal human brain, heart, lungs,



(a) (b)

Fig. 2. Measurement of time–activity curves for decay-corrected ^{18}F-FDG activity in normal human brain, heart, lungs, liver, and urine by placing the TLDs on the ORNL phantom. (a) The reference TACs adapted from the MIRD 19 report (solid line) and calculated TAC using the proposed TLD method (dash line). (b) The arrangement of TLDs on the ORNL phantom.

liver, and urine. A slight deviation was found between the calculated and reference TAC, but their trends were in close agreement in general. The percent sum of squared errors (PSSE) between the reference and calculated (decay-corrected) activities was 8.94%, 17.9%, 19.7%, 11.8%, 14.1%, 5.66%, 8.19%, and 5.93%, respectively, at the time of the TLD reading.

A proof of the concept–validation experiment using a physical phantom was performed. A cylindrical water phantom (200 mm diameter with 168 mm height, A_B) embedded with three cylindrical rods (A_1-A_3) (each with an inner diameter of 54 mm and an outer diameter of 58 mm) was constructed for experimental validation of the proposed method. Various ^{99m}Tc activities were added to A_1, A_2, and A_B while A_3 remained empty with four Experimental scenarios. For each scenario, four TLDs were attached to the surface of the physical phantom (D_1–D_3 and D_B).

Fig. 3. Materials and devices used in physical phantom study. (a)TLD reader system, (b)TLD annealing oven, (c)X-ray machine, (d)TLD plate, (e) RTI solid state detector, (f) TLD set, (g)dose calibrator.

Fig. 3 depicted the materials and devices used for our dosimetric procedures of TLDs in the phantom study. A batch of Harshaw TLD-100H (LiF:Mg, Cu, P) (Fig. 3(f)) were used in this study. All TLDs were annealed for 50 min by using a Barnstead/Thermolyne furnace (Fig. 3(b)) to remove any previously stored energy. A diagnostic X-ray system (Siemens Axiom Aristos Vx Plus, Germany) (Fig. 3(c)) was used to calibrate TLDs together with a solid-state detector (Fig. 3(e)). The dose response (nC) was obtained for each TLD from a Harshaw model 3500 reader (Fig. 3(a)). Then, the absorbed dose (mGy) can be calculated by multiplying the dose response (nC) with each individual calibration factor. To avoiding the non-uniformity of absorbed dose on the TLD plate (Fig. 3(d)) due to the heel effect and the scattered radiation, the absorbed dose for each TLD was measured by placing the solid detector at its corresponding position on the TLD plate. The fading effect of TLD within 24 h was assumed to be negligible. The energy-dependence correction of TLD is not employed in the present study. A CRC-35R dose calibrator (Fig. 3(g)) was used to measure the radioactivity of ^{99m}Tc before injection into the phantom.

Table 1. Comparison of calculated and reference ^{99m}Tc time–activity distribution in the source organs with four experimental scenarios at different time points.

Experimental scenarios	Time points	Compartments					
		A_1		A_2		A_B	
		Ref	Calc	Ref	Calc	Ref	Calc
Exp 1	1st	426.2	426.7	0.0	0.0	0.0	0.0
	2nd	390.1	415.4	0.0	0.0	0.0	0.0
	3rd	347.6	340.3	0.0	1.1	0.0	0.0
	4th	309.7	318.6	0.0	0.0	0.0	0.0
Exp 2	1st	27.0	20.6	501.2	497.6	0.0	0.0
	2nd	24.4	17.9	446.6	442.8	0.0	0.0
	3rd	21.7	12.0	397.8	400.4	0.0	0.0
	4th	19.4	20.9	354.4	293.2	0.0	6.6
Exp 3	1st	0.0	61.5	0.0	66.8	499.7	371.5
	2nd	0.0	76.4	0.0	83.9	445.2	269.4
	3rd	0.0	39.4	0.0	42.6	396.6	325.0
	4th	0.0	42.1	0.0	47.1	353.3	274.5
Exp 4	1st	264.0	288.4	180.2	179.2	52.2	0.0
	2nd	235.1	259.1	160.6	164.2	46.5	0.0
	3rd	209.5	240.4	143.0	146.7	41.5	0.0
	4th	186.6	213.8	127.4	127.6	36.9	0.0

Table 1 compares the reference activities measured from the dose calibrator and the calculated activities using the proposed method for each source compartment in the physical phantom with four experimental scenarios. Due to the physical decay of ^{99m}Tc, the activity of all sources decreased with time. The calculated TAC was found to be close to the calibrated TAC for each source. The result demonstrates that the proposed method can be used to measure the TAC of internal organs based on timely external TLDs measurement. The largest error occurred for Exp. 4, where three organs exhibited activities. As a result, background activity has a crucial impact on the accuracy of estimating activities for the proposed method.

4. Conclusion

The proposed method generates TAC information of radionuclide in organs that can be further used to estimate the total dose delivered to both cancer cell and critical organs. Simulations and experiments were performed to validate the feasibility of estimating TACs using external TLD dosimeters. The TAC curves of all source organs were successfully reconstructed and were quite consistent to the simulated for the ORNL phantom or the measured for the physical phantom. Development of a prototype by integrating TLD and Monte Carlo computing for the time activity curve estimation will be further investigated in future work. Such a design has great potential for dose evaluation of the treatment planning in radionuclide therapy.

References

1) S. Shcherbinin, J. Grimes, A. Bator, J. Cwikla, and A. Celler, "Three-dimensional personalized dosimetry for ^{188}Re liver selective internal radiation therapy based on quantitative post-treatment SPECT studies," *Physics in medicine and biology,* vol. 59, p. 119-134, 2014.
2) P. B. Zanzonico, "Internal radionuclide radiation dosimetry: a review of basic concepts and recent developments," *The Journal of Nuclear Medicine,* vol. 41, p. 297-308, 2000.
3) P. Vicini, A. B. Brill, M. G. Stabin, and A. Rescigno, "Kinetic modeling in support of radionuclide dose assessment," in *Seminars in nuclear medicine*, 2008, pp. 335-346.
4) T. Nakamura, Y. Hayashi, H. Watabe, M. Matsumoto, T. Horikawa, T. Fujiwara*, et al.*, "Estimation of organ cumulated activities and absorbed doses on intakes of several labelled radiopharmaceuticals from external measurement with thermoluminescent dosimeters," *Physics in medicine and biology,* vol. 43, p. 389-405, 1998.
5) M. Matsumoto, T. Nakamura, H. Watabe, M. Itoh, and J. Hatazawa, "Estimation of organ biodistribution and absorbed dose from external measurement with TLDs in PET studies," *Medical and Biological Engineering and Computing,* vol. 31, pp. S151-S156, 1993.
6) H. M. Deloar, T. Fujiwara, M. Shidahara, T. Nakamura, A. Yamadera, and M. Itoh, "Internal absorbed dose estimation by a TLD method for-FDG and comparison with the dose estimates from whole body PET," *Physics in medicine and biology,* vol. 44, p. 595-606, 1999.
7) W. S. Snyder, *" S," Absorbed Dose Per Unit Cumulated Activity for Selected Radionuclides and Organs*: Society of Nuclear Medicine, 1975.
8) C.-C. Lu, H.-H. Lin, K.-S. Chuang, S.-L. Dong, J. Wu, Y.-C. Ni*, et al.*, "Development and validation of a fast voxel-based dose evaluation system in nuclear medicine," *Radiation Physics and Chemistry,* vol. 104, pp. 355-359, 2014.
9) K. Chuang, J. Lu, H. Lin, S. Dong, H. Yang, C. Shih*, et al.*, "Improvements on a patient-specific dose estimation system in nuclear medicine examination," *Radiation protection*

dosimetry, vol. 158, pp. 1-7, 2014.

10) E. Y. Han, W. E. Bolch, and K. F. Eckerman, "Revisions to the ORNL series of adult and pediatric computational phantoms for use with the MIRD schema," *Health Physics,* vol. 90, pp. 337-356, 2006.

11) M. T. Hays, E. E. Watson, S. R. Thomas, and M. Stabin, "MIRD dose estimate report no. 19: radiation absorbed dose estimates from ^{18}F-FDG," *Journal of Nuclear Medicine,* vol. 43, pp. 210-214, 2002.

ISRE2016 (2017) 26-30

Risk of Natural Radiation of Japanese

Michikuni SHIMO
Fujita Health University
1-98, Dengakugakubo, Kutsukake-cho, Toyoake, Aichi Pref. Japan
E-mail: shimomichikuni@sf.commufa.jp

Abstract

The cancer risk due to external and internal exposures by natural radiations was estimated using the nominal risk factor 5.5×10^{-2} Sv^{-1} adapted by ICRP. Two hypotheses were taken in estimation. One is that the health effect by radiation was caused by dose accumulated with time, without reduction effect. Another is adaption of LNT (linear no-threshold) model. The accumulated dose is taken from mean accumulated dose of each 5-years layer. The used data are the population visual statistics of Japan that released by the Ministry of Health, Labor, and Welfare, and the Japanese annual dose due to natural radiation of 2.1 mSv that was estimated by the Atomic Safety Research Association. The results are as follows; the mean dose is 95.6 mSv from mean age of 45.5, the lifetime dose is 175 mSv from lifetime of 83.5、and age-weighted mean lifetime dose is 160 mSv.

When we assume that every cancer leads to death with no-effect of treatment, the death rate of cancer exposed by natural radiation is estimated to be 0.88%, the rate to all dead to be 0.29%, and the rate to population to be 0.0029% (risk was 2.9×10^{-5}), where Japan population, annual death of Japanese and cancer death are 120,000,000, 1,200,000, 400,000, respectively.

１．はじめに

自然放射線による外部被ばくは宇宙線と大地放射線に由来し、それらの 1 年間の合計線量の世界平均値は 0.87 mSv[1)]であり、日本平均は 0.63 mSv[2)]である。これらの値を参照して、自然放射線による 1 年間の外部被ばくは、およそ 1 mSv であると言われることが多い。内部被ばくも入れた自然放射線による 1 年間の総線量は、世界平均値が 2.4 mSv、日本平均値が 2.1 mSv である。

本稿では、自然放射線によるリスクはどれぐらいかに関心がある。自然放射線レベル程度の低線量率の放射線を長期間継続的に被ばくした場合、放射線によって受けた損傷はかなり修復され、また排除されることが明らかになっているが、数量的には明らかでない。そこで、ここでは修復や排除を考慮に入れず、また、線量はどれほど小さくても発がんをもたらすと仮定（LNT モデル）する。そのために、過大で大まかな評価になるであろうことを承知の上で、自然放射線によるがん死亡のリスクの上限値を試算することになる。

２．線量

(1) 累積被ばく線量

自然放射線の被ばくは途切れることなく連続している。この時、生体に与えられた影響は残り、累積すると考えると、長期間の被ばくのリスクは、累積線量で考えなければならない。つまり、ある 1 年間で受ける線量は、年齢に関係なく同じであるが、累積線量は年齢とともに増加する。自然放射線を誰もが常に一定量を浴びていると考えると、線量は、若年層ほど累積線量が少なく、また高齢者ほど累積線量は大きい。累積線量は「年齢に比例して直線的に増加する」と仮定すると、わが国の年間線量は 2.1 mSv であるから、0 歳児の終わりでは 2.1 mSv であるが、9 歳児の累積線量は 21 mSv であり、99 歳の老人の累積線量は 210 mSv となる。

(2) 自然放射線によるリスク推定のための加重平均累積線量

自然放射線による発がんの影響を知る場合には、自然放射線による発がんで死亡した人の年齢分布データが必要であり、彼らの累積線量を知る必要がある。しかし、自然放射線のような低レベル被ばくでの発がんは、理論上考えられるが、臨床医学的に、疫学的に明らかにされないから、残念ながら、自然放射線による発がんで死亡した人に関するデータは望めない。ところで、がん死は、幼児から高齢者までの各層で見られる [3)]。ここでは、若年層のがん死は実際には少ないが、自然放射線によるがん死がどの年齢層でも同じ割合で発生し、かつそれは累積線量に比例すると仮定する。これに基づけば、自然放射線によるがん死に寄与する線量、すなわちリスク評価のための線量は、各年齢層の累積線量を加重平均した「加重平均累積線量」でなければならない。

３．加重平均累積線量の算定

(1) 算定式

加重平均累積線量 D を、次式で定義する。すなわち、

$$D = \Sigma (kN_i \cdot D_i) / \Sigma kN_i \qquad (1)$$

である。ここで、N_i は各年齢層の人口またはがん死亡者数で、D_i は各年齢層の累積線量である。k は発がんのうち放射線が原因となる割合であるが、ここでは年齢層に関係なく一定と仮定しているので、分母分子で相殺される。D は、Ni に人口を取った時は生存者の加重平均累積線量を、がん死亡者数を取った時はがん死亡者の加重平均累積線量を表す。

(2) 算定値

厚生労働省から出されている「平成 25 年の人口とがん死亡者の年齢階層別（5 年刻み）に記された統計データ [3)]」を使い、式(1)により加重平均累積線量を求めた。自然放射線による線量は 1 年に 2.1 mSv[2)] とし、年齢階層の線量には、たとえば、0-4 歳児の場合では 5 年の中間の 2.5 年分の 5.25 mSv とした。以下、同様に各年齢階層の中間年の値を取った。これを人口、がん死亡者数などと共に表 1 にデータを示した。

同表 H 欄（生涯線量と表示）に、加重平均累積線量を示したが、この 160 mSv（159.6 mSv を丸めた）が、自然放射線による発がんで死亡した個人の生涯線量の加重平均値を意味する。G 欄には各階層での被ばく線量を示した。F 欄（平均線量と表示）の 97 mSv（96.62 mSv

を丸めた）は、平成 25 年末に生きている人が、生まれてからその時までに被ばくした累積線量を階層の人口で重み付けした個人の平均線量である。

表 1　平成 25 年の生存者の平均線量とがん死亡者の生涯線量

A	B	C	D	E (B*D)	F ΣE/ΣB	G (C*D)	H ΣG/ΣC
年齢階層	人口 (人)	がん死亡者 (人)	線量 (mSv)	(人・mSv)	平均線量 (mSv)	(人・mSv)	生涯線量 (mSv)
0-4	5,239,000	83	5.25	2.75E+07		4.36E+02	
5-9	5,361,000	104	15.8	8.47E+07		1.64E+03	
10-14	5,790,000	97	26.3	1.52E+08		2.55E+03	
15-19	6,047,000	149	36.8	2.23E+08		5.48E+03	
20-24	6,205,000	176	47.3	2.93E+08		8.32E+03	
25-29	6,869,000	301	57.8	3.97E+08		1.74E+04	
30-34	7,623,000	635	68.3	5.21E+08		4.34E+04	
35-39	9,060,000	1496	78.8	7.14E+08		1.18E+05	
40-44	9,667,000	2871	89.3	8.63E+08		2.56E+05	
45-49	8,406,000	4690	99.8	8.39E+08		4.68E+05	
50-54	7,734,000	8206	110	8.51E+08		9.03E+05	
55-59	7,731,000	14,252	121	9.35E+08		1.72E+06	
60-64	9,666,000	30,891	131	1.27E+09		4.05E+06	
65-69	8,699,000	40,200	142	1.24E+09		5.71E+06	
70-74	7,596,000	49,260	152	1.15E+09		7.49E+06	
75-79	6,302,000	60,437	163	1.03E+09		9.85E+06	
80-84	4,762,000	65,554	173	8.24E+08		1.13E+07	
85-89	2,926,000	51,990	184	5.38E+08		957 E+06	
90-	1,614,000	33,292	200	3.23E+08		6.66E+06	
合計	127,297,000	364684		1.23E+10	96.62	5.82E+07	159.6

すなわち、日本人は毎年 2.1 mSv を浴びているとすると、人口全体で見たときの累積の平均線量は 97 mSv である。これは生存者の平均線量である。他方、自然放射線による発がんで死亡したと想定した場合の人の自然放射線の生涯線量は 160 mSv とみられる。

４．自然放射線によるがんリスク

(1) 名目リスク係数と前提条件

がん死亡リスクを求めるために、ここでは、放射線による発がんの名目リスク係数（nominal risk coefficient）として、ICRP Publication 103 の 5.5×10^{-2} Sv^{-1} [4] を使う。これは高

い生存率のがんも含んだ罹患率データに基づいているが、本稿では、先述したように、発がん者は治癒しないで全員死亡すると仮定する。

(2) がん死亡リスクの推定

平成 25 年は、わが国の総人口は 1.273 億人、同年の全死亡者は 126.8 万人であり、全死亡者の内、悪性新生物（がん）による死亡者が 36.47 万人であった。これを比率でみた場合、全死亡率は 0.996%で、がん死亡者に限ると 0.286%であり、死亡者の内のがんによる死亡者の割合は 28.8%である。これらを丸めた概数で見れば、それぞれ 1.0%、0.29%、29%である。

自然放射線が発がんを起こすとすると、自然放射線の加重平均生涯線量が 160 mSv（丸めた値）であるから、全がん死に占める自然放射線によるがん死の比率は、リスク係数 5.5×10^{-2} Sv^{-1} を使って、8.8×10^{-3}（0.88%）と見積もられる。

人口動態は年によって違いがあり、また経年の変動傾向も考慮すると、丸めた数値で概数として見るのが適切である。わが国の最近の人口動態の概略値として、総人口 1.2 億人、年間の死亡者 120 万人、そのうちのがん死亡者を 35 万人とすると、死亡率は 1%とみられ、死亡者のうちのがん死者の比率は 29%（人口に対するがん死亡率は 0.29%）とみられる。さらに、がん死亡者のうちで自然放射線による発がんでの死亡率は 0.88%とみられるから、死亡者に対するその比率は 0.26%と見積もられる。わが国の人口全体でみた時のリスクは、2.6×10^{-5}（0.0026%）となり、この値がわが国における他のリスクと比較できる数値となる。

これらを表 2 にまとめた。ただし、リスク係数が高い生存率のがんも含んだ罹患率から出されていることや、低線量率で長期間継続して被ばくしている間に傷害を受けた細胞の修復や除去などを併せて考慮すると、2.6×10^{-5} はかなり大きめの値である。

がん死に対する様々な原因のリスクがハーバード大学レポートで評価されている[5)]が、それによれば、「放射線・紫外線」のリスクは 2%である。両者の寄与の割合をそれぞれ 1%とすると、放射線のリスクは本稿で算出した 0.88%とほぼ一致する。日本と米国では、人種や生活習慣、食習慣、また線量など様々な面で違うにもかかわらず、発がん原因に対する自然放射線の割合は同程度と思われる。

表２　モデル人口・死亡者等による自然放射線によるがん死亡リスク

	人口	死亡者	がん死亡者	自然放射線のリスク
人数	1.2 億人	120 万人	35 万人	
率		1%	29%（対死亡者） 0.29%（対人口）	0.88%（対がん死亡者）* 0.26%（対死亡者） 0.0026%（対人口）
リスク				2.6×10^{-5}

*リスク係数（5.5×10^{-2} Sv^{-1}）×加重平均生涯線量（160 mSv）

５．おわりに

自然放射線による発がんがあると必ずしも明らかになっているわけではない。しかし、

自然放射線によるリスクがあるとすれば、上限値としてどれぐらいかを推定した。

わが国で毎日浴びている自然放射線（1 年で 2.1 mSv）に基づけば、生存している個人の加重平均累積線量は、97 mSv となり、これは年間線量 2.1 mSv にわが国の平均年齢 45.5 歳を掛けた値に等しい。放射線によるがん死という観点からみた場合、個人の加重平均生涯線量は約 160 mSv に相当するが、これは年間線量に男女の平均寿命（男 : 80.21 歳 ; 6,191 万人、女：86.61 歳 ; 6,539 万人）を加重平均した 83.5 歳を乗じた値（175 mSv）よりも少し小さい。

自然放射線によるがん死があるとしても、それは全がん死の 1%未満と見積もられる。また、わが国の人口からみた場合の自然放射線のリスクは 2.6×10^{-5} と算定された。この値は、リスク評価の分野で概ね容認されるとみられているリスクの 10^{-5} [6]と同じオーダーである。本稿で使用したリスク係数は、高い生存率のがんも含んだ罹患率から出されていること、また低線量率で長期間継続して被ばくしている間に傷害を受けた細胞の修復や排除のあることを考慮すると、実際の自然放射線によるリスクは本稿で求めたリスクよりもかなり小さいと考えられ、それゆえ、本稿で求めた値は上限値といえる。

参考文献

1) United Nations; Sources and Effects of Ionizing Radiation. UNSCEAR 2008 Report. 日本語版（放医研）第 1 巻 p.351, 2008.
2) 原子力安全研究協会；新版生活環境放射線（国民線量の算定）、p.73, 平成 23 年.
3) 厚生労働省：平成 26 年(2013)人口動態統計の年間推計、統計表第 7 表
4) ICRP; Annals of the ICRP, ICRP Publication 103, p.182, 2007.
5) Harvard Report on Cancer Prevention: Cancer Causes & Control 7, 55-58, 1996.
6) 辻本忠、草間朋子；放射線防護の基礎（第２版）、p.288, 日刊工業新聞社、1992.

要旨

外部被ばく及び内部被ばくに係る自然放射線による発がんリスクを算定した。名目リスク係数は、ICRP2003 の名目リスク係数 5.5×10^{-2} Sv^{-1} を使用した。算定では、2 つの仮定を置いた。すなわち、①放射線の生体への影響は単純な経年累積線量で、逓減効果はないとし、②しきい値のない直線仮定の LNT モデルの採用である。累積線量は、年齢 5 年刻みの加重平均累積線量を採用した。データには、わが国の平成 25 年の人口動態（厚生労働省）を使用し、また、年間の放射線量は 2.1 mSv（原子力安全研究協会；新版生活環境放射線 2011）とした。わが国の平均年齢は 45.5 歳であるから、平均線量は 95.6 mSv となり、また、男女を平均した平均寿命は 83.5 歳であるから、生涯線量は 175 mSv となり、さらに、がん死亡者に限ると、年齢加重の平均生涯線量は 160 mSv となる。

仮に、放射線により発がんした人は、治癒がなくすべて死亡すると仮定すると、自然放射線による発がんによる死亡率は 0.88%、また死亡者に対する割合は 0.29%、全人口に対する割合は 0.0029%（リスク：2.9×10^{-5}）となる。ただし、概数として、日本の総人口 1.2 億人、年間の死亡者 120 万人、がん死亡者 40 万人としている。

Nuclear Technology Education at the Secondary Level in Thailand

Thanakit LERDLU, Professional Level Teachers,
Hongsonsuksa school under the Patronage of HRH Princess Petcharat Rajsuda Sirisopaphannawadee.
E-mail: thanakit553@hotmail.com

Chuntana BOONMARK, Professional Level Teachers,
Sa-nguan Ying school, Suphanburi. E-mail: tippawan154@hotmail.com

Prayong PIYANART, Professional Level Teachers,
Princess Chulabhorn's College, Pathumthani. E-mail: prayongpccp@hotmail.com

Surat CHUMTHONG, Practitioner Level Teachers,
Sa-nguan Ying school, Suphanburi. E-mail: chedsurapatter@gmail.com

Mutita AODTON, Practitioner Level Teachers, Banchangkarnchanakulwittayaschool, Rayong. E-mail: mutita.maew@gmail.com

Khawee SUNTHORNOWARD, Practitioner Level Teachers, Banchangkarnchanakulwittayaschool, Rayong. E-mail: Khaweekub@gmail.com

Abstract

The modern development of nuclear technology has both advantages and disadvantages. In Thailand, an electric nuclear factory will be operational in 2020. Therefore, people should be informed about the positive and negative effects of nuclear technology. An authorized organization should pass this knowledge down to people. At the moment, there is no official science organization has incorporated nuclear technology into its curriculum. In accordance to this problem, the researchers of this article have discussed, surveyed, and collected data about nuclear technology education at the secondary level in Thailand. This was done in order to present the various problems with nuclear education and identify how to reform them.

The results of this study show that there are less informational resources for people or students to access. Additionally, it was found that people didn’t realize how important nuclear education is. This was further reflected in the abysmal level of nuclear technology education at the secondary level.

1. Background

Nowadays, a great number of countries benefit from nuclear energy and radiation in many aspects such as agriculture, medicine, and industry. Although the modern development of nuclear technology is necessary, this caused the crisis of fossil energy and pollution, one of the factors of severe global warming and climate change. Also, the modern development of nuclear technology has both advantages and disadvantages. In Thailand, an electric nuclear factory will be operational in 2020. Therefore, people should be informed about the positive and negative effects of nuclear technology. An authorized organization should pass this knowledge down to people. At the moment, there is no official science organization that has incorporated nuclear technology into its curriculum. Authorized organizations or schools should realize the importance of passing this knowledge down to students by adding nuclear information into the science curriculum at the secondary level. Students should be informed about these issues before entering adulthood. In Thailand, there was less content about modern development of nuclear technology in physics courses.

In accordance to this problem, the researchers of this article have discussed, surveyed, and collected data about nuclear technology education at the secondary level in Thailand. This was done in order to present the various problems of nuclear education and identify how to reform them. This study will also be presented to the fifth international symposium on Radiation Education on the 16th through the 19th December, 2016 in Japan.

Purposes

1. To study issues of nuclear education at the secondary level in Thailand.
2. To present the resolution of nuclear education issues at the secondary level in Thailand.

This article will discuss issues which were directly experienced by Physics teachers and researched from other resources. The suggestions of this article were analyzed by only the authors and a representative of Thai teachers. This article may not cover all the issues that were faced in Thailand.

2. Nuclear education at the secondary level in Thailand

The study of nuclear education in Thailand is normally a part of Physics course in higher secondary level education. In Fundamental Physics courses, the content includes radioactivity and nuclear energy. It is divided into three parts: radioactivity, radiation and human and nuclear energy. In Additional Physics courses, the content is divided into eight parts containing the discovery of radioactivity, nuclear transformation, isotope, nuclear stability, nuclear reaction, the advantages of radioactivity and nuclear energy, natural radioactivity, and its disadvantages and prevention. Actually, these courses focus on mechanics, wave, dynamics, electricity rather than nuclear education.

Banchang Kanchanakulwittaya High School (2559), Muang, Rayong Province. There are three physics teachers who teach at the higher secondary level (grade 10, 11 and 12). In grade 10, students will only study mechanics. In grade 11, students will study mechanical wave, sound wave, light wave, light qualitative physics, atomic physics, and nuclear physics. In grade 12, students will study dynamics, electricity, electromagnetic wave. At each level students will spend three hours per week studying the lesson. Additionally, all schools have holidays on which students do not attend class. Thus, teachers have to shorten each unit to teach all of material. Teachers do not teach in deep detail about the positive and negative effects of nuclear energy, but instead focus on calculation of energy because it important for student's national test or university exams. Teachers do not teach in a deep detail about positive and negative effect of nuclear energy but they focus on the calculation of energy because it is important for students' national test or university exam. Students know what the advantages and disadvantage of nuclear energy are, but they are not informed how people can use it in the most beneficial ways. In a survey where students were asked what they first thought about nuclear energy, 100 % of students said that it could make nuclear bombs and was dangerous. Teachers need to teach more about how nuclear energy can be beneficial when used in the right ways and how people can prevent the disadvantages from nuclear energy.

Sa-nguan Ying High School (2015), Muang, Suphan Buri Province. This school opens to teach students grade 7-12 and there are three physics teachers in this school. Physics courses will be taught in grade 10-12. There were two sections of physics course taught in this school. In the first section, 2008-2015, physics courses were based on the Thai national curriculum in 2008 and the Institute for the Promotion of Teaching Science and Technology. The courses are divided into The Basics of Physics and Physics 1-5. In grade 10, students study the Basics of Physics, including nuclear energy and Physics 1 (mechanics, movement, momentum, mass, and force). In grade 11, students study Physics 2, including work and energy, momentum, rotational motion, equilibrium and elasticity and Physics 3 (mechanical wave, sound wave, light wave. In grade 12, student study Physics 4 and 5. The courses includes dynamic, electricity, electromagnetic, fluid and heat, atomic physics and nuclear physics. Students have three classes per week for all levels. During the second semester, in grade 12, teachers always could never teach students the topic of physics nuclear because university exams would start before the end of school semester. Thus grade 12 students had to take the national exam without learning nuclear physics. This is the same problem that Ban Chang Wittaya School has faced. For the second section, in 2016, the Physics curriculum has been reformed. Grade 12 students have to study Physics 1-5 by finishing the first semester of grade 12. Students study fundamental Physics in the second semester so they will have time to review the lessons before taking a national test and university examination. In Thailand, at Kasetart University, there is a Department of Radiation and Isotope for students who are interested in this field. In 2015, a Sa-ngun Ying student studied in this field. At Sa-ngun Ying School, the Physics lessons are based on the objectives of the national curriculum. As part of their teaching materials, teachers also use a book written by the Institute for the Promotion of Teaching Science and Technology. In addition, teachers use a cartoon book written by the Office of Atoms for Peace. Students also present and display informational boards about the modern development of nuclear technology. As part of the National curriculum, students have to do an assessment, a basic operation, and a nuclear test.

Hongsorn Suksa High School (2016). Teachers will begin by teaching the topic of radioactivity discovery, followed by the experiment of scientists, nuclear structure, Half Life Analog Kit, comparing and radioactivity decay, analyzing isotope and mass of isotopes, nuclear forces, binding energy, binding energy to nuclear, fission and fusion reaction of nuclear energy, the positive and negative effects of nuclear and radioactivity, and finally how to prevent the bad effects of nuclear energy and radioactivity. Teachers manage the class by focusing on the scientific processes including researching, surveying, checking, recording data, discussion and data cluttering.

Conclusion

The finding demonstrates that there were problems of nuclear education in Thailand including the following:

1. There were less informational resources for students to access.
2. It was found that people did not realize the importance of nuclear education is.
3. This was further reflected in the abysmal level of nuclear technology education at the secondary level.

Implementation

1. Add more informational resources for students for access readily in anyplace.
2. Physics Teachers should help students to realize how important and beneficial nuclear energy is.
3. Add more ways to inform students about positive and negative effects of the modern development of nuclear technology.

References

1) The Institute for the Promotion of Teaching Science and Technology, Ministry of Education, 2011. Basics Physics. Bangkok.
2) The Institute for the Promotion of Teaching Science and Technology, Ministry of Education, 2011. Physics 5. Bangkok.

ISRE2016 (2017) 35-38

Radiation Education and Nuclear Power Plant in Taiwan
台湾における放射線教育と原子力発電所について

Chin-Wang HUANG
黄　金旺
Emeritus Prof., Chung Yuan Christian University,
台湾中原大学栄誉教授
200, Chung Pei Rd,Chung Li,Taiwan 32023,RO.C.
台湾桃園市中壢区中北路 200 號
E-mail: yt_huang@cycu.edu.tw

Abstract

Radiation education at school and the current state of the nuclear power plant in Taiwan are described. In compulsory education, radiation education and radioactivity education are not so much accomplished. The explanation of radioactive materials using a periodic law table is mentioned during "natural life and science technology" by science of a junior high school. Safety of radiation, division chain reaction and nuclear fusion reaction are mentioned about an X-ray at a high school. A chapter of nuclear physics and nuclear chemistry is in the general physics and the chemistry texts of a university, but the majority teachers actually do not lecture.

There are four nuclear power plants and six nuclear power plants are working at present in Taiwan. A problem describes some facts to administrative correspondence of a government in a safety management side in a nuclear power plant.

１.はじめに

台湾における学校での放射線教育と原子力発電所の現状について述べます。
義務教育では、放射線教育及び放射能教育はあまりなされていません。中学校の理科で、「自然の生活と科技」の中に周期律表を用いた放射性物質の説明が載っています。高校ではX線について放射線の安全性、核分裂連鎖反応及び核融合反応が記載されています。大学の一般物理と化学の中に、核物理と核化学の章がありますが、大部分の教員は講義していないのが現状です。

台湾には4つの原子力発電所があり、現在6基の原発が稼動しています。原発の安全管理面で、政府の行政的な対応に問題があることなど述べます。

２．学校における放射線教育について

台湾の小・中学校の義務教育の就学率は、95%以上に達成されています。義務教育における、放射線と放射能に関する教育は、あまりなされていないのが実情です。小学校の理科に「自然と生活科技」がありますが、その主な内容は太陽の光のエネルギーを利用した

電球の発光について述べているだけです。

2011 年 3 月 11 日、東日本に大地震と大津波が発生し、莫大な被害が起こりその結果、東京電力福島第一原子力発電所の原子炉が水素爆発し、放射性物質による汚染おこしたことが、台湾で特別に注目されています。今まで、中学校の授業が軽視している、放射線の知識の内容を改めて、少しばかり充実されています。最近の中学校理科「自然の生活と科技」の中に、周期表の発明者とともに原子番号が 92 より大きい超ウラン元素は人工的に造られ、原子核の性質が不安定なため短時間で安定な元素に変化する、との紹介があります。また、このような性質をもった元素が放射性物質で、マリー・キュリーが放射能の研究でノーベル物理学賞（1903 年）とラジウムとポロニウムの発見でノーベル化学賞（1911 年）と 2 回受賞したこと、同位元素（同位体）は原子構造が異なっているが、化学的性質は同じであるとの説明があり、例として、$^{1}_{1}H$ および $^{2}_{1}H$ が挙げられています。

高校の理科に「基礎物理と基礎化学」があります。基礎物理のエネルギーの項目に、X 線の発見とその応用について、X 線の性質は電気および磁力に影響されないが、感光性があることが載っています。また、その応用は、結晶構造の解析、生物の品種改良、医学的な診断、そして空港の手荷物検査などに利用されていることが書かれています。放射線の安全に関しては、α、β、γ 線それぞれの放射線強度の比較、放射線の強さは、距離の二乗に反比例し、時間に正比例の関係にあるなどが記されています。また、日常生活中での放射線量について、台湾一般居住民の自然放射線量の平均値は年間 2 mSv、また日常生活中の放射線量の図が掲載されています。コバルト-60 による局部照射（全治療）の放射線量は、60.000 mSv 、テレビジョンから 3 m の距離で毎日 1 時間見るとすると、年間の放射線量が 0.01 mSv と述べられています。

核分裂連鎖反応については、ウラン-235 に熱中性子を照射すると核反応が起こると説明されています。その核反応のときに放出された熱を、原子力発電所で発電に利用しています。火力発電所は大量の二酸化炭素ガスを排出して、酸性雨が発生し環境に悪影響を及ぼすことがあります。そのほかに、核融合についても触れていますが、簡単な紹介に留まっています。

基礎化学の化学とエネルギーの項目では、核反応前後の質量数の変化によるエネルギーの算出は、アインシュタインが提出したエネルギーと質量の式（$E = mc^2$ ） から求めます。核分裂反応は、熱中性子による反応で、

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{52}_{36}Kr + 3\ ^{1}_{0}n, \quad ^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{54}Xe + ^{90}_{38}Sr + 3\ ^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{57}Cs + ^{93}_{37}Rb + 3\ ^{1}_{0}n, \quad ^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{54}Xe + ^{90}_{38}Sr + 3\ ^{1}_{0}n$$

などの式から核反応により放出されるエネルギーを算出します。

核融合は二つの軽い原子核が、超高温度の条件下において核反応を起こし、より重い原子核に変わる際に大量のエネルギーを放出します。たとえば、$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ +エネルギーで、太陽の中では核融合反応が引き起こされています。また、東京電力福島第一原子力発電所事故も紹介されています。

３.台湾の原子力発電所について

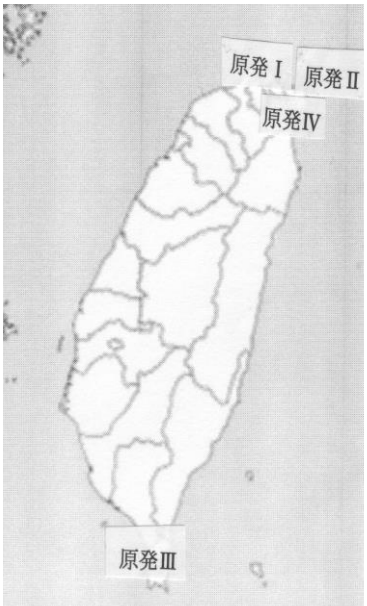


Fig. 1. Atomic power station

大学の一般物理と化学には、英文版と中文版の教科書が多数あります。その中には、核物理と核化学が関連している章がありますが、大部分の教員はこれらを講義していません。ただし、ラジオアイソトープ(RI) と放射線の使用者は、国家試験をパスして初めて使用の資格が得られます。政府は、原子能委員会を設置し、RI と放射線を全国統一して管理を行っています。原子力発電所は、経済部（通産省）に付属しておりますので、安全管理については、スムースに統括することが困難であると感じています。また、県政府には放射性物質の管理組織制がなく、一般大衆は RI、放射線に対して無知の状況です。

台湾には、四つの原子力発電所が設置されています。原発I、原発II、原発IIIは運転中、原発IVは近いうちに建設が完了し、安全審査がなされます。Fig. 1 と Table 1 から、原発I、原発II、原発IVは台湾の北部にあり、原発IIIは南部にあります。原子力発電所を設置する地域の選択には、まず活断層がある地震帯と人口密度の高い場所を回避することが先決と考えます(Fig. 2)。

Table 1. Atomic nuclear power stations

	原発I	原発II	原発III	原発IV
場所	新北市 石門区	新北市 萬里区	屏東県 恒春鎮	新北市 貢寮区
運転	*1. 1978.12 *2 1979.7	1981.12 1983.3	1984.7 1985.5	______ ______
容量	1,272 kw	1.970 kw	1.902 kw	2,750 kw
型式	BWR	BWR	PWR	BWR
停止	2019.7	2023.3	2025.5	

しかし台湾の原発I、II、IVの原発は、いずれも設置条件に合致しておりません。今までは、原子力発電所の事故演習は、毎年 1 回おこなわれています。原発から半径 5 km 圏内の少数市民が事故演習に参加していましたが、最近やっと 9 km 圏内に拡大されました(Fig. 3)。福島第一原子力発電所事故を考えると、台湾でこのような状況は、政府経済部の非常に無責任なやり方であると思います。

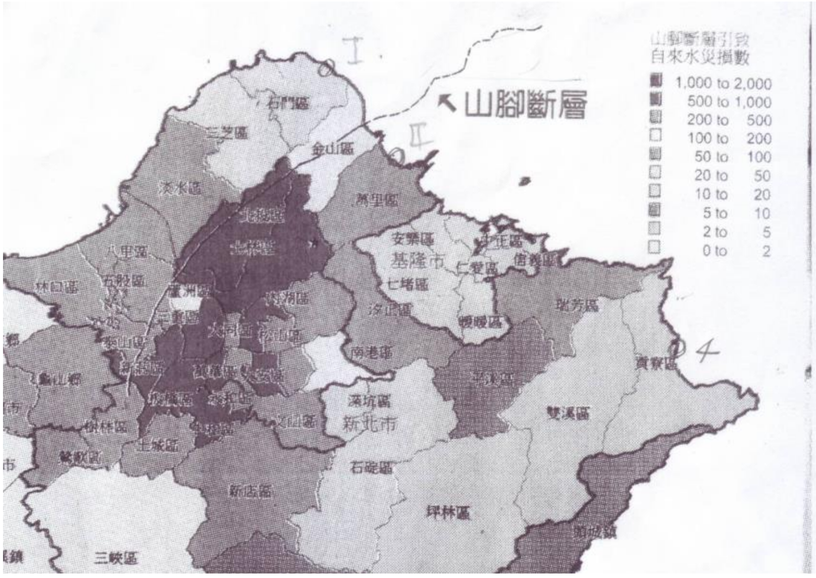


Fig. 2.　Fault of north in Taiwan

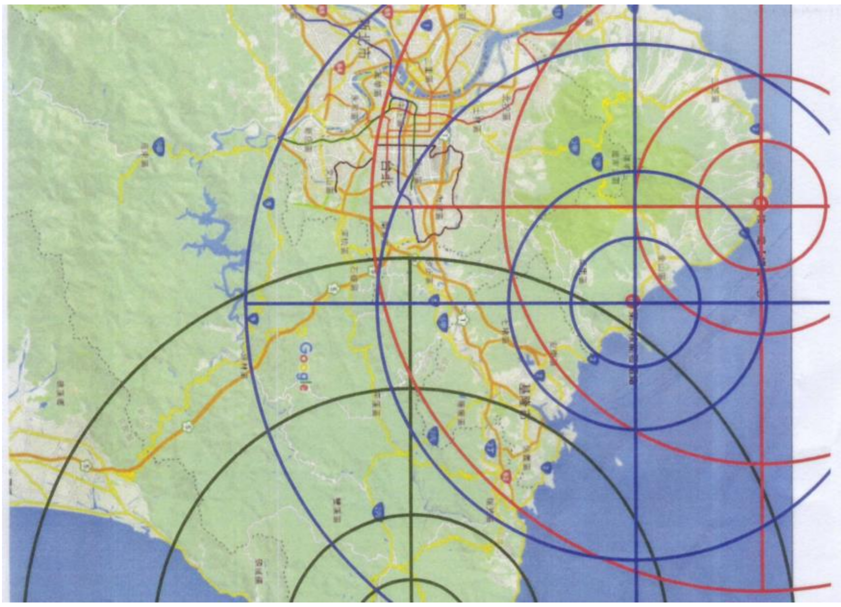


Fig. 3.　Distance from atomic nuclear power station

４．最後に

以上、台湾の一般市民の放射線・放射能の知識不足、さらには管理者の放射線に対する安心・安全思考の軽視の傾向があり、いろいろな課題が山積しています。このような情況から今後益々、放射線教育の充実を図っていくことが重要と考えています。

ISRE2016 (2017) 39-47

An Example of Lectures on the Nature of Radiation for General Public

Hiroshi KUDO
Professor Emeritus of Tohoku University
Tohoku Radiation Science Center, Chuo 2-8-13, Aoba-ku, Sendai 980-0021, Japan
E-mail: kudo.hrs@nifty.com

Abstract

To make general public interested in and familiar to radiation, the author has given lectures on the basic science of radiation for more than a decade. Because scientific literacy of general public is limited, it was sometimes hard to let people understand what radiation is and how it interacts with matter, within a limited time available for the lecture. After the FUKUSHIMA nuclear accident in 2011, however, the situation has dramatically changed: a lot of Japanese people worried about health hazards of radiation, stirred up mainly by mass media that emphasized only risks of radiation even at the dose as low as 1 mSv. Variety of news put the society into confusion for a while. At present, more than 5 years since the nuclear disaster, the confusion has almost settled down and most of the people fairly accept not only the risk, but also the benefit of radiation. The author presents an example of his lecture, by which the audience could understand the nature of radiation. To know fundamental features of radiation such as the origin and interactions with matter would help the audience to feel safe from danger of radiation in their daily life.

1. Introduction

Many Japanese vaguely fear radiation and think that they will not be exposed to radiation if there is no nuclear power station. On the other hand, however, many Japanese are pleased to visit hospital for diagnosis using radiation. Their contradictory behavior would come from a lack of radiation literacy due to a limited chance of radiation education. In fact, the teaching of radiation in a Japanese junior high school has restored in 2012 for the first time in 30 years.

From experience of giving lectures about radiation to general public for more than a decade, the author found some key factors of letting them interested and understood what radiation is and how it interacts with matter. One of the significant factors is to give a lesson of radiation as a “science class”, not only for pupils in school, but also for general public. The learning of basic science of radiation can make an audience feel secure for a low level of radiation, although they would probably like to know definite radiation effects on living bodies, particularly for the people living in Fukushima.

In the present paper, the author will introduce a science talk on the nature of radiation with emphasis laid on its origin and interactions with matter. It is stressed that radiation is not necessarily special, but ubiquitous in the environment. Knowing its origin and nature, people would be able to express reasonable fear about a risk caused by radiation.

2. An example of the talk "The nature of radiation: Its origin and interactions with matter"

Two years after the nuclear accident of Fukushima Daiichi Nuclear Power Station, Fukushima Prefecture, Japan, the author was invited to talk about radiation to people evacuated from Katsurao-mura that is a village where all residents left after the nuclear accident in 2011. That was his first occasion to talk in front of the evacuees from the nuclear accident. The big confusion stirred up mainly by mass media immediately after the accident excluded the talk on real nature of radiation. Scientists who told that the exposure of radiation as low as 1 mSv had no risk were hardly trusted and did not invited to talk in front of the evacuees immediately after the accident. But after the talk on that day, the author was pleased to hear from audiences that the talk helped them to understand the real risk of radiation and they were encouraged to be back to their home as soon as possible. "We should have heard today's talk earlier," they added.

In the following described are the main subjects of the talk.

2.1 Introductory remarks

Someone believes that there is no radiation if we have no nuclear power plant. But this is misunderstanding with prejudice. Huge doses of radiation, like in a core of nuclear reactors, causes a big risk for health, but radiation itself is ubiquitous in the environment, albeit low in dose. Knowing its origin and nature as well as its interaction with matter, we will be able to express reasonable fear about radiation. This is a basis of the lecture, and the author gave the lecture in an atmosphere making the audience feel themselves to be attending in a "science class" of high school.

2.2 The origin of radiation

The source of radiation is a nucleus in the atom as illustrated in Fig. 1. And radiation is ubiquitous in the environment, because everything in our world is ultimately composed of various atoms. The atom comprises of a nucleus with positive charges and electrons (e^-) with a negative charge. The size of an atom is around a few ångström (Å) or ~100 picometers [pm, 10^{-12} m] and that of the nucleus is in a order of femtometers [fm, 10^{-15} m]. The nucleus is composed of protons with a positive charge and chargeless neutrons. The mass of both particles is about 1 atomic mass unit [u] and that of an electron is 1/1840 of a proton or a neutron.

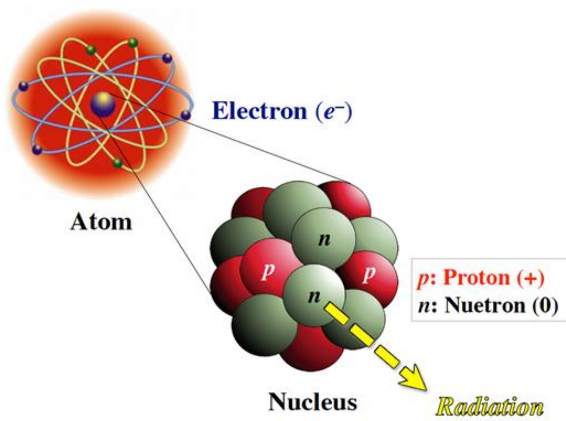


Fig. 1. A model of the structures of an atom and a nucleus.

2.3 The mass number and nuclear structure

Immediately after the nuclear accident in Fukushima, 2011, we have frequently read such words as "Radioactive iodine-131 and radioactive caecium-137" in newspapers or on TV. These digits 131 for iodine-131 (^{131}I) and 137 for ceasium-137 (^{137}Cs) are called the mass number, and indicate directly the feature of nuclei. The mass number means the sum of protons and neutrons in a nucleus, and we can understand that ^{137}Cs with the atomic number 55, for instance, has 82 neutrons in the nucleus (Fig. 2). The number of neutrons is of importance, because there are many isotopes in the same element; the isotope means nuclear species with the same number of protons but different in the number of neutrons such that ^{133}Cs, ^{134}Cs and ^{137}Cs. Of these isotopes; ^{133}Cs is not radioactive but stable, while both ^{134}Cs and ^{137}Cs are radioactive. The difference between ^{134}Cs and ^{137}Cs are in the nuclear character such as the half-life, ~2 years for ^{134}Cs and ~30 years for ^{137}Cs, as well as the energy of emitted radiation.

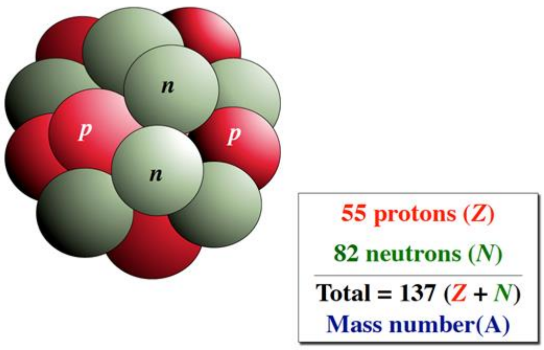


Fig. 2. The nuclear structure of caesium-137 (^{137}Cs) consisting of 55 protons and 82 neutrons.

The atomic number is equal to the number of protons in the nucleus. We usually place the mass number on the left shoulder of the symbol of an element, like ^{137}Cs, but we do not need to put the atomic number because the symbol of a chemical element holds the atomic number as shown in Fig. 3. We use another term "nuclide", that represents every nuclear species with the mass number to the symbol of an element like ^{2}H, ^{4}He, ^{137}Cs and ^{235}U regardless of elements. More than 3000 nuclides are known until now and 90% of which is radioactive nuclides with a variety of half-1ife from picoseconds to 14 Giga years (^{232}Th).

2.4 The real nature of radiation

The radiation is defined as "moving energetic particles or photons" emitted from nuclei, but it sounds a little bit difficult for general public to understand. Although such names of radiation as α rays, β rays and γ rays are popular, most people do not know what the radiation is, because it is difficult to see on eyes. The first radiation was X ray, which was discovered in 1895 by German physicist W. C. Röntgen. He named it as X rays because of the faint nature of it at that time, albeit supposed to be unseen light. But the use of X rays spread rapidly all over Europe to take photographs inside the living body, and Röntgen received the first Nobel Prize in physics in 1901. Hearing the Röntgen's discovery of strange rays, French physicist A. H. Becquerel noticed that something unknown was emitted from uranium ore, and named it as alpha radiation later. At the same time, French physicists Pierr Curie and Marie Curie found so called α rays emitted from newly discovered radium. And these three

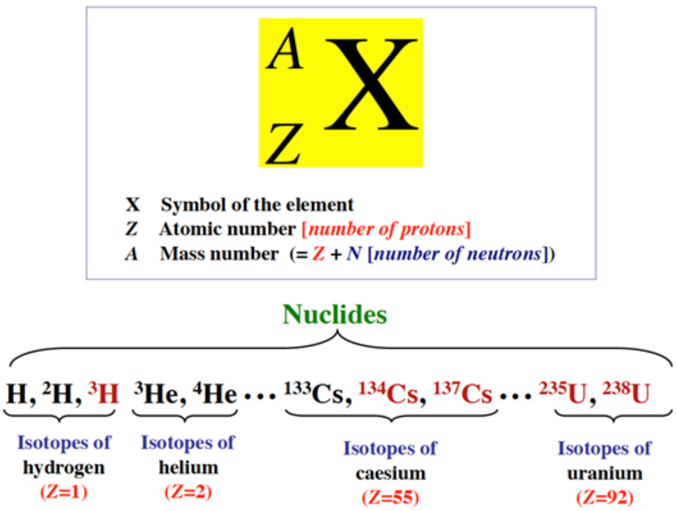


Fig. 3. The terms element, isotope and nuclide.

scientists received the Nobel Prize in discovery of spontaneous radioactivity and radiation phenomena in 1903.

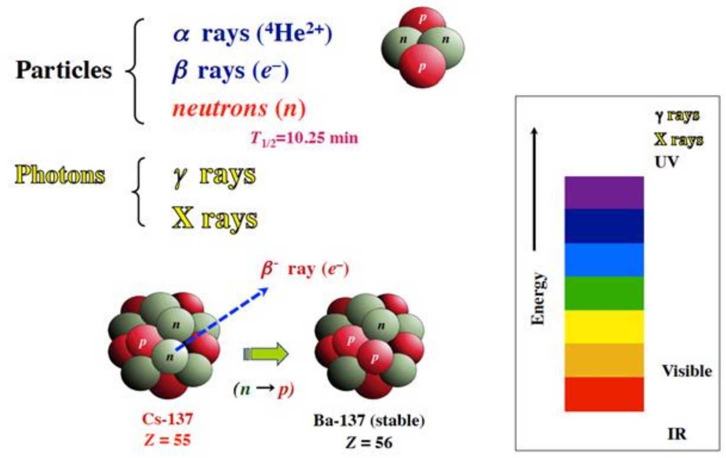


Fig. 4. A variety of radiation that defined as moving energetic particles or photons emitted from nuclei; the X ray is emitted from atomic shells.

At the present time of more than 120 years since discoveries of radiation, we know the real nature of radiation: X ray is the photon (a few keV in energy) emitted from atomic shells, α ray the bunch of 2 protons and 2 neutrons (*i.e.* $^4He^{2+}$) emitted from nuclei heavier than bismuth (Bi), β^- ray the high-energy electron (e^-) emitted from nuclei and γ ray the high-energy photon emitted from nuclei, as summarized in Fig. 4.

2.5 Interaction of radiation with matter

Radiation interacts mainly with electrons in atoms comprising materials including living bodies, and the interaction occurs when radiation is absorbed in the material, because the energy carried by radiation is transferred to or deposited in constituent atoms of the material. The main processes are ionization and excitation of the electron shells, resulting in production of active chemical species such as ions, radicals and solvated electrons (Fig. 5). The term "active chemical species" sounds rather difficult, but the audience would be familiar to "active oxygen." If such active species play hazardous roles in living bodies, the radiation is a risk to health. On the contrary, if such active species play therapeutic roles for cancer, for instance, the radiation is of a great benefit to our life.

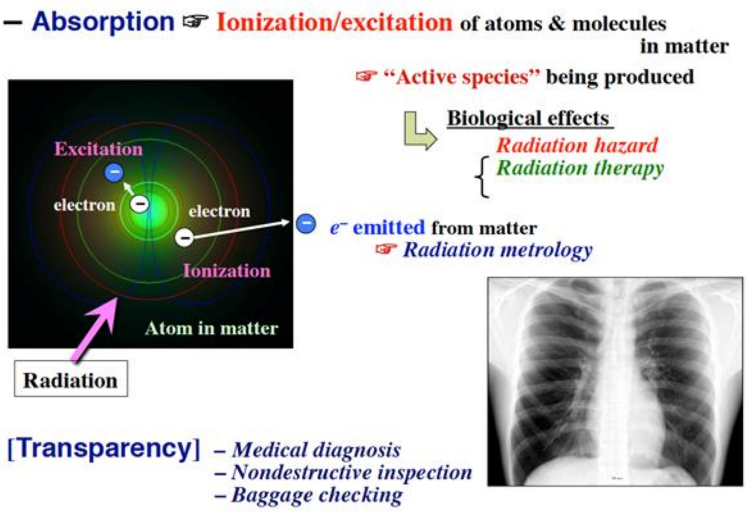


Fig. 5. Interactions of radiation with matter.

When radiation interacts with gaseous species, electrons (e^-) are emitted through the ionization processes. And we can use such electrons to detect the radiation; *e.g.* a G-M (Geiger-Müller) counter and an NaI scintillation survey meter.

Radiation penetrates through matter and can be used for medical diagnosis such as an X-ray photograph taken by using X rays, as most of us have experienced. The X ray is widely used also in industries as a significant mean of a nondestructive inspection and we are familiar to a baggage inspection at airports.

The penetrability of radiation varies depending on the kind of radiation. As illustrated in Fig. 6, α rays do not penetrate a sheet of paper, while β rays penetrate a sheet of paper but stop at a thin plate of aluminum. The X rays as well as γ rays stop at a thick plate of heavier metals like iron and lead. Neutron beams are somewhat strange and stop in water as well as in concrete blocks through elastic collisions with protons in the water (H_2O). Radiation is defined as "moving energetic particles or photons", and it is not radiation anymore when these particles or photons stop at such shielding materials as paper, metals and concrete. It is instructive to note that helium gas filled in balloons, for instance, is an underground resource resulting from energetic $^4He^{2+}$ particles; *i.e.* the origin was α rays emitted from uranium and thorium ores in the earth's crust.

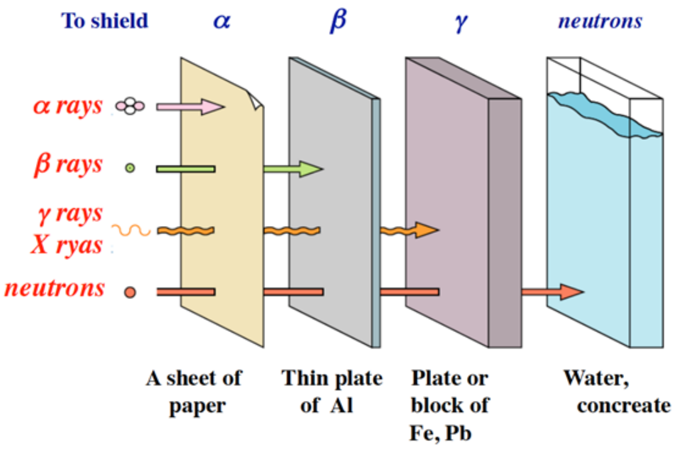


Fig. 6. Depiction of penetrability of α, β and γ rays as well as neutrons. When the particles or photons are stopped, they are not radiation anymore.

2.6 Radiation and radioactivity

Confusion is seen in the use of technical terms "radiation" and "radioactivity." It should be clarified as follows: Radiation like α, β and γ rays are substantial because they are moving energetic particles or photons emitted from radioactive materials or radionuclides, albeit unseen. On the other hand, the radioactivity is a concept or definition. One of the concepts is a natural character of spontaneous emission of radiation from matter; used by A. H. Becquerel for the first time in 1896. At present, the radioactivity is defined as the number of atoms decaying every second and its unit is becquerel [Bq] in the SI system. Namely, the meaning of radioactivity is the amount of radioactive materials or radionuclides, although most of Japanese mass media use it with a meaning of radioactive materials in confusion.

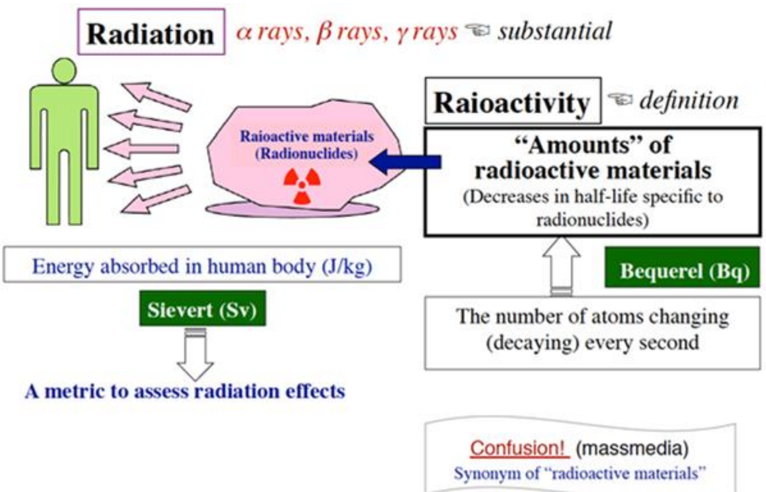


Fig. 7. The terms radiation and radioactivity.

The unit of the radiation dose or equivalent dose is sievert

[Sv], which is used for assessing radiation effects on a living body, derived from the energy absorbed in matter (kJ/kg) by exposure to radiation, expressed in the unit of grey [Gy]. The comparison of radiation and radioactivity is summarized in Fig. 7.

The radioactivity decreases at a constant rate specific to a nuclide, and the reciprocal of the rate is called a half-life ($T_{1/2}$) which is the amount of time that it takes to lose half its radioactivity as shown in Fig. 8, and the inset of this figure lists half-lives of popular nuclides such as ^{131}I ($T_{1/2}$ = 8 days) and ^{137}Cs ($T_{1/2}$ = 30 years). The shortest half-life listed here is 15 hours for ^{24}Na and the longest is 4.5x10^{9} years for ^{238}U.

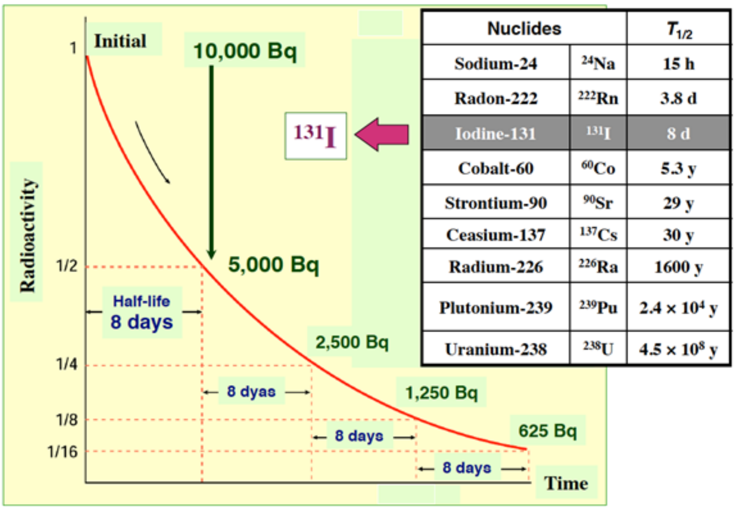


Fig. 8. A feature of 8-days half-life of iodine-131 (^{131}I) and a list of half-lives for some nuclides.

In addition to the "physical half-life" of radionuclides mentioned above, we sometimes use another half-life called a "biological half-life" as shown in Table 1, that is used when we discuss a risk of internal exposure of radiation from ingested radioactive materials.

Table 1. Biological half-life and physical half-life.

Nuclide	Biological half-life (T_{bio})		Physical half-life (T_{ph})	Effective half-life (T_{eff})
Iodine-131 (^{131}I)	Babies	11 d	8 days	4.6 d
	5 years old	23 d		5.9 d
	Adults	80 d		7.2 d
Ceasium-137 (^{137}Cs)	0 ~ 1 year old	9 d	30 years	9 d
	2 ~ 9	38 d		38 d
	10 ~ 30	70 d		70 d
	31 ~ 50	90 d		89 d

Consumer Affairs Agency, Japan (25 Aug. 2011)

2.7 Exposure to radiation in daily life

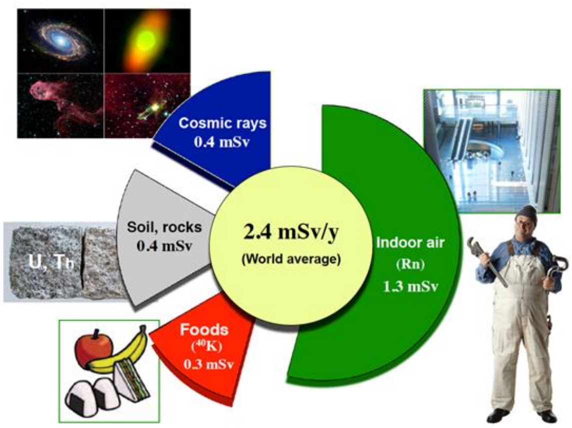


Fig. 9. World average doses a year for living bodies in daily life on the earth.

As shown in Fig. 9, we are exposed to 2.4 mSv of radiation a year on world average. That is the sum of 0.4 mSv from cosmic rays, 0.4 mSv from the ground containing uranium (^{238}U) and thorium (^{232}Th), 1.3 mSv from radon gas (^{220}Rn, ^{222}Rn) inhaled from indoor air and 0.3 mSv from daily ingestion (^{40}K). Potassium is one of the essential elements for living things and our muscle contains 0.2% of potassium. Although the natural abundance of ^{40}K ($T_{1/2}$ = 1.3 x 10^{9} years) is as low as

0.01%, the equilibrium radioactivity of ^{40}K in our body resulting from ingestion through everyday life is calculated to be around 4000 Bq for a person with 60 kg of weight as shown in Fig. 10, and the equivalent dose from ^{40}K is estimated to be about 0.3 mSv a year. This figure also depicts the typical radioactivity of ^{40}K in a kilogram of foods (Bq/kg) such as rice, spinach, fish, seaweed and milk. The value is clearly high in the potassium chloride (KCl) fertilizer widely used in agricultural fields.

2.8 Typical affairs associated with exposure to radiation

To discuss a health risk caused by radiation, it is instructive to pick up typical affairs associated with the exposure to radiation. Table 2 lists the related affairs as a function of the equivalent dose (mSv). Although it is difficult to make clear the clinical symptom at exposure to radiation below 200 mSv, a temporary decrease in the number of leucocyte in blood becomes clear around 500 mSv. In this respect, a twice a year of blood tests are obliged in Japan for persons working in a controlled area for radiation, in addition to the official dose limit of 50 mSv a year and 100 mSv in very five years. Above 4000 mSv of exposure for a whole body is so dangerous as 50% of persons will die within 30 days. In Japan, a huge number of persons were killed in exposure to terribly huge doses of radiation

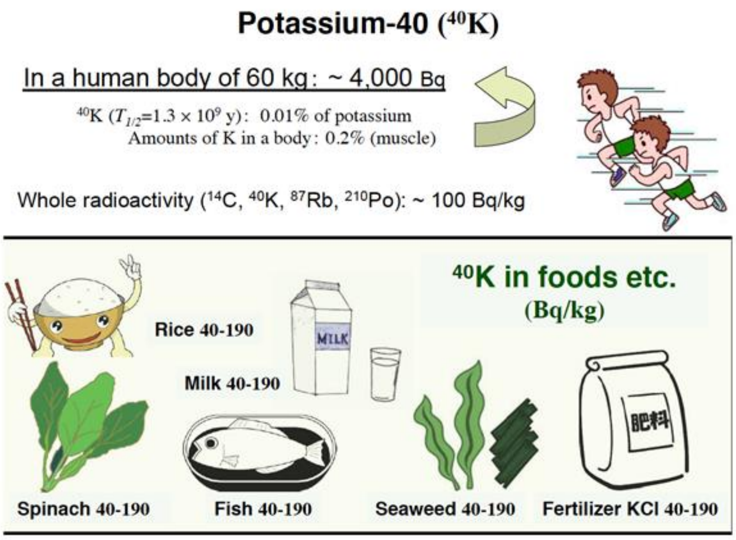


Fig.10. Radioactivity of potassium-40 (^{40}K) in muscle of living body taken from foods we ingest in daily life.

Table 2. Typical affairs associated with exposure to radiation.

Dose/mSv	Affairs
4000	**50% Death within 30 days**
2000	Loss of hair
1000	Abrupt decrease of lymphocyte (vomit, feel tired) 5%-increase in death risk of cancer (☜ ICRP)
500	Temporary decease of leucocyte (lymphocyte)
250	Emergency dose limit for workers
200	Clinical symptom not observed
100	**5-year dose limit for workers in controlled area**
50	1-Year dose limit for workers in controlled area
6.9	CT diagnosis of chest with X rays (once)
2.4	Exposure to natural radiation for 1 year (World average)
1.0	**1-year dose limit for general public** (☜ ICRP)
0.6	X-ray diagnosis of stomach (once)
0.2	Boarding for NY from Tokyo (a round trip)
0.05	X-ray diagnosis of chest (once)

induced by the explosion of nuclear bombs in Hiroshima and Nagasaki in 1945.

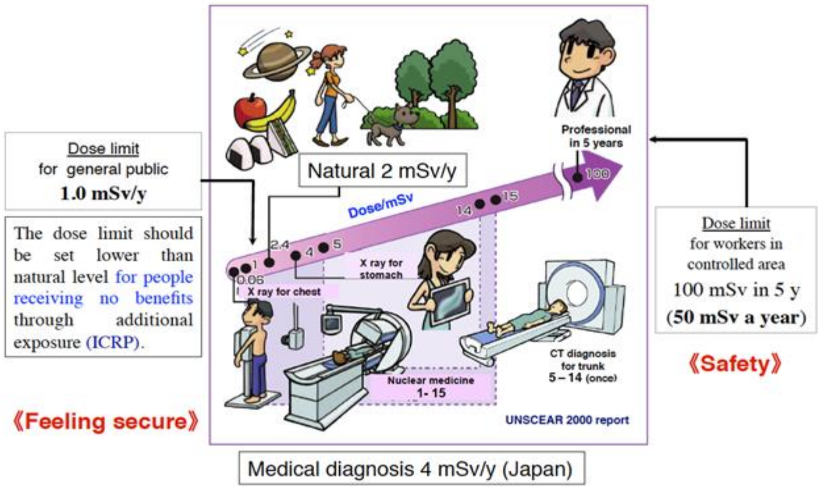


Fig. 11. A dose limit recommended for general public by ICRP (International Committee on Radiation Protection) and the official dose limits applied to professionals working in controlled areas.

Figure 11 summarizes dose limits in respects of our daily life and the obligation for professional workers. We should feel safe for exposure as low as 1 mSv a year, although we should always be careful to be exposed to a higher dose of radiation. Here, it is to be pointed out that Japanese people are receiving about 4 mSv a year of radiation on average through medical diagnosis. This value is the highest in the world, and the availability of such a medical diagnosis makes Japanese the longest life in the world.

2.9 Applications of radiation and benefits for daily life

In developed countries, radiation is used in a variety of fields such as medicine, engineering and agriculture as well as in research. Figure 12 shows examples of the application of radiation in Japan. In addition to the medical use of radiation for diagnosis and therapy, we would recognize that the radiation sterilization of medical device — *e.g.* sterilization of medical needles and syringes by γ-ray irradiation — is of great benefit to medical safety. In the field of materials modification, on the other hand, radiation is used to produce foamed polyethylene to be used for a dashboard of vehicles and heat-resistant cables used for wiring around a high-temperature engine.

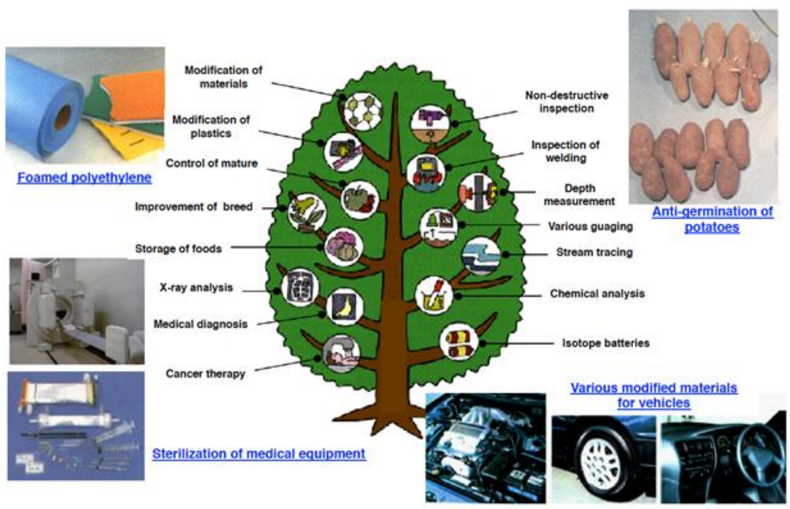


Fig. 12. Beneficial use of radiation in medicine, agriculture, engineering and research & development.

The above-mentioned is the essentials of the one-hour lecture for general public. The tables and figures attached here are copies of the slides selected for a handout distributed to the audience.

3. Summary

From the experience of giving lectures for general public including evacuees from the nuclear accident in Fukushima, the present author has recognized that it is effective to give a lecture with emphasis laid on the basic science of radiation rather than on the influence of exposure to radiation. Although it seemed first a roundabout way for the audience, the learning of the basic nature of radiation was eventually a shortcut to understand a real risk of radiation even if any special case occurs.

Radiation Education Experiments and Other Science Education Experiments with a Handmade GM Counter

手作り GM 管計数器による放射線教育実験と他の理科教育実験

Chizuo MORI
森 千鶴夫
Chubu Atomic Conference, Adviser
中部原子力懇談会　顧問
2-10-19 Sakae, Naka-ku, Nagoya, Aichi Pref., 460-0008, Japan
〒460-0008　愛知県名古屋市中区栄2-10-19 商工会議所ビル6F
E-mail: moric@wh.commufa.jp

The seminar on radiation education experiment named "Radiation watching" has been held over many years by Chubu Atomic Conference for high school students and teachers. The participants fabricate GM counter and counting equipment by themselves. We recently developed air-filled GM counter with a darning needle as an anode. The counter is very easy to fabricate and the counting performance is stable. The usual radiation measurement experiments are possible. Moreover, since this counter can open the widow, alpha-particle source is able to be put inside the counter and alpha-particle absorption experiment is possible. When a small metal plate such as aluminum or zinc is put into the counter and irradiated with light, photoelectrons can be counted, and hence the experiment of metal surface oxidation is possible. When optical films are inserted between the light emitter and GM counter, the absorption of ultraviolet ray can be evaluated. The air-filled GM counter would be useful for science education experiments as well as for radiation education experiments at school teaching.

“放射線ウオッチング”と名付けた放射線教育実験を、中部原子力懇談会が中学・高校の生徒や先生を対象として長年開催してきた。受講者がＧＭ管や計数器を自ら組み立て、放射線実験をする。最近我々は、とじ針を陽極にした組立ての極めて簡単な空気ＧＭ管を開発した。通常の放射線実験は可能であるが、ＧＭ管の窓を容易に開くことができるため、中にアルファ線源を入れたアルファ線の吸収実験、薄い金属板を入れて外から光を照射する光電子放出実験、紫外線吸収実験、金属表面の酸化やエキゾ電子放出などの放射線実験以外の実験ができるので、中学・高校の先生がこれらの実験に活用することができる。

Key words: radiation education, experiment, GM counter, handmade, photoelectric effect, ultra-violet ray, oxidization, exo-electron, electrostatic experiment

1. Introduction

Radiation education experiment is a part of radiation education. However, experiment needs experimental instruments and is generally time consuming. It is therefore not so easy to carry out experiments in the class work. The author considered that school teachers might hesitate to perform the experiments only for radiation education. They might be interested in using the radiation education experimental instruments for other science experiments or in carrying out radiation experiments combined with other general science experiments.

The author and his collaborators developed handmade GM counter filled with air with a version of a GM counter [1]. Since it is possible to open the window of the counter, various specimens can be inserted in it and some general science experiments other than radiation experiments became possible. If radiation education experiments or experimental equipment can be related to other science education experiments, it would be more attractive and educational. Teachers in high schools and even in elementally schools would be interested in such experiments.

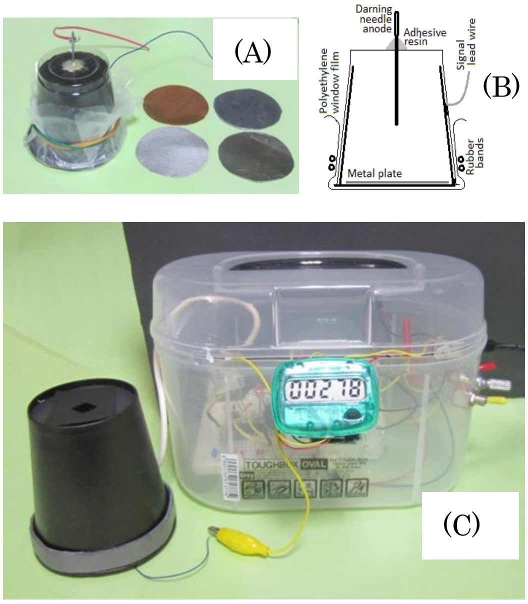


Fig. 1. (A) Handmade GM counter with metal plates, (B) cross sectional view of the counter, (C) light shield box covering GM counter and counting equipment.

2. Counting equipment and radiation experiment

Fig. 1(A) shows a handmade GM counter and some metal plates to be put inside the counter. The GM counter had a darning needle as an anode and electric conductive paper lined inside a plastic cup as cathode. The window was covered with thin plastic film. Butane gas from cigarette lighter was blown into GM counter for about 10 seconds as quenching gas. (B) shows the cross-sectional view of the counter, and (C) the whole view of the equipment with a light shielding box including GM counter in it.

Fig. 2 shows Plateau curve of the counter. The applied voltage was decided to be 4.2 kV.

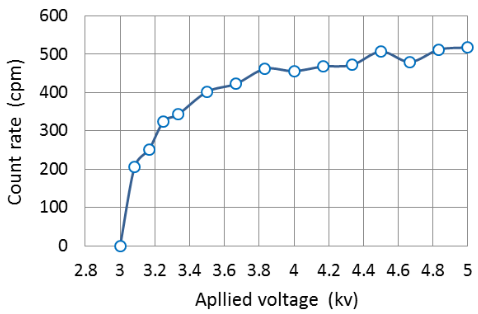


Fig. 2. Plateau curve of the counter

Fig. 3 shows absorption curves of alpha particles emitted from a monazite source [2] and so-called mantle source. The absorber was cooking aluminum foil with thickness of 12 µm. Experiment on alpha particle absorption is not so easy because of very short penetration range of the particles.

3. Experiments other than radiation experiment

3.1 Photoelectric effect

Fig. 4 shows the experimental setup (left) and the photoelectron count rate for various materials (right). Fluorescent light tube emits visible light and ultra-violet light (UV) which enter into the GM counter through a diaphragm aperture of the light shielding cup and through the transparent back of plastic GM counter cup and irradiate the surface of specimen put inside the counter. Photoelectrons are emitted when the energy of UV is larger than the work function of the material. The work function of aluminum is 3.3-4.2 eV depending on the surface condition and that of zinc is 4.08 eV. The other materials in the figure have larger work function. Even aluminum, when the surface is oxidized, photoelectron emission is small. Incandescent light showed almost the same photoelectron emission to fluorescent light, whereas ordinary LED (light emitting diode) light did not emit photoelectrons.

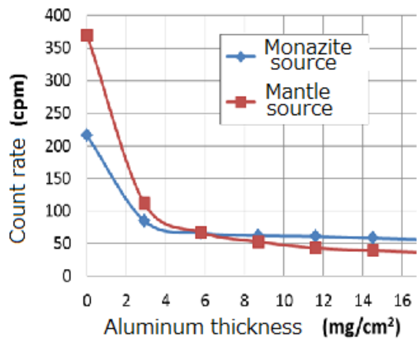


Fig. 3. Absorption curves of alpha particles from two different sources

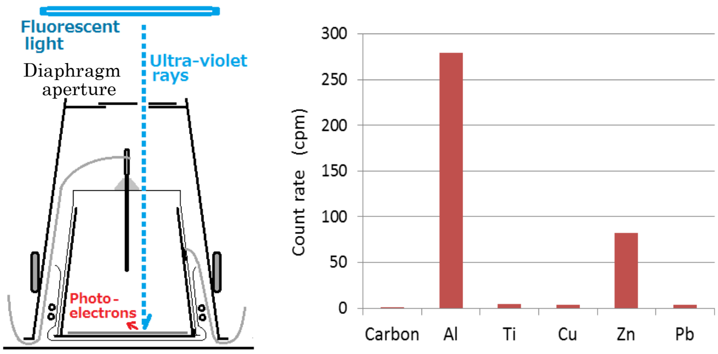


Fig. 4. Experimental setup for photoelectric effect (left) and photoelectron count rate for various materials (right)

Photoelectric effect caused by γ-rays and X-rays is physically the same phenomenon to that caused by UV light mentioned here.

3.2 Absorption of ultra-violet rays by various materials

UV rays emitted from fluorescent light tube are absorbed by thin plate etc. Fig. 5 shows the count rate of photoelectrons emitted from the oxidized surface of aluminum when thin film etc. were placed on the diaphragm aperture shown in Fig. 4. When UV cut film was put on the diaphragm the photoelectron count rate was very small compared with the

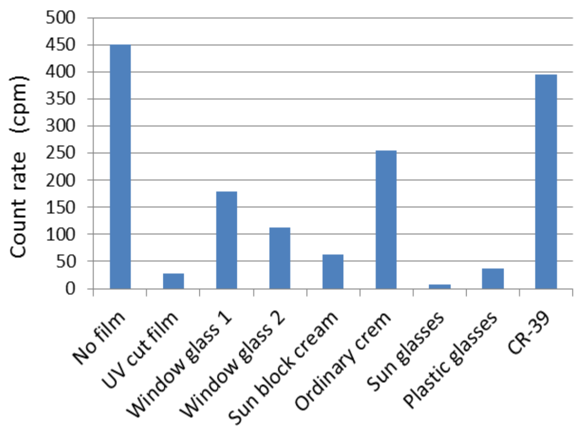


Fig. 5. Absorption of ultra-violet rays by thin film and glass plate, etc.

case of no film. Thin polyethylene film coated with sun block cream absorbed UV, whereas the film coated with ordinary cream did not so much. Plastic glasses made with CR-39 coated with UV block material absorbed UV, whereas pure CR-39 did not so much.

Absorption of γ-rays and X-rays is similar to that of UV, but not to that of visible light.

3.3 Decrease of photoelectron emission with elapsed time

The surface of zinc plate was fully polished with emery paper and immediately inserted inside the counter. The count rates shown by circles ● in Fig.6 gradually decrease with elapsed time due to the oxidization of the surface. Background count rate and exo-electron count rates (mentioned later) were subtracted.

When zinc plate was heated in a toaster 80 ℃ for 10 second, the count rates shown by triangles ▲ suddenly decreased. The count rates for gamma rays shown by ■ irradiated from the outside of the counter with light aperture closed were almost constant which showed the stable performance of the counter throughout the measurement time.

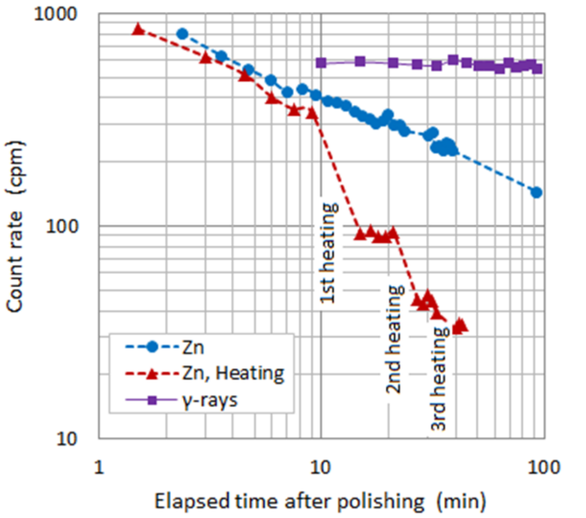


Fig. 6. Decrease of count rate of photoelectrons emitted from the fully polished zinc plate surface with elapsed time after polishing. When the plate was heated in a toaster for 10 seconds, the count rates suddenly decrease due to the increase of oxidization.

3.4 Exo-electron emission

When material surface was fully polished or irradiated with nuclear radiations, exo-electrons are emitted (Fig. 7). The surfaces of three metals were fully polished with emery paper and immediately inserted inside the GM counter. In this case, the diaphragm aperture was closed not to enter any light. Exo-electron emission strongly depended on the degree of polishing and lasted only for a few tens of minutes.

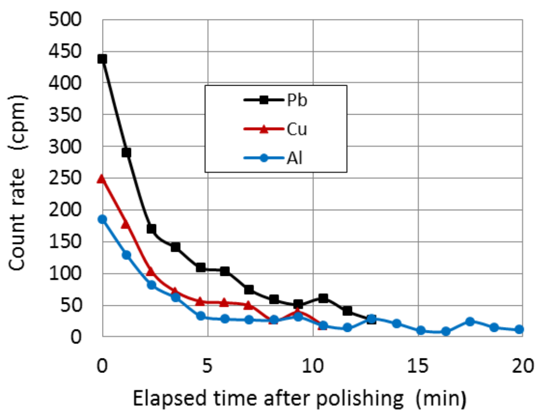


Fig. 7. Exo-electron emission from the heavily polished surface of metal plates. In this case, the diaphragm aperture was closed not to enter any light.

4. Utilization of high voltage supply

The handmade counting instrument proposed here contains high voltage supply up to 5 kV with output resistance of 1 GΩ for safety. The resistance makes it possible even to touch on the high voltage terminal. In our surroundings, there is no such safe high voltage supply, which is very useful for electrostatic experiment. Fig. 8 shows tissue paper cut into strips, which is connected to the high voltage terminal. When the power switch was off, the strips were closed (left). Whereas the switch was on, the strips opened.

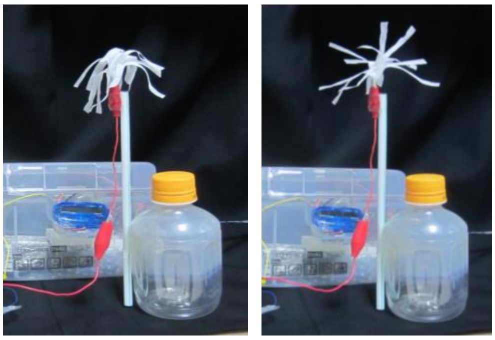
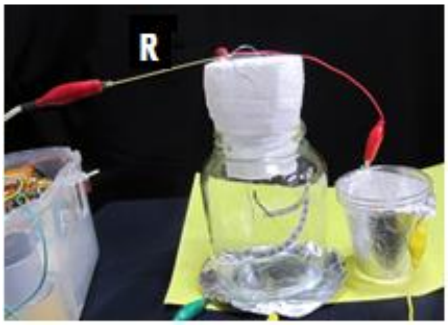


Fig. 8. High voltage was not supplied to the strips of tissue paper (left). The voltage was supplied (right) and the strips opened.



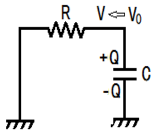


Fig. 9. Measurement of very high resistance R

As shown in Fig. 9, the high voltage was supplied to a handmade leaf electroscope through very high resistance R which was a strip of thick paper with a resistance of 10^{11}-10^{12} Ω. Measurement of such a high resistance is usually is not so easy. Measurement of the time ($T_{1/2}$) to decrease the angle of the leaf to the half of the maximum angle gives the resistance R as follows when the capacitance is known. The measurement of capacitance C is usually possible by using digital circuit multi-meter (tester). $R = T_{1/2}/(C*\ln 2)$

5. Conclusion

The handmade GM counter presented here is able to open its window, it is then possible to insert various specimens inside the counter. When alpha particle source was put inside, alpha particle absorption curve was easily obtained.

Science education experiments other than radiation experiment were proposed. When metal plates were inserted inside the counter, the experiments on photoelectric effect by ultra-violet rays included in fluorescent light, absorption of ultra-violet rays, oxidation of metal surface, and exo-electron emission were possible.

The high voltage supply to the GM counter was able to utilize for electrostatic experiments. Measurement of very high resistance 10^{11}-10^{12} Ω was possible.

Utilization of the instruments for radiation education experiments to other science education experiments is not only economically effective but also effective to understand the similarity and the difference between radiations and light through the experiment of, for example, photoelectric effect or photon absorption.

References

1) Aoyama T., Mori C., Kamiya H., Sagou Y., Hayakawa I., Iida T., and Goi S., Handmade Air-filled GM Counter with Needle Anode and Ethanol Quenching Gas, *Isotope News*, No.744, 22-25 (2016) (in Japanese)
2) Mori C., Hayakawa I. and Sagou Y., Theoretical Calculation of the Number of α-ray Track in a Petri Dish-type Cloud Chamber with Monazite Source, *RADIOISOTOPES*, **61**, 399-406(2012) (in Japanese)

Development of Radiological Educational Program Using a Peltier-Cooling-Type High Performance Cloud Chamber

ペルチェ冷却式高性能霧箱を用いた放射線教育プログラムの開発

Masafumi AKIYOSHI[1], Hirokazu ANDO[2], Yasuki Okuno[2], and Hiroto MATSUURA[1]
秋吉優史 [1]、安藤太一 [2]、奥野泰希 [2]、松浦寛人 [1]
[1]Radiation Research Center, Osaka Prefecture Univ. 大阪府立大学・放射線研究センター
[2]Quantum Rad. Eng., Osaka Prefecture Univ. 大阪府立大学・量子放射線系専攻

Abstract

A Peltier-cooling-type high performance cloud chamber was developed which is very effective equipment for performing radiological education. Observation in a few tens of seconds after a power supply is possible without dry ice, and not only simple observation of alpha-rays track, but also observations of beta-rays track or a delta-rays track arisen from gamma rays are possible. It enables us to perform far deep radiological education. In this paper, the technical features for the hardware of this equipment and the educational program as software using this equipment are introduced.

1. はじめに

各地で行われている放射線に関するオープンスクール活動において、霧箱工作は世代を問わず大変人気があり、目で見て直感的に放射線の存在を知ることが出来るため教育的効果が大変大きく、様々な研究・教育者が霧箱の改良に携わってきた。近年多く行われるようになった工作を中心とせず、測定などを中心とした放射線セミナーなどでも、工作は行わなくても展示物として設置が望まれている。

しかしながら、従来は霧箱の展示を行うためにドライアイスの準備が必要であり、遠隔地でのオープンスクールや、小規模な展示の場合ドライアイスを準備することをためらうことも少なくない。エチレングリコールを用いた高温拡散型の霧箱も販売されているが、電源を投入してから安定して観察できるまで時間がかかり、観察途中の線源の交換などが難しい、大勢の子供が来るオープンスクールではヤケドに対する注意が必要、価格も高価で、展示中のメンテナンスの際に有害なエチレングリコールの蒸気を吸ってしまう可能性があるなどの問題があり、余り推奨できない。さらに、これまで用いられてきた霧箱では、天候などにより飛跡が観察できないことも多かった。また、内容としても「α 線の飛跡が見えた」に留まっていた。

そこで、簡単に-20℃以下の低温を得る手段として、ペルチェ素子を使用した高性能霧箱を開発した（http://bigbird.riast.osakafu-u.ac.jp/~akiyoshi/Works/index.htm#CloudChamber）。最大の特徴はドライアイスが不要であることに加えて、長時間安定してクリアな飛跡の観察が可能であるため、一般的な霧箱での α 線の飛跡の観察に加えて β 線の飛跡の観察も可能であり、さらには γ 線により放出された光電子なども観察可能なことである。これにより、放射線の種類による物質との相互作用の違いを直感的に学習することが出来るため、ただ単に飛んでいるのが見えた、に留まらない奥が深い放射線の世界を紹介することが可能である。

既に当初の開発から一年以上が経過し、試験的な販売を行いながらの改良を繰り返すことにより十分な耐久性と信頼性を得ることが出来ており、多数の大学や中学校などの教育機関、放射線に関連した研究所などへの導入実績を得るに至っている。本論文に於いて、このペルチェ冷却式高性能霧箱の技術的な情報を公開することで、各地の研究・教育者が自分でペルチェ冷却式霧箱を製作し、よりすぐれた装置の製作、改良が行われることを期待する。

さらに、放射線の種類により生体への影響がどう異なるのか（4000 Bq の K-40 と 20 Bq の Po-210 による実効線量の違い）を実習の結果を交えて説明できる。そのことからベクレルだけでは生体への影響（シーベルト）は評価できないこと、さらに、どういった核種がどのような放射線を出しているかという情報から、身の回りの放射線と福島の事故で放出された核種からの放射線について、同じ土俵で比較する力を付けることが出来るような教育プログラムを作成し、実践を行ったので紹介する。

2. ペルチェ冷却式高性能霧箱の技術的特徴

・ペルチェ素子とヒートシンク

一番の心臓部であるペルチェ素子は、電流を流すと素子の片側から反対側に熱を輸送するという働き（ペルチェ効果）を持つ。熱を輸送する際に仕事をするため素子自体の発熱も伴い、闇雲に電流を流せばよく冷えるというわけではないことに注意する必要がある。TEC1-12708 素子単体を Shuriken Rev.B CPU クーラーに載せて（銀ペーストは後述の MX-4）、アルインコ DM-330MV 安定化電源で入力電圧を変えたときの電流と素子表面の到達温度の関係を図 1 に示す。電流は単純に電圧に比例している。ペルチェ効果による熱輸送量は電流量に比例するが、ジュール発熱量は電流の二乗に比例するため、12 V 程度を境に温度が上昇してきている。ペルチェ素子は様々な業者を通じて広く一般的に販売されている商品であり、40 mm 角の大きさで、結露水に対する防水加工済のものを一枚 800 円以下で入手可能であり（図 2）、TEC1-127xx の型番で消費電力、吸熱能力が異なる様々な製品が販売されている（http://www.everredtronics.com/thermoelectric.TEC1.html）。

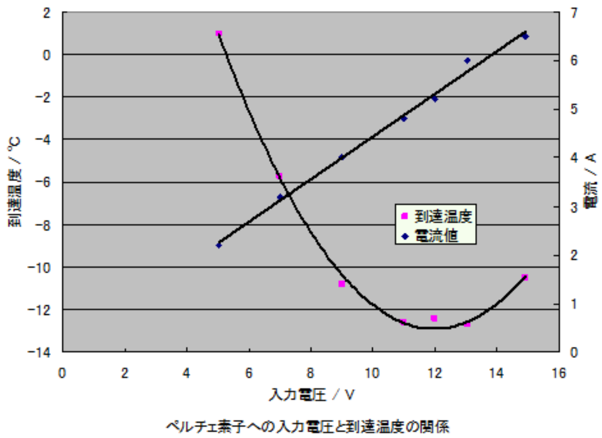


図 1. TEC1-12708 ペルチェ素子単体で入力電圧を変えた際の到達温度　ペルチェ効果による熱輸送は電流に比例するが、ジュール発熱は電流の二乗に比例する。

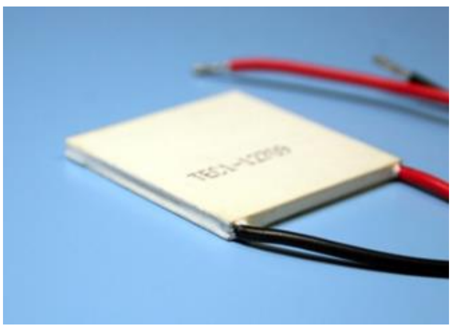


図 2. ペルチェ素子の例　型番の印字面が冷却側である。結露水に対応するため防水処理がされている。

いずれの素子も単体では霧箱として観察可能な-20℃以下に冷却することは出来ないため、二段重ねのカスケードを形成することで十分な冷却能力を達成する必要がある。一段目と二段目の組み合わせによっては到達可能な温度が異なり、下段の素子に 12 V、上段の素子に 5 V 印加という条件で素子の組み合わせを検証した結果（表 1）、TEC-12705 を上段に、TEC1-12708 を下段に配置すると最も到達温度が低くなることが確認された。

表 1. 上段と下段のペルチェ素子の組み合わせを変えた際の到達温度（℃）の変化
測定時気温は 25℃

		下段(12V)							
		なし	12703	12705	12706	12708	12709	12710	12715
上段 (5V)	なし	25	−13	−15	−14	−15	−10	−9	4
	12703	0	−20	−22	−24	**−25**	−24	−22	−4
	12705	0	−17	−23	−21	**−26**	−21	−20	−4
	12706	0	−17	−23	−20	**−25**	−21	−17	−4
	12708	−2	−12	−19	−17	**−23**	−17	−12	0
	12709	0	−12	−22	−18	**−25**	−19	−14	−1
	12710	1	−6	−15	−13	−19	−13	−7	−6
	12715	13							

使用上の注意点としては、150℃以上に素子の温度が上がると、内部で素子を固定しているハンダが溶けてしまい、使用不能になってしまうという点が挙げられる。ヒートシンクとの間に異物が挟まるなどして素子背面の冷却が上手くいっていないと簡単に破損するため、到達温度が不十分な場合どちらかの素子が破損していないか確認する必要がある。

ペルチェ素子はあくまでも熱を輸送する素子であり、吸収してしまうわけではないので、必ず高温側の熱を放熱するヒートシンクが必要となり、PC 用の CPU クーラーを使用する。現在の CPU は高集積化、高クロック化が進んだ結果、発熱量が非常に上昇しており、最新の製品では TDP（熱設計電力） が 140 W にも達しているため、ヒートパイプを使用した高性能な CPU ファンが開発されている。なお、ヒートパイプは開発当初は設置する向きが決められており傾けたり回転したりすると熱輸送を行う事が出来なかったが、現在の CPU ファンなどに用いられている製品ではその心配はなく、どの向きでも使用することが可能である。現在販売している霧箱では、Scythe 社の Shuriken Rev.B という、トップフロー型であるが十分な性能を持つ CPU クーラーを使用している。

CPU クーラー同様に、大きな発熱量を処理するために様々な熱伝導グリスが PC 用に市販されている。高性能の熱伝導グリスとして銀の微粒子を使用した製品が数多く売られており、定番と言われている物に、熱伝導率 9.0 W/m・K の Arctic Silver 社の AS-5、熱伝導率 8.5 W/m・K の ZAWARD 社 MX-4 が挙げられる。MX-4 は長期間高温で使用してもグリスのオイルが抜けず硬化しにくいと言われており、現在販売している霧箱ではこの MX-4 を使用している。銀以外では、JouJye Computer 社のナノ・ダイヤモンドサーマルグリス OC7 は、20 nm の人工ダイヤを 40%使用していると謳っており、12.6 W/m・K に達

する。

なお、ペルチェ素子を二段重ねにしてCPUヘッドに乗せる際に、熱伝導接着剤（ワイドワーク社製 2 剤混合の高熱伝導性シリコーン系接着剤 J-Thermo-14C (14 W/m・K) や、Arctic Silver社の熱伝導製エポキシ接着剤 Thermal Adhesive (7.5 W/m・K) など）を開発の初期に使用していたが、当初は良好な性能を示すものの使用したペルチェ素子が次々と使用不能となる（導通が無くなる）トラブルが多発したため、それ以降使用していない。

・ATX 電源

ペルチェ素子 2 枚、CPU クーラー、LED ライト、高電圧回路を駆動するために、電源が必要となる。+5 V と、+12 V の二種類の出力を使用する。実験用の安定化電源などを使用しても良いが、一台につき 12 V で 5 A 程度とかなりの容量が必要で高価な電源となるため、PC で使用する ATX 電源を使用する。容量は、一台だけの駆動であれば 150 W 程度、同時に二台並べて使用する場合は 300 W 以上の物を選ぶ必要がある。ペリフェラル 4 ピンコネクタ（大）などと呼ばれる、コマーシャルメイテンロック ソケットハウジング 1-480426-0（図 3）があれば十分で、最新のマザーボードに対応するためのコネクタなどは一切必要ないため､不要になった古いデスクトップPCから抜き出して調達が可能である。

なお ATX 電源は PC 用のマザーボードに挿して使用することを前提としているため、そのまま電源を入れても動作しない。そのため、マザーボードに接続する 20 pin もしくは 24 pin のコネクタのうち、緑の線が繋がっている PS_ON を、黒い線が繋がった適当な COM（左右どちらでも良い）に Y 端子などを使用して短絡して単体で動作するようにする必要がある。

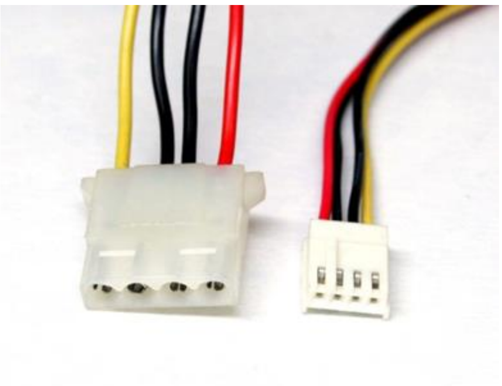


図 3. ペリフェラル 4 ピンコネクタ大（左）と FDD4 ピンコネクタ（右）

図 4. ダイソーのコレクションケース（ミニ）

・観察用チャンバーと LED ライト

観察用のチャンバーとして、ダイソーのコレクションケース（ミニ）が非常に優れている（図 4)。底面が黒色で、9.3 cm 角×高さ 8.7 cm と手頃な大きさであり、LED ライトの貼付けの際に円筒状のケースでは加工が困難であるので四角いケースが望ましく、材質的にもアクリルはアルコールに徐々に侵されてひび割れなどが入ってしまうが、このコレクションケースは台座もフタもポリスチレン製であり全く問題無く使用することが出来る。なお、ペルチェ冷却式の霧箱作成のパーツとしてだけでなく、ドライアイスを用いた従来型の霧箱を作成する際にも、台座が最初から黒く、薄く熱伝導が良いため、スポンジテープ

を付けるだけの短時間の作業で極めて安価で高性能な霧箱が出来るため、最適な選択支と言える。300 円程度のより大型のケースも販売されており、これを用いた大型の展示用の霧箱も実証済である。これらのケースのチャンバーは薄いプラスチックであるため、天板にマントル線源を載せればα線は透過せずに、β線・γ線だけをチャンバー内に入れることが可能であり、特殊な線源無しにβ線観察を可能としている。ガラス製のチャンバーでは不可能であり、大きな特徴となっている。

照明としては、普通の室内程度の明るさでも飛跡を明確に観察可能とするため、電飾用に市販されている 12 V タイプの高輝度 LED モジュールを使用している。現在は SMD 5730 3-LED モジュール（図 5）を使用しているが、抵抗などもモジュールに組み込まれておりそのまま 12 V 電源に繋ぐだけで終端処理等せずに使用することが出来る。

図 5. SMD 5730 3-LED モジュール
20 個単位で入手可能

・UV レジン

コレクションケースとペルチェ素子の接合には UV レジンを使用している。エポキシ接着剤などでも構わないが、仕上がりの綺麗さと 2 分程度で固まる作業性、接着強度で UV レジンは非常に優れている。通販や手芸店でネイルアート用やアクセサリー製作用などで多数売られている。製品によっては臭いがきつかったり表面がべたついたりするが、硬化後にアルコールで拭き取ることで概ね解決可能である。硬化には日光に当てるか UV ライトを使用するが、LED 式の UV ライトは 375 nm LED を使用していると明記していないと硬化に必要な波長と合わず、多灯式の物でも役にたたないため注意を要する。

UV レジンの硬化は、放射線による重合反応の説明に応用することが出来る。また、紫外線自体も、電波や可視光線から続く光の仲間として、X 線やガンマ線を説明する際に理解の助けとなる。近年 UV レジンを使用したアクセサリー工作は極めて人気が高く、母親層を含めた広い年齢層に対してアピールすることが出来る新しい放射線教育のツールとして現在ソフトウェアを開発中である。

・線源

容易に入手できる線源としては、トリウムを含んだランタン用のマントルが最も適しているが、近年ほとんどの製品がトリウムを含んでいない。現在手に入るトリウム含有マントルとして、サウスフィールドブランドの SF-2000 用マントル SF-2000MT と D-X ハイパワーランタン 3000 用の D-X ハイパワーマントルが挙げられる（図 6）。しかし、同社の似たような製品でも SF 200MT や SF-DX400MT と言う製品は全く放射線を出しておらず、前述の製品も産地によってはトリウムを含んでいないという情報もあるため、返品が可能かなど注意が必要である。なお、元々がキャンプ用品であるため、冬場はほとんど市場に出回っておらず、入手しにくくなるため、夏場に購入しておく必要がある。

次に入手しやすいのは、ラジウムセラミックボール（図 6 下）で 100 g 2000 円程度で入手可能だが、マントルに比べるとやや線量率が低く、丸いボールなので、ワッシャーのような物を

台座にする必要がある。

最も簡単に α 線源を入手するには、空気中のラドン娘核種を掃除機で捕集するのがよい。掃除機は一般的な物で十分であるが、オープンスクールや授業など、限られたスペース、時間で捕集を行う場合は、Electrolux 社製のエルゴスリーマルチフロアという極めて静粛性が高い製品が適している。捕集する際にろ紙のような目の詰まったフィルターを用いると、非常に捕集効率が悪く時間がかかるため、ベンコットなどのようなガーゼを使用するという点に注意する。掃除機の吸い込み口にガーゼを当てて輪ゴムで止め 10 分程度吸引するだけでよい(図 7)。建物の素材（鉄筋コンクリートかどうか）や空調の状況などによって異なるが、地下室などがあればマントルに匹敵する強度の線源も作成可能である。半減期 40 分程度で減衰するため霧箱工作教室などでの配布の際にも安心である。USB 接続して PC に計数値を取込可能な高感度のパンケーキ型の広窓 GM サーベイメーターである SE International 社製インスペクターUSB などの製品を用いれば、授業時間内程度で半減期を明確に評価可能であり、減衰挙動を直接学習することが出来る貴重な線源となる。

図 6. サウスフィールドブランド D-X ハイパワーマントル（左）と SF-2000MT （右）、ラジウムセラミックスボール（下）

・高圧電源

通常の霧箱では、雨天時など α 線の飛跡がよく観察できない事態が頻繁に発生する。これは、空気中の雑イオンが多すぎるため、放射線が通らなくてもアルコールが核生成してしまい過飽和蒸気圧が低下するためである。この雑イオンを、高電圧を印加することで除去する必要がある。

最も簡単には、化学繊維の布などでチャンバーを直接こすることで静電気を発生させるが、飛跡が見えない悪天候時は静電気も発生しにくく、上手くいかないことも多い。小型のバンデグラーフ起電機なども利用可能であるが、長時間の運転には向かず、電圧のコントロールも容易ではない。

図 7. ベンコットと掃除機を用いて空気中のラドントロン娘核種を捕集している様子

そこでコッククロフト・ウォルトン回路（図 8）を用いた高電圧発生装置を利用する。冷陰極管（CCFL）用のインバータ回路（図 9）が安価で入手できるため、これを 1 kV 程度までの交流の高圧電源としてコッククロフト・ウォルトン回路に入れて、昇圧・整流を行う。余り電

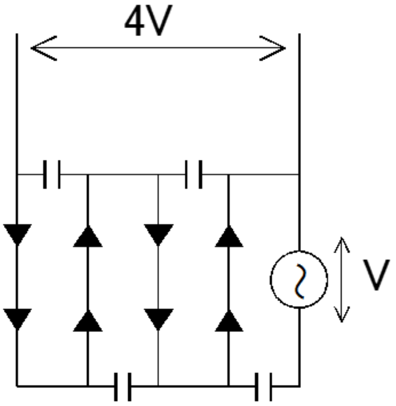


図 8.コッククロフト回路の例
ダイオードを直列に繋いでいるのは耐圧を上げるため。図では4段であるが製品では2段に留めている。

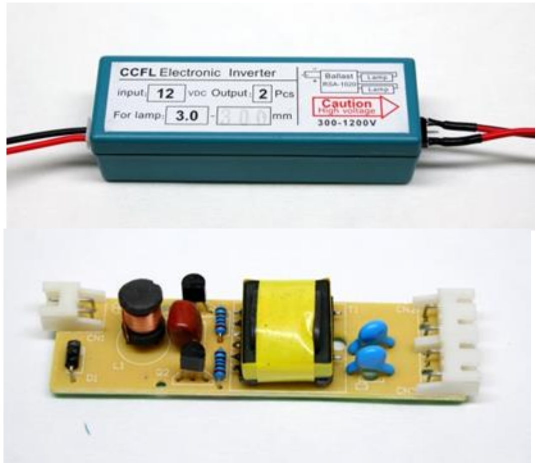


図 9. 冷陰極管用インバータ回路の例

圧を上げすぎると、逆にイオンを加速して雑イオンを増やしまうことが、これまでの研究で明らかになっている。インバータに入れる電圧を 50 Ω の半固定抵抗器を用いてコントロールすることで出力電圧を可変としているが、最適な電圧を評価したところ 500 V 程度であった。これは放射線検出器の電離箱領域上限に相当し、それ以上になると比例計数領域から GM 領域となることから、印加電圧の妥当性が説明される。ただし、今後より適切な電極形状などの検討を行う必要があり、より厳しい条件でのクリアな観察を可能とすることを目指す。

・素子表面の塗装

霧箱中のペルチェ素子表面は観察しやすくするために黒く塗る必要があるが、室温から -40℃以下への温度変化を繰り返し受け、さらにアルコールに曝され続けるため、その双方に耐えうる塗装は非常に困難である。当初はアサヒペンの高耐久性ラッカースプレーを使用していたが、エタノールに徐々に侵されたため、同じくアサヒペンの弱溶剤 2 液ウレタンスプレーに変更した。塗膜は非常に強靭であり、イソプロパノールにも全く侵されなかったが、温度変化によりひび割れ・素子表面からの剥離が発生した。このため素子表面をシリコンオフ（ヘプタンが主成分）でしっかりと脱脂し、密着性の良いプライマー剤を塗布した後に弱溶剤 2 液ウレタンスプレーを使用することで、温度変化にも溶剤にも強い塗膜を得ることが出来た。2 液ウレタンスプレーは 1 回使い切りであり、補修なども困難なため、一般向けには車の補修用のタッチペンなどが手頃である。

3. ペルチェ冷却式高性能霧箱を用いた放射線教育プログラム

2016/8/18 に福井県立若狭高校から、および 2016/12/13、15 には京都府立桃山高校から、大阪府立大学放射線研究センターへの訪問研修があり、ペルチェ冷却式高性能霧箱を用いた放射線観察実習を行ったので、その内容を以下に紹介する。

・熱電対を用いたペルチェ素子表面温度の測定

熱電対式のデジタル温度計により霧箱表面温度（-30℃程度）を測定する。熱電対とは、温度差があると電流が流れる、ゼーベック効果を利用しているが、ペルチェ素子は逆に電流を流すと温度差が発生する、吸熱している訳ではなく熱を裏面に輸送している事などを説明する。点接触では正確な温度測定は出来ず、アルミテープでしっかりと熱接触を取って測定する事に注意する。

・空の霧箱とポリパックに入れたマントル線源を入れた霧箱の観察

スポンジテープへエタノール（イソプロパノール入りの安価な消毒液で構わない）を注入して線源を入れずにチャンバーを閉じ電源を入れる。ペルチェ素子によりアルコールの蒸気が冷やされ過飽和となり、空気中の雑イオンなどにアルコール分子が集まって核生成してうっすらと霧状の液滴が漂っていることを観察する。もう一つのチャンバー中にはポリパックに入れたマントル線源を入れておき、ビニール一枚でα線は遮蔽されていることを確認する。また、いずれのチャンバー中でもよく観察を続けると空気中のラドンなどからのα線や、バックグラウンドのβ線などが観察される。

・ポリパックから取りだしたマントル線源を入れた霧箱でのα線の観察

一般的な霧箱観察同様に、マントルからの α 線の飛跡を観察する。飛行機雲と同じく、粒子自体は見えなくても飛跡が見えている（原子の小ささを説明する）、空気中での飛程はせいぜい数 cm だが、はっきりと直線的に飛ぶことから、後述する β 線に比べ α 粒子はずっと重たく、空気との相互作用によるイオンの生成も激しいことを説明する。なお、線源からの α 線は上下方向にも飛んでいるが、過飽和層が層状になっているため水平方向に飛んだ α 線だけが観測できている。

・空の霧箱の上にマントル線源を置いての β 線の観察

α 線はチャンバー天板のプラスチック板を透過できないが、β 線は薄いプラスチック板程度は透過できる上に、非常に軽く散乱されやすいので、上から入射しても空気や素子表面で散乱されて素子に平行に走る電子線が観察できる。相互作用は α 線よりもずっと小さくうっすらとしか観察されない、平行に走っている間にも散乱されて糸くずのように曲がりくねる、と言う点に注意して観察する。

・空の霧箱とマントルの間にアルミ板を載せての γ 線 （からの光電子など）の観察

ウラン系列核種からの β 線のアルミ中での最大飛程は、Bi-214 からの 3.27 MeV の β 線による 6.1 mm であるため、6 mm のアルミ板をマントル線源とチャンバー天板の間に入れて β 線を遮蔽し、γ 線のみをチャンバー内に入射する。すると、非常にイベント数は落ちるが、γ 線によって放出された光電子などが電離作用を示す、δ 線が観察される。見た目は β 線と同様であり、γ 線が最終的には β 線と同じような作用を示すことが分かる。

・α 線、β 線、γ 線の物質との相互作用との違いと、生体影響の違いを説明

α 線、β 線、γ 線それぞれ物質との相互作用が異なり、それによって霧箱での見え方が異なる。紙一枚で遮蔽されてしまう α 線は、実は短い距離で強烈な相互作用をしており、内部被ばくを考えると非常に危険。透過力の強い γ 線は逆に体をほとんど素通りしており、時々δ 線を出して β 線と同じような作用をする、などが理解できる。このことから何発出

たかのベクレルだけでは生体影響は評価できず、αβγ の種類の違いやエネルギーの違いも考えなくてはならないこと、それによってたった 20 Bq の Po-210 が年間 800 μSv の実効線量を与えるのに対して、4000 Bq の K-40 は年間 170 μSv にしかならない訳が説明できる。

4. 結言

放射線教育を行う場で極めて有効な装置であるペルチェ冷却式高性能霧箱の開発を行い、ハードウェアとしての技術的特徴と、それを用いたソフトウェアとしての教育プログラムを紹介した。販売されている製品のユーザーのみならず、これから開発を行う研究・教育者にとって、製作・運用上の参考となれば幸いである。

運用を行う上で、ガスストーブを使用している部屋では観察が非常に困難であるという情報をユーザーから得ているが、実際にその通りであった。様々な環境の現場での使用報告は非常に参考となり、今後の開発の助けとなるため、ユーザー間の ML を作成して情報交換を行い、より確実な観察を可能とするよう、ハード面と運用面からの改良を、また様々な層の受講者に対してより効果的な学習が出来るよう教育プログラムの開発を行っていく予定である。

また、低予算で授業を行う小・中学校の教育現場に必要なハードウェアを供給できるよう、ふるさと納税制度を用いた大阪府立大学つばさ基金でのプロジェクトを立ち上げている。大阪府立大学は公立学校という特殊な立場であるため、この制度が利用可能であり、既に数件の受入と僻地や福島の中学への霧箱提供の実績がある。今後全国的にこの仕組みを活用したシステムを展開できないか検討を行う予定である。

ISRE2016 (2017) 63-66

Utilization of Small $^{68}Ge/^{68}Ga$ Generators as Experimental Tool in Wide Fields of Education

Tadashi NOZAKI[1] and Toru SASAKI[2]
[1]Kitasato University, School of Sciences; 1-1 Kitasato, Minami-ku, Sagamihara, Japan
[2]Kitasato University, School of Allied Health Sciences; 1-1 Kitasato, Minami-ku, Sagamihara, Japan

Abstract

Regarding small $^{68}Ge/^{68}Ga$ generator as highly useful main tools in experiments for education of various fields, we first made possible the self-manufacture of the generator. We then selected about 20 kinds of suitable experiments and have tested them for the preparation of their manuals. We intend to contribute to arouse interest of citizens in various fields of sciences by wide use of the generator.

Introduction

In Japan at present, study and use of radioisotopes are declining, and opinions concerning promotion or refusal of atomic power are based either on "safety myth" or on "radiation allergy". We now need Renaissance to replace these religious situations by scientific discussions. Unique properties of radioisotopes, i.e., decay characteristics, highly sensitive, continuous and nondestructive detectability, and equal behavior with stable isotopes, are thought to be useful in experiments for education of various categories. Isotope generators are the best supply of radio-isotopes to the experiments, and, of all generators shown in Table 1, small $^{68}Ge/^{68}Ga$ generator is probably the most useful. First, we looked for a simple method of manufacturing small types of the generator, and now "manufacture of the generator" is ranked in the titles of experiments. We selected about 20 experiments based on the generator, and have tested them following trial procedures for publishing a guide book of experimental manuals.

In this presentation, first the superiority of this generator is explained, then the title and main aim are shown for each of the experiments together with the stage of progress in our work. Some comments not directly scientific but inevitable in the achievement of our task are added.

Superior Properties of the small $^{68}Ge/^{68}Ga$ Generator

Decay properties of ^{68}Ge (271 d; EC 100 %; no γ) and ^{68}Ga (67.7 m; β^+ 90 % and EC 10 %; γ weak) are quite suitable, making it possible to milk easily the daughter, ^{68}Ga, several times every day for more than a year, and to observe clearly the growth of ^{68}Ga in the generator just after milking without any interference from radiations of ^{68}Ge. The milked carrier-free ^{68}Ga can be used for a variety of tracer studies. Fig. 1 shows our self-made generator, which is simply a column chromato-graphic set, with the column being 1 mL plastic disposable syringe and the adsorbent SnO_2 powder prepared by our method. Attendants to the class of experiments will be able to select a course involving self-manufacturing of generator, though ready-made adsorbent powder, requiring a long time of preparation, is offered. Fig. 2 shows the milking and column-washing stages. Experiments based on ^{68}Ga milked from such a generator surely gives stronger impressions to the attendants. Still smaller generators can be manufactured similarly and used also as nearly point sources of annihilation radiations. The highest ^{68}Ge radio-activity treatable free of the law restriction is 100 kBq, by which several experiments shown below can be undertaken by several groups simultaneously.

Attendants to the course of experiments are regarded as learning more about radioisotopes and radiations than about its main/nominal aims. This fact is really a two-bird-one-stone solution.

Table 1. Generators useful in education

Parent/Daughter (Half-life)	Parent/Daughter (Half-life)	Parent/Daughter (Half-life)
^{42}Ar / ^{42}K	^{87}Y / ^{87m}Sr	*^{137}Cs / ^{137m}Ba*
(33 y, 12.4 h)	(79.8 h, 2.82 h)	*(30.2 y, 2.55 m)*
^{44}Ti / ^{44}Sc	*^{90}Sr / ^{90}Y*	*^{140}Ba / ^{140}La*
(60 y, 3.97 h)	*(28.9 y, 64.0 h)*	*(12.8 d, 40.3 h)*
^{68}Ge / ^{68}Ga	*^{99}Mo / ^{99m}Tc*	*^{188}W / ^{188}Re*
(271 d, 67.7 m)	*(66.0 h, 6.01 h)*	*(69.8 d, 17.0 h)*
^{72}Se / ^{72}As	^{113}Sn / ^{113m}In	*^{194}Os / ^{194}Ir*
(8.4 d, 26.0 h)	(115 d, 99.5 m)	*(6.0 y, 19.3 h)*

Normal font: Neutron Deficient Nuclides (β^+, EC)
Italic font: Neutron Excess Nuclides (β^-)

Fig. 1. Manufactured generator assembly with its parts. From bottom to up: adsorbent SnO_2 powder (before HNO_3 treatment); Generator connected with eluent syringe; and porous plastic diskette and short end of plastic tube (see text for more detail).

Experiments: Title, Main Aim, and Stage of Manual Preparation

Table 2 shows the title, the main aim and the stage of manual preparation for each of the experiments. The total experiments can be divided into three categories: (A) manufacture and properties of the generator, (B) experiments by ^{68}Ga, and (C) measurement and use of annihilation radiation.

In (A), the treatment of the results of decay and growth measurements can be a valuable exercise of differential equation. In tracer experiments with carrier-free ^{68}Ga, characteristic behavior of ultra-minute amount or hyper-low concentration substances are learned to become some knowledge valuable for understanding entropy of mixing and the second law of thermodynamics.

Fig. 2. Milking by ordinal procedure (right), and Column washing by intravenous drip system (left).

Fig. 3 shows the adsorption of the ^{68}Ga from acetate buffer solutions of various pH in a single pass through a sheet of filter paper 4A. Some ill reproducibility is inevitable for these kinds of experiments.

Table 2. Title, aim and present stage of manual preparation for each experiment

Title	Aim	Present stage*
A. Manufacture and properties of generator		
1. Manufacture of $^{68}Ge/^{68}Ga$ generator	Self-manufacture of tool for experiment	End
2. Milking and half-life measurement of ^{68}Ga	Relation among exponential, real number and logarithm	End
3. Growth of ^{68}Ga in generator after milking	Intimacy with differential equation	End
4. Milking yield and breakthrough of ^{68}Ge	Properties of generator	End
B. Experiments by ^{68}Ga		
1. Adsorption, coprecipitation and solvent extraction	Behavior of ultra-low concentration and ultra-minute amount materials Entropy of mixing and the second law of thermodynamics	Near end
2. Ion exchange and chromatography	Chemical separation and analytical chemistry	Near end
3. Isotope exchange	Intermolecular atomic exchange without chemical change	Midway
4. Chelate chemistry, and synthesis of Positron radiopharmaceuticals	Radiopharmaceutical chemistry	Before starting
5. Uptake by plants	Nondestructive, continuous measurement of RI taken up by plants	Midway
6. Contamination and decontamination, and Leak hunting	Advantageous utilization of short-lived RI	Midway
C. Measurement and use of annihilation radiation		
1. Absorption by various substances	Absorption mechanism of γ-ray	End
2. Dependence of coincidence counting efficiency on geometrical arrangement	Principle and utilization of coincidence counting	End
3. Low background counting of β^+ emitters	Naturally existing RI and radiations	Near end
4. Principle of PET and image reconstruction	Nuclear medicine	Some new idea needed

* Present stage of test experiments for manual preparation.

Without isotopes, isotope exchange cannot be observed. Isotope exchange between Ga-EDTA complex and $^{68}Ga^{3+}$ can be recognized to occur by solvent extraction as oxinate, though correct analysis of its rate seems to be too difficult for the attendants except chemists. The milked ^{68}Ga can be obtained as citrate complex in a neutral solution by an on-line treatment in a cation exchange column. This ^{68}Ga is often taken up by some plants, e.g., Eulalia (Susuki) with the rate enough for being followed by coincidence measurement of annihilation radiation. However, the uptake by any plant changes so remarkably, depending on conditions of both the plants and environments, that next experiment time often cannot be scheduled.

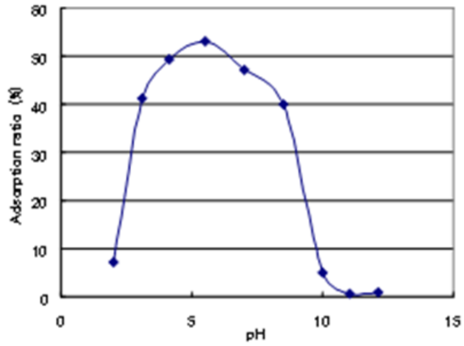


Fig. 3. Dependence on pH in the adsorption of carrier-free ^{68}Ga on filter paper 4A

Safety Guarantee and other Problems for our Task

Internal exposures caused by ^{18}F and ^{68}Ga are roughly the same when these possess the same first activity (in Bq) and decay away in the body. We have planned to use 10 to 100 kBq $^{68}Ge/^{68}Ga$ generator, while about 100 MBq of ^{18}F is injected in usual FDG PET diagnosis. The dose (in Gy) from ^{68}Ge is clearly smaller than from the ^{68}Ga. Hence, the radiation exposure in our experiments can be regarded as being negligible. The fact that about 4 kBq/person of ^{40}K always exists in our body also gives the same result.

More and more expensive modern apparatus will be needed for science education in future, but these will be used less frequently in each school. This will be of considerable similarity with our generator experiment. Rental system or round-robin use will be unique and profitable solution.

ISRE2016 (2017) 67-71

Detection of Spatial Distribution of Dual Photon Emitters Using TOF Coincidence Imaging Technique with Stochastic Origin Ensemble Approach

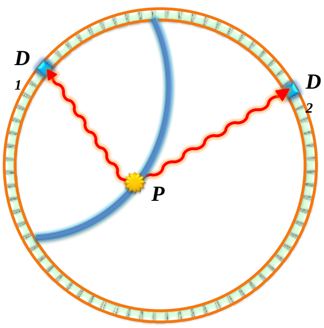
Chih-Chieh CHIANG, Keh-Shih CHUANG, and Hsin-Hon LIN
Department of Biomedical Engineering and Environmental Sciences, National Tsing-Hua University, Hsinchu, Taiwan.

Introduction

The nuclear waste classification is an important issue in the process of nuclear waste disposal. In this study, the time of flight (TOF) coincidence imaging technique is employed to obtain the spatial distribution of dual photon emitters. Co-60 is a dual photon emitter (1.17 and 1.33 MeV) and plays an important role in the process of nuclear waste disposal. The proposed technique can be applied to Waste Inspection Tomography (WIT) system for nuclear waste drum characterization and activity measurement in the future.

Method

Dual photon emitters emit two directionally uncorrelated photons simultaneously. If both photons are detected in the same time, the possible location of decay could be determined by TOF information and the coordinates of detectors. By detecting the gamma rays with TOF information in coincidence, the hyperbolic response curve can be described on the space (Fig. 1). Actually, the concept of TOF coincidence imaging technique is the same as time difference of arrival (TDOA) technique, which is an electronic technique used in direction finding and navigations[1-3].



Equation of hyperbola:

$$L = |\overline{PD_1} - \overline{PD_2}| = 2a$$

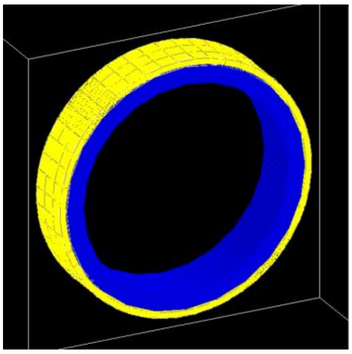
$$\frac{(x-h)^2}{a^2} - \frac{(y-k)^2}{b^2} = 1$$

$$a^2 + b^2 = c^2$$

Fig. 1. The illustration of TOF coincidence imaging technique.

Due to the complexity of the spatial distribution, the activity map was reconstructed by using stochastic origin ensemble (SOE) algorithm. Stochastic origin ensemble algorithm, fist proposed by Sitek in 2008, is one of iterative reconstruction method, which is based on Markov chain and use Metropolis–Hastings algorithm[4,5]. In the proposed SOE reconstruction, the origins of each event are randomly assigned to locations on hyperbolic response curve. After a sufficient number of iterations, the possible origins can converge to actual position of emitters.

In order to validate the proposed concept an algorithm, a full-ring PET-like detection system was built to detect the dual-photon emitters (e.g. Co-60, Se-75, or In-111). The system was built referring to the geometry of Siemens Biograph 6 PET scanner and the detail geometric parameters are shown in Fig. 2.



Geometry of the scanner

- LSO crystals
- 48 detector modules
- 39 detection rings
- 13x13 array of 4x4x20 mm^3
- Total of 24,336 crystals
- Diameter of 83 cm
- Dual Energy window:
  108-164 keV and 211-318 keV
- Time window: 2.0 ns

Fig. 2. The full-ring PET-like detection system.

An in-house developed GATE/MPHG Monte Carlo software was used for the simulation study of selenium-75. In this study, Se-75 was used as preliminary test and its decay scheme was shown in Fig. 3. A point source and two phantoms (contrast and Jaszczak-like array phantom) were built in simulation for assessment of performance (shown in Fig. 4 and Fig. 5). Five different CRT of detectors (0, 50, 100, 150, and 200 ps) were set to estimate the system spatial resolution under different conditions in point source measurements. In all cases, the activity of Se-75 was set to 1 mCi.

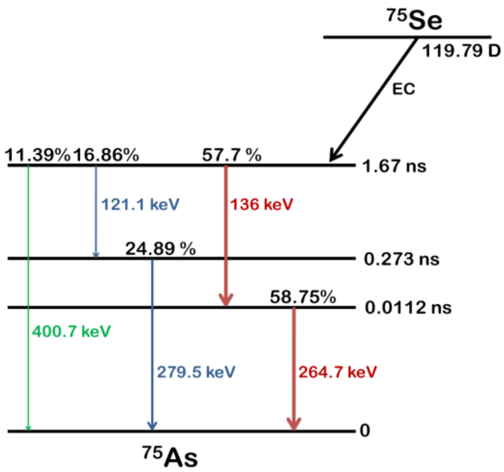
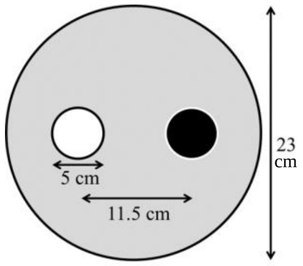


Fig. 3. Decay scheme of Se-75.



Compartment	Relative activity concentration
Cold Cylinder	0 ○
Background	1 ◯ (grey)
Hot Cylinder	5 ●

Fig. 4. The phantom configuration of Contrast phantom that was used in Monte Carlo simulation. The phantom was a 30 cm diameter uniform cylinder containing 10 cm diameters hot/cold rods and placed on the center of system. The ratio of activity concentration was 5:1:0.

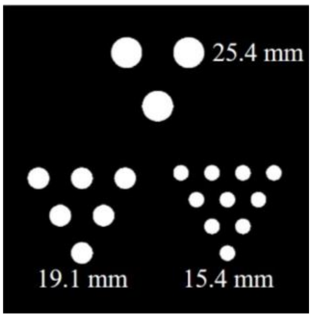


Fig. 5. The phantom configuration of Jaszczak-like phantom that was used in Monte Carlo simulation. The phantom was 25.6 cm diameter and contained 19 independent rods with varying diameters (15.4, 19.1, 25.4 mm).

Results

We have simulated and reconstructed three different objects: a point source, contrast phantom and Jaszczak-like array phantom. Fig. 6 shows the point spread functions evaluated along the central x-axis of reconstructed images with varying CRT and its corresponding reconstructed images. The figure illustrates the relationship between the spatial resolution and the coincidence resolving time. It shows that as the coincidence resolving time decreases the resolution improves. The reconstructed FWHMs as function of iteration numbers for different CRT are shown in Fig. 7. Following the iterative process, the number of event origins per voxel reaches steady state after 50 iterations. The results show that the value for the FWHM of the PSF in the central field-of-view can achieve about 25 mm when CRT is under 100 ps. Fig. 8 displays the reconstructed images of contrast and Jaszczak-like phantoms. For the final image made with SOE after running for 500 iterations, the spatial distribution of dual photon emitters is reconstructed successfully. We demonstrate that the SOE seems practical for proposed system and can obtain acceptable image quality.

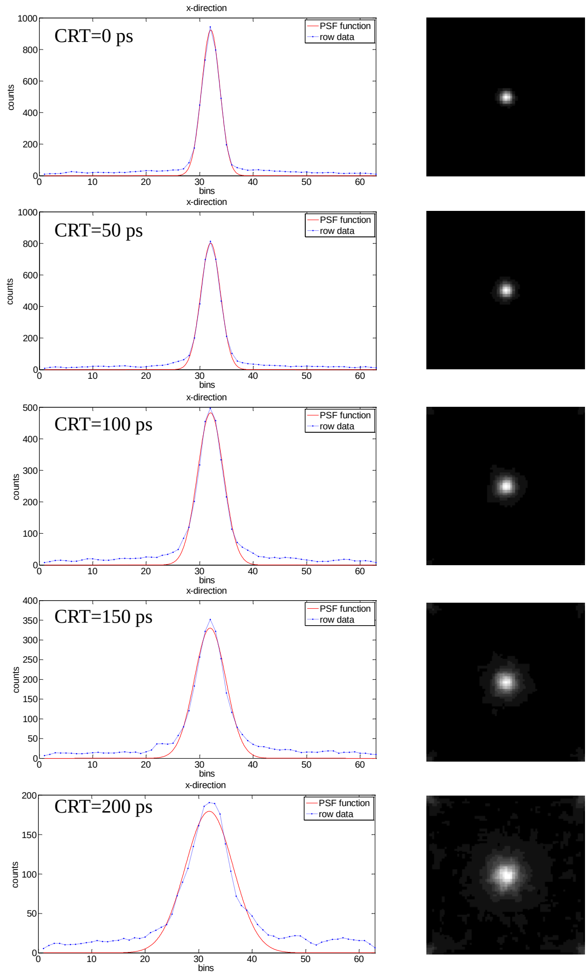


Fig. 6. The point spread function evaluated along the central x-axis of reconstructed images with varying CRT and its corresponding reconstructed images.

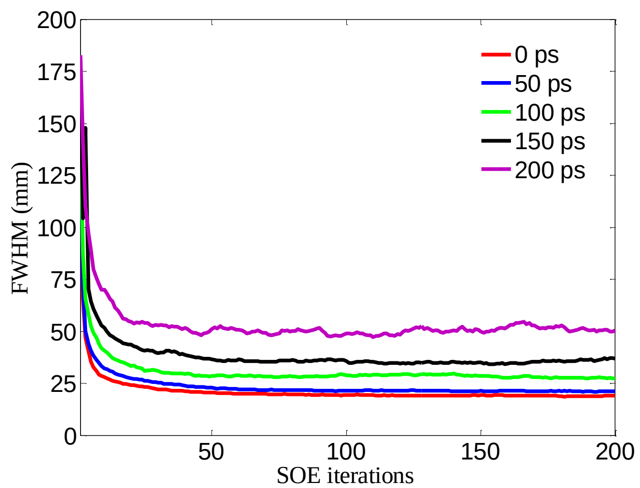


Fig. 7. FWHM as function of iteration number for different CRT

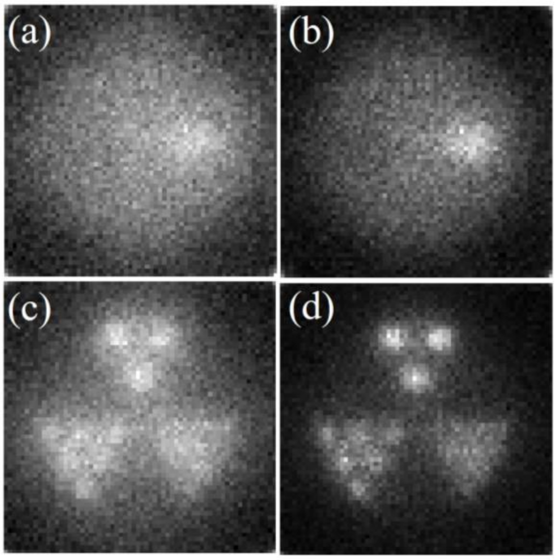


Fig. 8. Results of the phantom studies: (a) initial event density images for the contrast phantom (b) reconstructed images of contrast phantom with 500 iterations (c) initial event density images for the Jaszczak-like phantom (d) reconstructed images of Jaszczak-like phantom with 500 iterations

Conclusion

The TOF coincidence imaging technique can locate radioactive sources, provide internal activity approximations, and provide the data needed for waste classification. Our results show that TOF coincidence imaging technique combined with SOE reconstruction technique is feasible and might open other avenues that can be used for the existing multimodality WIT system to acquire the spatial activity distribution of nuclear waste inside the drum. By using the technique, the classification accuracy and quantification accuracy may be enhanced as well.

References

1) Spirito, M. A., & Mattioli, A. G. (1998, September). On the hyperbolic positioning of GSM mobile stations. In Signals, Systems, and Electronics, 1998. ISSSE 98. 1998 URSI International Symposium on (pp. 173-177). IEEE.
2) Misra, P., & Enge, P. (2006). Global Positioning System: Signals, Measurements and Performance Second Edition. Massachusetts: Ganga-Jamuna Press.
3) Powell, M. D. (1989). Multiphoton, time-of-flight three-dimensional radionuclide imaging. Medical physics, 16(5), 809-812.
4) Andreyev, A., Sitek, A., & Celler, A. (2009, October). Stochastic image reconstruction method for compton camera. In Nuclear Science Symposium Conference Record (NSS/MIC), 2009 IEEE (pp. 2985-2988). IEEE.
5) Sitek, A. (2008). Representation of photon limited data in emission tomography using origin ensembles. Physics in medicine and biology, 53(12), 3201.

ISRE2016 (2017) 72-76

Post-311 Promotion Activities for Science & Disaster Literacy of Citizenry and School Students by Means of 'Bulletin', Symposium, and Summer School

都市圏市民・中高生の科学・災害リテラシー向上に向けた文書および実践による 3・11 後の活動

Haruko NIHON'YANAGI[1], Tomie ISHIKAWA[1], Toshie KIKUCHI[1], Toshi MATSUMOTO[1], Sachiko SAWAYA[1], Setsu OKAYAMA[1], Kaoru ENDA[1], Kinue KANAZAWA[1], Hiromi TODOROKI[1], Kayoko YOKOYAMA[1], Harumi OKUKAWA[1], Teruko UENO[1], Eiko NAKAYAMA[2], Kiriko MIYAMOTO[2], Chikako ISHIKAWA[2], Hiroko HIRANO[2], Nobuko KUMANO[1], and Michi ARATANI[3]
二本柳晴子 [1], 石川とみゑ [1], 菊池トシエ [1], 松本とし [1], 澤谷幸子 [1], 岡山せつ [1], 遠田薫 [1], 金澤きぬゑ [1], 轟博美 [1], 横山香代子 [1], 奥川春美 [1], 上野照子 [1], 中山榮子 [2], 宮本霧子 [2], 石川稚佳子 [2], 平野浩子 [2], 熊野伸子 [1], 荒谷美智 [3]

[1] Reading Circle, Rokkasho Culture Association
六ヶ所村文化協会読書愛好会
Cultural Assoc. Address: 1-8 Nozuki, Obuchi, Rokkasho, Aomori, 0393212 Japan
〒039-3212 青森県上北郡六ヶ所村尾駮野附 1-8、六ヶ所村文化交流プラザ内
E-mail: suwany97@jomon.ne.jp

[2] The Society of Japanese Women Scientists
一般社団法人 日本女性科学者の会
Nakayama, E. Address: Graduate school, Showa Women University
1-7-57 Taishido, Setagaya, Tokyo, 1548533 Japan
〒154-8533 東京都世田谷区太子堂 1-7-57 昭和女子大学大学院
E-mail: enaka@swu.ac.jp

[3] Radiation Education Forum
NPO 法人 放射線教育フォーラム
1-8 Nozuki, Obuchi, Rokkasho, Aomori, 0393212 Japan
〒039-3212 青森県上北郡六ヶ所村尾駮野附 1-8
E-mail: rks00031@rokkasho.jp

Abstract

At Rokkasho, the site of reprocessing facilities of spent nuclear fuels, members of Reading Circle, an affiliate of Rokkasho Culture Association (RCRCA, since 1995, Represetative: H. Nihon'yanagi) have been promoting Science Literacy for themselves under support of the Society of Japan Women Scientists (SJWS), mostly Northeast Block (Head: M. Suzuki). After the 311 catastrophe, promotion was extended to Science & Disaster Literacy for themselves, and citizenry and high school students.

The members of RCRCA were apprehensive about the public sentiment of "No More *Genpatsu* (Nuclear Power Station)" accompanied by the government policy at that time. In view of the situation of such an island country with no natural energy resources, it seemed unwise and impolitic for Japan and for residents of Rokkasho as well.

The highlights of our activities are: 1) publication of the first English version of our 'Bulletin' (selected articles of 1995-2011) "Women's Messages from the Village of Rokkasho to the World" (2012), 2) Holding Symposia entitled 'Messages from Rokkasho Women' in Rokkasho (2013), in Tokyo and Sendai (2014) and in Mutsu (2015), and 3) Carrying out Summer School for junior & senior high school girls at National Women Education Center (NWEC), Ranzan, Saitama Pref. (2012-16).

General view of our principal activities

In 1995, the villagers of Rokkasho, the site of reprocessing facilities of spent nuclear fuel, took first step of Rokkasho Reading Circle, an affiliate of Rokkasho Cultural Assoc. (RCRCA, Representative: H. Nihon'yanagi, one member of SJWS in addition). The aim was to improve our own literacy in radiation and science, while sending messages through Nos. of 'Bulletin'[1, 2]. Things went favorably by working together[3] of SJWS, Soloptimist Intl. Aomori (SIA, comprised of leading businesswomen), and RCRCA.

Circumstances changed suddenly by an unbelievable criticality accident of JCO in Tokai (30 Sept. 1999). From necessity, our activities had to be more extensive, and socially evaluated as a result; Aoi-Mori Science BBL (Founder: Y. Osanai[4-7], a member of both SJWS & SIA) was selected as a promotion program (2007), while RCRCA won Grand Prix 'Nourishing Seedlings in Science' (2007).

Situation turned out more serious after the nuclear catastrophe[9] following the East Japan Earthquake[8-11] and Tsunami[11, 12] (11 March 2011). A nationwide mood 'Ex Nuclear Power' prevailed throughout, even coupled with national policy at that time. In aware of what to do, we extended our activities; "Women's Messages from the Village of Rokkasho to the world" was published (2012), symposia were held successively in Rokkasho (2013), Tokyo (2014), Sendai (2014), and in Mutsu (2015), for instance.

Featured further is the Summer School of NWEC for students (junior & senior high) we participated for 5 years (2012-16), as an extension of our 'Science School for Parent-Child' (led by M. Kazuno, the then President of SJWS): Experiment/Practice: 'Learning energy from cosmic stars---Fundamentals of the nuclear accident in Fukushima', for instance. This program is for students, parents and teachers across the country (from Okinawa was the longest way off so far).

Timelines of our activities after March 2011

<u>2011</u>

Mar. 11	**The East Japan triple disaster (earthquake, tsunami & nuclear accident)**
July 24	"On the 'natural nuclear reactor' by Prof. Dr. P. K Kuroda", 'Bulletin' No. 251.
Aug. 23	"What can we do on the basis of correct understanding of radiations and observation of the stricken areas?" SJWS (Soc. of Jap. Women Scientists) Lecture Meeting (E. Nakayama, K. Miyamoto, N. Kumano), Visitor Center of JNFL, Rokkasho.
Oct. 01	"Radiation-related hands-on" Aoi-mori Science BBL, "Life-long Learning Fair 2011", Aomori Pref. Social Education Center, Aomori.
Oct. 26	"What can we do on the basis of correct understanding of radiations and observation of the stricken areas?" Mini Symposium to support Fukushima, Cultural Exchange Plaza (Swany), Rokkasho.

<u>2012</u>

Aug. 10	Experiment/Practice."Learning energy from cosmic stars---Fundamentals of the nuclear accident of Fukushima", Summer School 2012~for budding scientists and

engineers~, Natl. Women Education Center (NWEC), Ranzan.

Oct. 08 M. Aratani, E. Nakayama. K. Miyamoto: Report, The 9th Science Conference of SJWS, "NWEC Summer School 2012, Experiment/Practice, Learning energy from cosmic stars---Fundamentals of the nuclear accident of Fukushima", Arcadia Ichigaya, Tokyo.

Oct. 12 K. Yokoyama: "From my living right in the way of Dan (cut)-Sha (dump)-Ri (go away)" 'Bulletin' No. 267.

Dec. 12 Published "Women's Messages from the Village of Rokkasho to the World".

2013

Mar. 28 M. Aratani: On the circumstances of publishing "Women's Messages from the Village of Rokkasho to the World", Study Association for Revitalization of Peninsula Shimokita, Masakari Plaza, Mutsu.

July 08 Study visit: Recycle Fuel Stock Co. Ltd., Mutsu.

Aug. 09 Experiment/Practice "Learning energy from cosmic stars---Fundamentals of the nuclear accident of Fukushima", Summer School 2013~for budding scientists and engineers~, NWEC, Ranzan.

Sept. 22 The 20th year Commemorative Round-table Symposium of Rokkasho Reading Circle on the Vitrified High-level Radioactive Waste, N. Kumano: Science lecture "We are made of stardusts", Swany, Rokkasho.

Dec. 03 H. Nihon'yanagi: "Activities in Yokohama Town", T. Ishikawa: "The way I have come", M. Aratani: "Geothermal energy (hot spring) and radiation", Senior School of Yokohama Town Public Hall, Community Center, Yokohama.

2014

Jan. 31 K. Yokoyama: Let's begin the 'Fuk (u) kou (reconstruction and happiness) Egg' from Fukushima, 'Bulletin' No.289.

Feb. 02 E. Nakayama, K. Miyamoto, M. Aratani: "Career choice in Science~for you, future creators", Poster session, Korasse Fukushima, Fukushima.

Feb. 02 E. Nakayama, M. Aratani as facilitators of discussion around the lecturers (M. Takahashi, commentator of the Asahi, K. Abe, Prof. emer., Dept. Agriculture, Univ. of Tokyo), M. Katsuyama (Shiseido Res. Lab.).

May 30 Messages from Rokkasho "Nuclear energy and the way we have come" Tokyo Symposium, Vision Center Nihonbashi, N. Kumano: Science lecture "Nature's gifts in a long history of our planet", Tokyo.

Aug. 08 Experiment/Practice "Learning energy from cosmic stars---World of science spreading from Fukushima", NWEC Summer School 2014 for girls' students~Meet with Science, Technology and Human~, NWEC, Ranzan.

Oct. 05 Messages from Rokkasho "Nuclear energy and the way we have come" Sendai Symposium, El-sola Sendai, K. Yokoyama: Art display "Egg art", N. kumano: Science lecture "Cigar Lake uranium mine---a natural analogue of geological disposal"/Display & Experiment "Zeolite", Sendai.

Nov. 12 K. Yokoyama: "Profile of K. Yokoyama, the leader of Circle "Ka (fragrance)-Ri (Lapis Lazuli)-Mu (dream)", 'Bulletin' No.293.

Nov. 19 K. Yokoyama: "Being compelled to be on endless branch road", 'Bulletin' No. 294.

Nov. 22 Messages from Rokkasho "Nuclear energy and the way we have come" Exchange meeting with Higashidori, K.Yokoyama: Art school & display "Let's begin the 'Fuk(u)kou (reconstruction and happiness) Egg' art (Ukrinian egg art) from Fukushima", N. Kumano: Poster & display "Volcanic ashes as Nature's gift", Tomari Community Center, Rokkasho.

2015

July 30 Published the "Bulletin" No. 300 of Rokkasho Reading Circle.

Aug. 07 Experiment/Practice "Learning energy from cosmic stars---World of science spreading from Fukushima", NWEC Summer School for girls' students~Meet with Science, Technology and Human~, NWEC, Ranzan.

Aug. 30 Messages from Rokkasho 2015 "Future Shimokita and women's role", Mutsu Symposium, K.Yokoyama: Display "Nami'e Town Now", N. Kumano: Science display 1) Interior of the earth, 2) "Boreholes for Hot wastes" (Science 10 July 2015), Kasamai Hall, Mutsu.

Sept. 13 Exchange Meeting of Omaezaki Energy Group, Nagoya Energy-Ecology Wing, and Rokkasho Reading Circle, Hamaoka Power Station, Omaezaki.

Oct. 11 "Detoxification of radiation (experiment) and play school children with seashells", Tomari Community Center Festival, Rokkasho.

2016

Feb. 28 Published the "Messages" Vol. 12 (Part I & II, Nos.236-308 of the "Bulletin").

Aug. 07 Experiment/Practice "Know more and manage cosmic gifts, won't you?", NWEC Summer School 2016 for girls' students~Meet with Science, Technology and Human~, NWEC, Ranzan.

Sept. 25 Opinion-exchange Meeting with NPO HSE-Risk C-Cube (Tokai village), Crystal Palace, Hitachinaka.

Nov. 06 "Enjoy with seashells from Rokkasho/Radiations close to us", Apio-Aomori Fall Festival, Aomori.

Dec. 17 ISRE2016 Poster session, Koriyama.

Although the present authors are mostly nonmember of REF, we have been favored with occasional opportunity to be close to the then secretariat Prof. Dr. T. Matsuura and the then Chair of the board of directors Prof. Dr. A. Arima in either Aomori or Rokkasho.

Once Tohoku branch of REF was established indeed (Head: S. Tsushima, the then member of

Soloptimist International Aomori). We will be pleased to present our activities here in Koriyama, Fukushima Pref., and grateful for any comments or suggestions you could give for.

Acknowledgments

Continuous Nos. of our 'Bulletin'[1] never be realizable without all those thoughtful contributions. The budgetary support of the Town Coordinate Conference of Rokkasho was indispensable for the publication of "Messages" [2] (combined Nos. of 'Bulletin'). All those symposia listed were held in support of the subsidy of the Japan Atomic Energy Relations Organization (JAERO). We also owe the continuous support of those capable office staffs of the Rokkasho Cultural Exchange Plaza (Swany). We are obliged to all of the Rokkasho Public Hall in providing the booth for RCRCA.

References

1) The 'Bulletin' of Rokkasho Reading Circle, No. 246 (Mar.26, 2011) ~ No.334 (Nov.10, 2016) (in Japanese).
2) *Messages from Rokkasho Women*, **12** Part I & II, Kyodo Insatsu-kogyo Inc., Mutsu, 2015 (in Japanese).
3) Sasagawa S., Aratani, M: Women Scientists Joining Rokkasho Women to Sciences, Proceedings of the 1st International symposium on Radiation Education, Hayama,1999.
4) Osanai, Y., Aratani, M: Science Literacy Promotion Activities by Citizens in Aomori Pref., *J. Soc. Jpn. Women Scientists,* **2**, 75 (2001) (in Japanese).
5) Osanai, Y., Kudo, M, Kamayachi, T., Tsushima, K., Uchiumi, F., Aratani, M.: Science Education in the Life-long Education II, *J. Soc. Jpn. Women Scientists,* **5**, (2004) (in Japanese).
6) Osanai, Y., Aratani, M., Kudo, M., Kamayachi, T., Tsushima, K., Uchiumi, F.: Periodic Table as a Powerful Tool for Radiation Education, Proceeding of the 3rd International Symposium on Radiation Education, 407, Nagasaki, 2004.
7) Osanai, Y., Tsushima, K., Hosokawa, S., Uchiumi, F., Aratani, M.: Science Education in the Life-long Education II, *J. Soc. Jpn. Women Scientists*, **6**, 29, (2005) (in Japanese).
8) Aratani, M.: Contribution of Fundamental Science to Reconstruction of Human Beings and Region -Development of the idea of Nucleus and Earthquake Disaster-, *Earth Science (Chikyu Kagaku)* **61**,401 (2007) (in Japanese).
9) Aratani, M.: An Interpretation on the 'Natural Nuclear Reactor' of P.K. Kuroda: *Radiation Education*, **15**, 41 (2011) (in Japanese).
10) Kumano, N. edited: "Women's Messages from the Village of Rokkasho to the World", Kyodo-insatsu, Mutsu, 2012
11) Aratani, M.: Literature and Science---On Terada Torahiko, Proceedings of the 21st Century Unions Symposium, Nihon Kagaku Miraikan, Tokyo, 2003 (in Japanese).
12) Aratani, M.: Led by Terada Torahiko, To'ohnippo Column-kosaten, Oct.10, 2003 (in Japanese).

Mystery of Alpha Particle Track in Cloud Chamber!

霧箱におけるアルファ線の飛跡の謎

Chizuo MORI
森 千鶴夫
Aichi Institute of Technology
愛知工業大学
Yachigusa 1247, Yagusa-cho, Toyota, Aichi Pref., 470-0392, Japan
〒470-0392 愛知県豊田市八草町八千草1247
E-mail: moric@wh.commufa.jp

The track length of alpha particle with 6 MeV in air with the atmospheric pressure is about 4.7 cm and the flight time is only 7.3 ns. Then ion pairs are produced almost simultaneously throughout the track and therefore the white track in a cloud chamber with ethanol vapor is supposed to appear simultaneously. However, the white track of alpha particle is clearly seen to extend from the alpha particle source to the end of the track. This is mystery! The specific energy loss of alpha particle along the track is expressed by the Bragg curve. The track is visible only when the liquid drops of ethanol have grown to about 3 μm in diameter and then Mie scattering of light has appeared. At the beginning of the track, 2-3 ion pairs per 1μm of the track are produced and they are able to grow to the liquid drops with 3 μm diameter by the diffusion of supersaturated ethanol vapor diffused through about 0.3 mm distance. However, near the end of the track, 6-8 ion pairs per 1μm are produced and they need the ethanol vapor diffused through 0.46 mm distance to grow each of the drops to 3 μm diameter. Therefore, the end of the track appears later than the beginning of the track. Beta ray track, on the contrary, appears simultaneously throughout the track length because of very low density of ion pairs per unit length.

6 MeV のアルファ線の 1 気圧の空気中の飛程は 4.7 cm で飛行時間は 7.3 ns である。すなわち、全飛程にわたってほとんど同時にイオン対を作る。したがって霧箱中では飛程の全ての場所に白い飛跡（霧）が同時に現れると思われるが、飛跡は線源から遠方へと伸びて行く。これはまさに謎である。飛跡が白く見えるためには、霧滴は直径約 3 μm 程度に大きくなって Mie 散乱が生じなければならない。アルファ線のエネルギー損失はブラッグ曲線で表され､飛程の最初の位置では､飛跡の長さ 1 μm 当たりのイオン対の数は 2～3 個で、これらは､約0.3 mmの離れた位置からのエタノールの過飽和蒸気の拡散によって直径3 μmに育つ。しかし飛程の最後の方では 6～8 個のイオン対ができ、これらが直径 3 μm に育つには、0.46 mm のより遠方の過飽和蒸気が拡散して来なければならない。従って飛跡の終わりの方は最初の方よりも遅く現れる。対照的に、ベータ線の飛跡は飛跡長さ全長にわたって同時に現れるが､これは単位長さ当たりのイオン対の密度が非常に小さいからである。

Key words: extension direction, alpha-particle, cloud chamber, track, diffusion, energy loss

1. Introduction

Since Wilson invented the expansion cloud chamber [1, 2], these chambers have frequently been used to find new particles. In 1939, Langsdorf developed diffusion cloud chamber [3]. However, because of the development of new electronic radiation detectors, cloud chambers are little used today, excepting for radiation education purposes.

Large expansion cloud chambers were used mainly to study cosmic rays. After expanding the chamber, the droplets grew to a few micrometers in diameter and a strobe light was flashed to photograph them. In the study of cosmic rays, researchers observed comparatively light particles such as positrons, muons, and pions. Because the ion density created along the path of these light particles is very less and almost constant throughout the path, the liquid droplets appear almost simultaneously along the entire particle path. Therefore, the direction of the track extension was not accessible for researchers. Actually, in large diffusion cloud chambers, beta-ray tracks appear simultaneously throughout the path and we are not able to see the extension direction. Conversely, the direction of the tracks of alpha-particles can be determined with human eyes, even with small diffusion cloud chambers for educational purpose.

However, the flight time of alpha-particles in air is less than 10 nano-seconds. The author noticed there was a contradiction between the visibility of the extension direction of alpha-particle track and the flight time of alpha-particles. In this paper, the reason why the direction of the extension of alpha-particle track is visible will be described.

2. Extension time of alpha-particle track and flight time of alpha particle in air

Diffusion cloud chamber used in the present experiment was 12 cm×12 cm×7 cm(height) with ethanol sink at the upper part of the chamber. The temperature of the upper part was about 20℃. The chamber was put on dry ice so that the temperature of the bottom of the chamber was about -40℃. The saturated vapor pressures of ethanol at 20℃ and -40℃ were 44.0 Torr (5780 Pa) and 7.5 Torr (1000 Pa), respectively. Alpha-particle source was $^{232}ThO_2$ attached at the tip of a thin bar.

The extension of an alpha-particle track was observed in movie mode with 60 frames per second of a digital camera. As shown in Fig. 1, there was no track in the first frame (0 s), then the beginning of a track appeared in the second frame (17 ms) and it grew in the third frame (34 ms). Finally, the track completed in the fourth frame (51 ms).

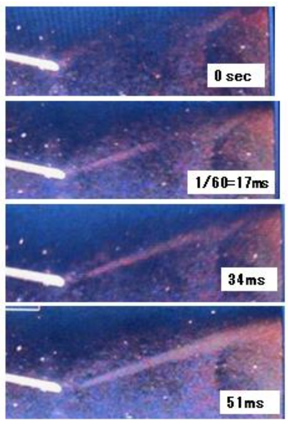


Fig. 1. The extension of an alpha-particle track

Fig. 2 shows the relation between travelling time and travelling distance of alpha-particles in air. The maximum energy of a natural alpha-particle is 8.785 MeV (for ^{212}Pb in the thorium series). The travel time is, therefore, less than 10 ns for all natural alpha-particles. There is the discrepancy between the extension time of the track (about 50 ms) and the travelling time (less than 10 ns) of an alpha-particle. This would be “mystery”.

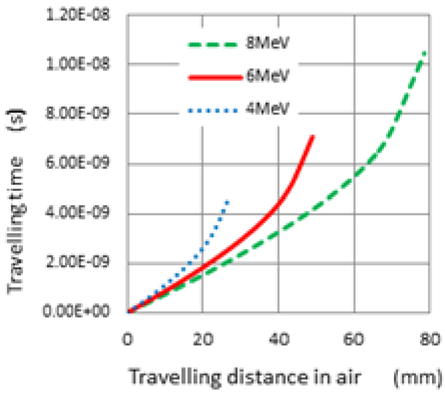


Fig.2. Travelling time against travelling distance of α-particles

3. Visibility of the direction of alpha-particle track

Fig. 3 shows the energy loss and the number of ion pairs per 1μm of alpha-particle track in air against the travelling distance of alpha particle. At the beginning of the track, 2-3 ion pairs per 1μm of are produced and they are able to grow to the liquid drops by the attachment of supersaturated ethanol vapor. However, near the end of the track, 6-8 ion pairs per 1μm are produced.

Electrons of ion pairs quickly combine with oxygen molecules forming negative ions O_2^-. When low electric voltage is applied on an ionization chamber, it is known that the ionization current is small due to the recombination of the ion pairs. When the applied voltage is zero, the current is zero. Similar phenomenon would appear on a cloud chamber without electric applied voltage. However, since the droplets actually appear, not all of the ion pairs recombine. It is difficult to determine the degree of the recombination. Here, it is supposed that the half of the ion pairs recombine. It means that the initial n ion pairs leave n ions.

Ions collect the supersaturated ethanol vapor and the liquid drops grow. The droplets scatter light by Mie scattering, and they are visible to human eyes when they grow to over about 3μm in diameter [4, 5]. Droplet with 3μm in diameter contains about 1.5×10^{11} ethanol molecules. The temperature at the upper part of the diffusion cloud chamber is about 20 ℃ (saturated vapor pressure of ethanol is 5,870 Pa) and the temperature at the lower part is about -40 ℃ (saturated vapor pressure of ethanol is 1,000 Pa). Therefore, the degree of super saturation (super saturation ratio) is 5.8 which satisfies the condition that the degree of super saturation is greater than 4 [6] to grow ethanol droplets in air. In saturated vapor at 20 ℃, the density of alcohol molecules is 1.55×10^{18} cm^{-3}. Thus, three droplets correspond to three ions per 1μm at the beginning of the track require $3\times1.5\times10^{11}$ ($=4.5\times10^{11}$) molecules to grow to droplets with diameter of 3μm. These alcohol molecules are contained in a volume of 2.9×10^{-7} cm^3 of air, which corresponds to a circular disk with a thickness of 1μm and a radius of 0.30 mm as shown in Fig. 4. For seven droplets (seven ions) near the end of the track, the disk radius must be 0.46 mm.

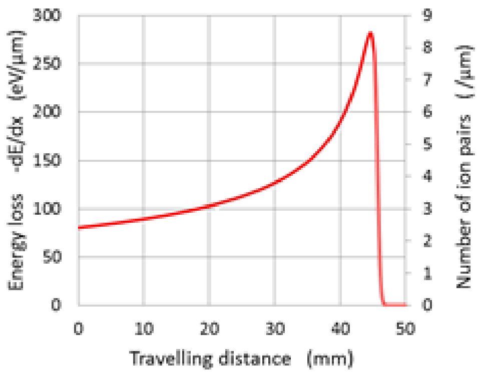


Fig. 3. Number of ion pairs per 1μm in alpha-particle track

We expect that the diffusion time of alcohol molecules in the larger disk diameter required to grow seven droplets with 3μm in diameter near the end of the track would be longer than the diffusion time required to grow three droplets with 3μm diameter near the beginning of the track. This would be the reason why we can see the direction of the extension of the track of alpha-particle in a cloud chamber.

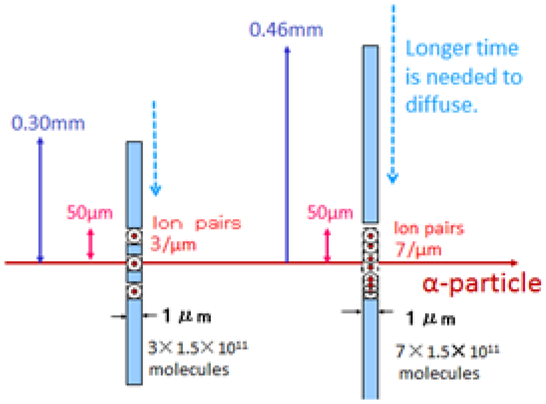


Fig.4 Number of ion pairs per 1 μ m on the path of alpha-particle in air and the distance from where ethanol molecules must diffuse to make each droplets to 3 μ m in diameter.

4. Comparison between calculated diffusion time and experimental result

To calculate the diffusion time of the required ethanol molecules to make an ethanol liquid droplet by being attached to a N_2 or O_2 ions, it is important to find the region where the ion pairs are created by an alpha-particle travelling in air. Although little information is available on this matter, it is considered that most ion pairs are substantially produced in a distance less than about 50μm by simple calculation.

Positive and negative ions rather quickly gather alcohol molecules forming droplets of ethanol and the diffusion coefficient of the droplets is very small compared with that of ethanol molecules. For this reason, only the diffusion of ethanol molecules is taken into account in what follows. Owing to the geometry shown in Fig. 4, the diffusion equation is expressed in cylindrical coordinates [7].

$$\frac{\delta C(r)}{\delta t} = \frac{1}{r}\frac{\delta}{\delta r}\left(rD\frac{\delta C(r)}{\delta r}\right) \qquad (1)$$

In Equation (1), *C(r)* is the density of ethanol molecules at radius *r*, *t* is the time and *D* is the diffusion coefficient of ethanol molecule in air. In the steady state, the flow rate *Q* (molecules/(sec×unit axial length)) from radius *b* with density *C(b)* to radius *a* with density *C(a)* is expressed by the following equation [7].

$$Q = \frac{2\pi D(C(b)-C(a))}{ln(b/a)} \qquad (2)$$

where $C(b)=1.55\times10^{18}$ cm^{-3} and $C(a)=0$ in the present case. Several ions are distributed within the disk of radius 50μm, so it is appropriate to consider the radius *a*=50μm. The diffusion coefficient *D* for an ethanol molecule in air is 0.088 cm^2/s which is the average value of the experimental value and the theoretically determined value extended to -40 ℃ by using values from the literature [8].

The total number of diffused molecules that is the current $Q\times10^{-4}$(molecules/s*μm) times diffusion time *t* must be 4.5×10^{11} molecules/μm for 3 drops/μm and 10.5×10^{11} molecules/μm for 7 drops/μm under the simple assumption that the molecules are supplied by a steady state current from radius *b* to radius 50μm, although the actual diffusion is not a steady state current but a transient current. The author has to admit that the above assumption is the first approximation.

Table 1 shows the comparison between the calculated diffusion time and experimental result (obtained by Fig. 1) for the number of droplets at the beginning of the track and at the end of the track. The both agreed each other, though under the rough assumption.

Table 1. Comparison between the calculated diffusion time and experimental result

Number of droplets	Calculated time (ms)	Experimental time (ms)
3 at the beginning of the track	18	17
6 at the end of the track	35	34
8 at the most end of the track	48	51

5. Conclusion

We examined why it is possible to see the extension direction of an alpha-particle track in a diffusion cloud chamber with human eyes despite alpha-particle travel time of less than 10 ns.

Ethanol droplets must grow to a diameter of about 3μm to become visible by Mie scattering of light. The energy loss ($-dE/dx$) of alpha-particle and thus the number of ions per unit length of alpha-particle path are very large compared with the corresponding quantities for beta-particles. In addition, the number of ions produced by alpha-particle per unit length near the end of the path is larger than that near the beginning of the path. Therefore, near the end of the path, a larger number of ethanol molecules have to diffuse from farther distance than that near the beginning of the path. The time required to grow droplets to a diameter of about 3μm near the end of the path is longer than that near the beginning of the path. For this reason, the alpha-particle track appears first at the beginning of the path and then at the end of the path, and thereby the direction of the extension can be seen with human eyes.

Acknowledgements

The author acknowledges Radiation Education Forum (NPO), Chubu Atomic Power Conference and Japan Atomic Energy Relations Organization, which have allowed him to attend various radiation seminars where he could find some interesting phenomena such as the subject of this paper.

References

1) Wilson C. T. R.: On the method of making visible the paths of ionizing particles through a gas, *Proc. Roy. Soc*. **85**, 285 (1911).
2) Wilson J. G.: *The Principles of Cloud-Chamber Technique*, Cambridge Univ. Press, London (1951).
3) Langsdorf A.: A Continuously Sensitive Diffusion Cloud Chamber, *Rev. Sci. Instr.* **10**, 91(1939).
4) Barret and Germain L.: Growth of Drops Formed in a Cloud Chamber, *Rev. Sci. Instr.* **18**, 84 (1947).

5) H. C. van de Hulst : *Light Scattering by Small Particles*, John Wiley & Sons, Inc. (1957) p.119.
6) Mori C., Shirakawa Y., Fujinami M.: Growth of Cloud Drops in Diffusion Cloud Chamber, *Isotope News*, No.7, 25 (2006) [in Japanese].
7) Crank J.: *The Mathematics of Diffusion, second ed.*, Clarendon Press, Oxford, (1975) p.69.
8) The Society of Chemical Engineers, Japan, *Bussei Jousuu,* Maruzen, (1964) p.248 [in Japanese].

ISRE2016 (2017) 83-87

The Image of Alpha Emitter Distribution on the Surface of Environmental Material with CR-39

身の回りの物品表面のアルファ放射体分布像を CR-39 で取得

Chizuo MORI
森　千鶴夫
Aichi Institute of Technology
愛知工業大学
Yachigusa 1247, Yagusa-cho, Toyota, Aichi Pref., 470-0392, Japan
〒470-0392　愛知県豊田市八草町八千草1247
E-mail: moric@wh.commufa.jp

Abstract

Some environmental materials, such as stone, brooch and ornament made of pottery, lead, solder, etc. contain Th-232 or U-238 and emit alpha-particles. The images of the distribution of alpha emitters on the surface of such materials are able to simply obtain using nuclear track detector CR-39 used for heavy particle radiations. The obtained images are very clear, because the penetration ranges of alpha-particles in solid are very short such as a few tens micro-meter. Since the method is simple and inexpensive, it can be used at science clubs at senior and junior high schools. From the etch pit density obtained by microscopic observation, the radioactivity density of materials can be determined with the help of some theoretical calculations.

身の回りの物品、例えば岩石、陶磁器でできたブローチ、徽章、鉛板、鉛を含む半田などは Th-232 や U-238 などを含んでいて、物品の表面からアルファ線を放出している。そのような物品表面のアルファ線放出核種の分布像を核放射線の飛跡固体検出器である CR-39 を使って簡単に取得することができる。アルファ線の飛程が固体中では数十ミクロンで極めて短いので、鮮明な像を得ることができる。この方法は簡単で安価なので、高校や中学校の科学クラブなどには適していると思われる。顕微鏡で CR-39 の表面を観察することによって、固体中に含まれる放射能強度を求めることもできる。

Key words: alpha emitter, distribution image, nuclear track detector, CR-39, environmental material, radioactivity,

1. Introduction

Geometrical distribution images of radioactivity on the surface of environmental materials are very helpful to understand natural radioactivity and natural radiations. With this intention, so far images of beta-ray emission from ^{40}K, which is naturally present in vegetables, meat, and other environmental materials, have been obtained using an imaging plate [1]. These images have been widely used in public education. However, an expensive image reader is necessary to obtain such images.

A unique method to obtain macro-autoradiographs of alpha emitters was developed by N. Ishigure [2] who used a solid-state track detector CR-39 plate to obtain plutonium distribution image with very strong radioactivity in a mouse's body after the injection of plutonium in a vein. The author considered that this method could be adaptable to obtain the image of natural alpha particle emission on the surface of environmental materials such as stone, and ceramics [3], although a very long exposure time would be necessary for these environmental materials. Such images would be very useful to understand natural radioactivity and natural radiations. Since this method is inexpensive and simple, it would easily be used even at the high schools.

2. Procedure to obtain alpha particle images with CR-39

An inexpensive solid-state track detector CR-39 plate, 280 mm×280 mm×0.9 mm in size, known as BARYOTRAK is commercially available through Nagase Landauar Ltd, Japan. For the present study, this plate was cut into 15 pieces. The detector is sensitive to alpha particles and insensitive to beta- and gamma-rays. Stone, ceramic ware, lead plate, etc. are appropriate specimens, because they emit natural alpha particles.

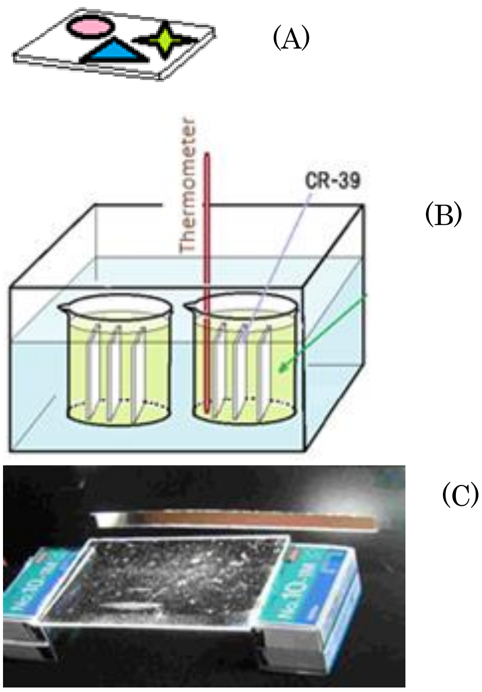


Fig. 1. (A) Alpha emitter specimens are exposed on a piece of CR-39, (B) pieces of CR-39 are chemically etched in sodium hydroxide solution, and (C) the photograph of the image was taken under the illumination of light through only one side of the plate as shown in (C).

The exposure process is very simple. Specimens are simply placed on a CR-39 plate as shown in Fig. 1 (A). It is not necessary to shield environmental radiations or light. However, the exposure time is very long as 2-3 months, because the alpha-radioactivity of environmental specimens is very small. It is important to make the specimen surface contact with the plate surface to obtain a sharp image.

Alpha particle leaves a radiation damage trail called a latent track. The chemical etching enlarges it to be visible size under the microscope or human eyes. In the present case, the CR-39 plate was immersed in sodium hydroxide solution (7.5N, 80℃) for 5 hours as shown in Fig. 1 (B). Cone-shaped etch pits with diameter in the range of 10-100 micrometers appear on the plate surface. Since the exposure time is as long as 2-3 months, the surface density of the number of etch pits is large and the reflection of light by these dense etch pits allows to observe the image with human eyes. If the observation with an optical microscope is desired, the etch pit density must be small. Therefore, in this case, the exposure time was chosen to be as short as several days depending on the radioactivity density of the specimen.

After chemical etching, the CR-39 plate was washed with water. The etch pit density image can be directly seen with the eyes. To obtain the photograph of the image, the plate was put in a dark box so as to face having etched pits downward and the plate was illuminated with light only through one side of the plate as shown in Fig. 1 (C). The photograph was taken and exhibited on the personal computer screen.

3. Some examples of alpha-particle emission distribution images

Fig. 2 (A) shows a photograph of a piece of granite with a flat surface. The granite was placed on the CR-39 plate for 3 months and (B) is the obtained image shown by pseudo color treatment. The radionuclides present in granite are thorium, uranium and their daughter nuclides. Therefore, the etch pits caused by alpha particles emitted from the radon gas emanated from granite and its daughter nuclides can be seen at outside the granite surface area. The black points (biotite containing ^{232}Th, ^{238}U and their daughters) shown in (A) coincide with bright points shown in (B).

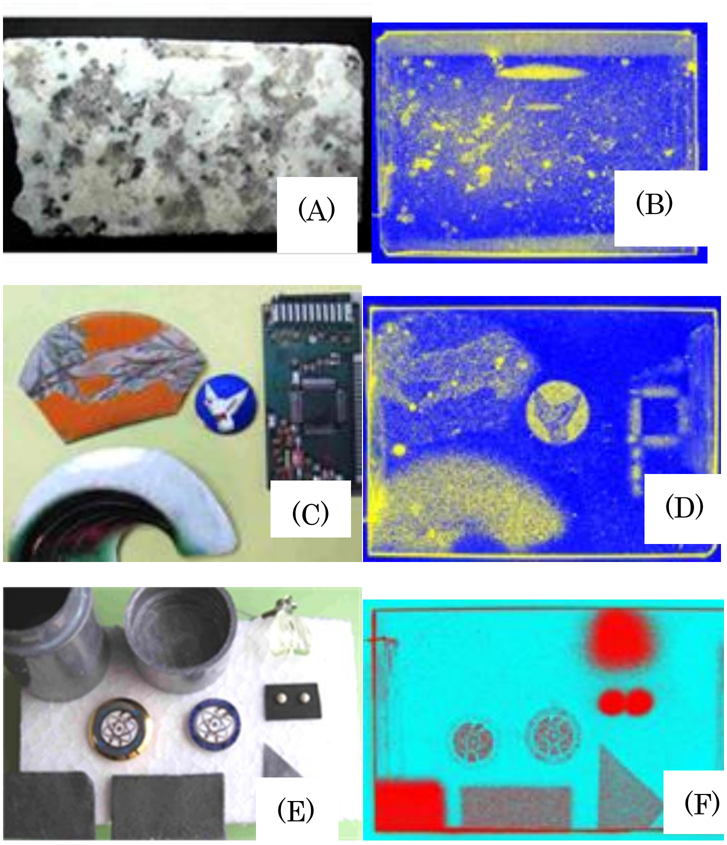


Fig. 2. Photograph of the flat surface of granite (A) and its image of alpha-emitter distribution (B). Two broaches, an emblem, and an IC part (C) and their images (D). Various lead specimens, two emblems, two monazite spheres and uranium glass (E) and their images (F).

Fig. 2 (C) shows two broaches, an emblem with a pigeon pattern, and an IC (integrated circuit) part in a broken electronic desk calculator. Fig. 2 (D) shows the distribution images of alpha emitters of these materials. The wirings of the IC were attached with solder containing lead. Lead contains natural alpha emitters, although recently manufactured solder does not contain lead. Fig. 2 (E) shows the photograph of a lead container and the cap, from upper left to right, uranium glass, two emblems of the Atomic Energy Society of Japan, two monazite spheres with a diameter of 2.5 mm, and three different lead plates. Fig. 2 (F) shows the auto-radiographs obtained by the exposure of (E) for two months. Different three small lead plates showed different lead contents depending on the content of ^{210}Pb (half-life is 138.4 days) of the daughter nuclide of ^{238}U. Two monazite alpha sources have been used for small cloud chamber at the radiation seminars held by Chubu Atomic Conference and their alpha-particle emission rate is only about 0.8 particle /second [4]. However, the exposure time was so long as 5.2×10^6s that the density of the pits was extremely large as about 100 pits per the area of 100 μm×100 μm.

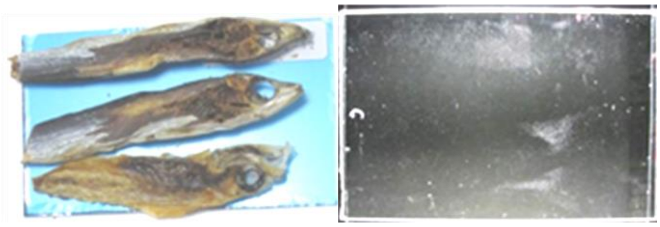


Fig. 3. Three dried sardines (left) and their alpha emitter distribution images (right)

Fig. 3 gives the case of dried sardines (left) and their alpha-particle pit image (right) which shows alpha-emitters were included in special internal organs. The author obtained the image of the same specimens after about one year to confirm whether the alpha emitter was ^{210}Po with the half-life of 138.4 day or not. The image of alpha emitters was faint, so that the emitter was estimated to be ^{210}Po.

From the etch pit density obtained by microscopic observation, the radioactivity density of materials can be determined with the help of some theoretical calculations [5]. In this case, however, the exposure time should be much shorter than 2-3 months not to overlap the pits depending on the radioactivity density in the specimen.

4. Conclusions

By using solid state track detector CR-39, very sharp alpha particle macro-autoradiographs can be obtained which are very useful for understanding natural radioactivity and natural radiations. Since this method is very simple and inexpensive, it can be adapted in extra-curricular activities under the supervision of a teacher at high schools or junior high schools. At universities or research institutes, this method can be used for studying petrology. Radioactivity density in a specimen is able to obtain from the pit density observed by microscope.

Acknowledgements

The author would like to express his sincere thanks to Prof. Takao Iida and Assoc. Prof. Jun Moriizumi of Nagoya University for their valuable advice on chemical etching of CR-39.

References

1) Mori C.: Measurement of extremely low level radioactivity distributions with imaging plate, *Radioisotopes*, **48**, 589 (1999) (In Japanese).

2) Ishigure N.: Application of CR-39 plastic to rapid and quantitative macro-autoradiography of α-emitters in a whole body section of an experimental animal, *Radioisotopes,* **34**, 101 (1985) (In Japanese).
3) Mori C.: Obtaining alpha-ray image of surrounding material with CR-39, *Proc. 2011 Annual Meeting of the Atomic Energy Society of Japan*, Fukui Univ., Japan, March 28-30, (2011), M20 p617, ISBN 978-4-89047-151-5 [CD-ROM]. (In Japanese)
4) Mori C.: Theoretical calculation of the number of α-ray track in a Petri dish-type cloud chamber with monazite source, *Radioisotopes* **61**, 399 (2012) (In Japanese)
5) Mori C.: Macro-autoradiographs of alpha emitters in environmental materials observed with solid-state track detector CR-39, *J. Nucl. Sci. and Technol.*, **50**, 891 (2013)

ISRE2016（2017）88-93

Analysis of the Consciousness of University Students in Okinawa about the Radiation

沖縄県の若者の放射線に対する意識分析

Nanaho SAKASHITA and Eisaku HAMADA
坂下 奈奈穂，濱田 栄作
Faculty of Education, University of the Ryukyus
琉球大学 教育学部
1 Senbaru, Nishihara-cho, Nakagami-gun, Okinawa 903-0213, Japan
〒903-0213 沖縄県中頭郡西原町字千原 1 番地
E-mail: e-hamada@edu.u-ryukyu.ac.jp

Abstract

By revising curriculum guidelines for junior high school in 2008, radiation was added to the third grade science. Most of the students who enrolled in the university in last year (2015) were the first student who learned a radiation at the age of the junior high school. In this study, we compared the awareness of radiation of undergraduate students who received the new curriculum versus the old curriculum by survey. The revision of the curriculum has brought about improvement of some knowledge of radiation. However, no significant difference was found in many other question items. Since the awareness of the topics of radiation related to Okinawa was low, we should develop familiar teaching materials for students.

1. はじめに

学習指導要領の改訂に伴い, 平成 23 年度から放射線に関する内容が中学校理科第三学年に復活し,「放射線の性質と利用にも触れること」と明記された。また，中学校学習指導要領解説理科編においては，その取扱いについて「原子力発電ではウランなどの核燃料からエネルギーを取り出していること，核燃料は放射線を出していることや放射線は自然界にも存在すること，放射線は透過性などをもち，医療や製造業などで利用されていることなどにも触れる」と記載されている [1]。平成 27 年度に入学した大学生の多くは，中学校で放射線を学習した第一期生となった。そこで，本研究では学習指導要領の変更に伴う学生の理解度の変化を明らかにするために，大学生を対象とした放射線に関するアンケート調査を実施した。

2. 学生の放射線に関する認知度調査

2.1 アンケート調査の概要

本研究では, 中学校第三学年で放射線を学んだ第一期生となる平成 27 年度の大学一年生と，学習指導要領改訂前の内容を学習した大学二年生以降を対象にアンケート調査を実施し，学生の放射線に関する知識の定着度合いを調査・分析した。なお，学生によっては，入学年度が同じであっても年齢が異なる場合もあり，学習指導要領の新旧の属性は生年月

日で判断した。質問項目は以下の通りである。Q1 放射線の種類に関する認知度，Q2 放射線の性質に関する認知度，Q3 放射線の利用に関する認知度，Q4 放射線の透過力と危険認知。

平成 27 年 7 月から 8 月にかけて記入式アンケートを 342 枚配布し，335 枚を回収した。その内，323 枚の有効回答があった。有効回答者の属性から以下のグループに分け集計し比較した。I 新課程履修者（N=99）・旧課程履修者（N=224）（以下,「新課程」「旧課程」），II 男性（N=177）・女性（N=146），III 出身高校県内（N=263）・県外（N=60），IV （教育学部を除く）理系学生（N=128）・文系学生（N=73），VI 教育理系（N=48）・教育文系（N=74），VII 男性新課程（N=54）・男性旧課程（N=123），VIII 女性新課程（N=45）・女性旧課程（N=101），IX 理系学生新課程（N=41）・理系学生旧課程（N=87），X 文系学生新課程（N=28）・文系学生旧課程（N=45），XI 教育学部理系新課程（N=10）・教育理系旧課程（N=38），XII 教育文系新課程（N=20）・教育文系旧課程（N=54）。なお，教育学部を除く理系の学部（医学部，工学部，農学部，理学部）に在籍している学生を理系学生，文系の学部（観光産業科学部，法文学部）に在籍している学生を文系学生とした。また，教育学部に在籍している学生の内，理系教科に属する学生を教育理系，その他を教育文系とした。Q1，Q3 については，イェーツの連続補正を行ったカイ二乗検定を基本としたが，期待度数が 5 未満のセルが 20%あるとき，または期待度数が 1 未満のセルが存在するときにはフィッシャーの正確検定（Fisher’s exact test）を用いた。また，Q2，Q4 については Mann-Whitney の U 検定を用いた。何れも有意水準は P＜0.05 とした。

2.2 アンケート分析結果

2.2.1 放射線の種類に関する認知度

最も認知度が高かったのはエックス線で，次いでガンマ線，アルファ線，ベータ線，中性子の順となった（表 1）。新課程を履修した学生の方が，全ての放射線種に対する認知度が高かったが，統計的に有意な差がみられたのはベータ線と中性子のみであり，学習指導要領の改訂の明確な効果は確認出来なかった。その他の属性間の比較では，学生理系の方が学生文系に比べアルファ線，ベータ線，ガンマ線について有意に認知度が高かった。学生理系の新課程・旧課程については，アルファ線，ベータ線，中性子で，新課程の方が有意に高かった。一方で，文系学生，教育理系，教育文系の新課程・旧課程については，全ての線種について有意な差は見られなかった。

表 1. 放射線の種類に関する認知度（新課程・旧課程）

Question	Method of Analysis	Curriculum	Know (%)	P-value
alpha ray	Chi-squared test	New	75.76	0.067
		Old	64.73	
beta ray		New	71.72	0.038*
		Old	58.98	
X-ray		New	94.95	0.138
		Old	92.86	
gamma ray		New	78.79	0.646
		Old	70.09	
neutron		New	40.4	0.003**
		Old	23.66	

*p<.05　**p<.01　***p<.001

2.2.2 放射線の性質に関する認知度

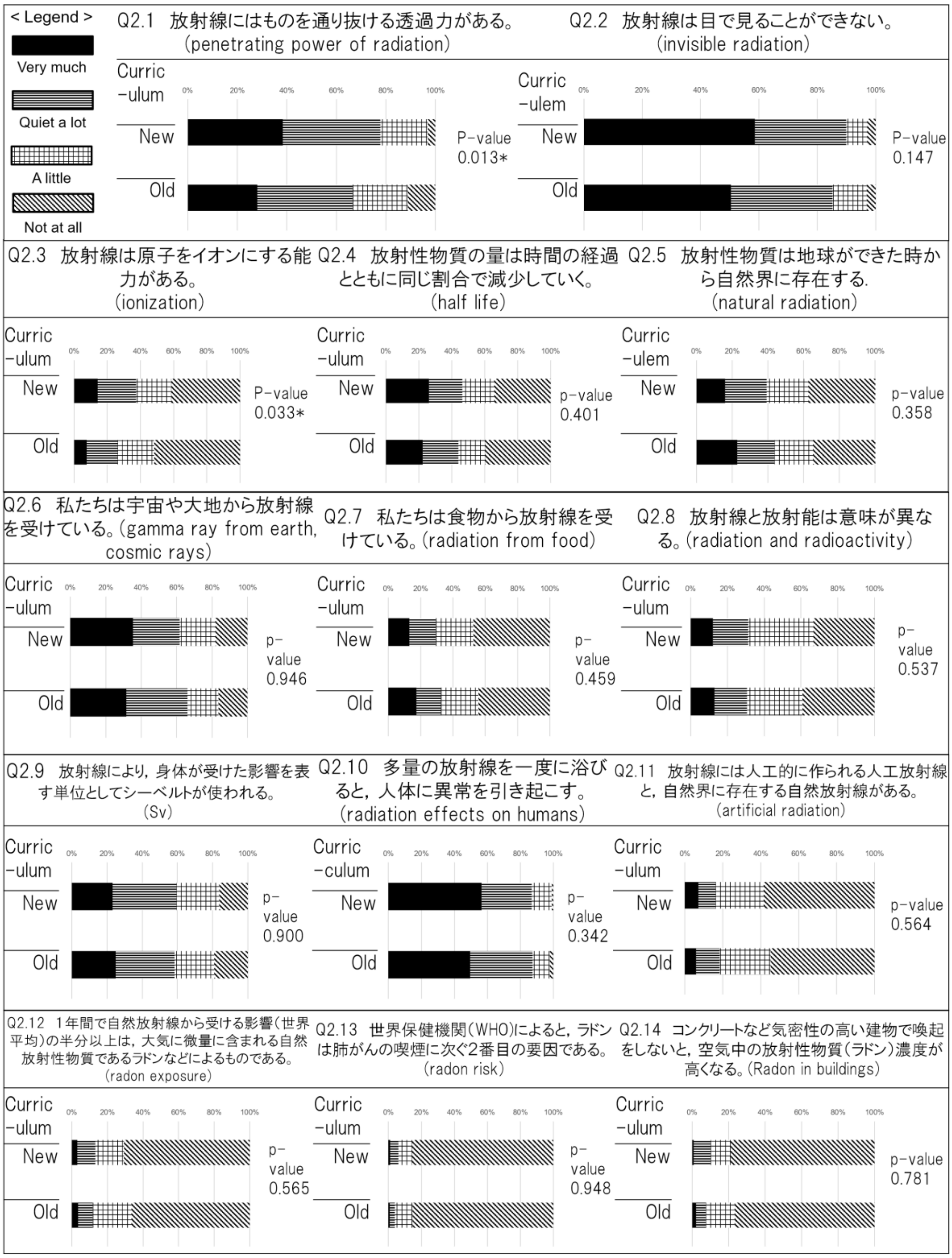


図 1. 放射線の性質に関する認知度（新課程・旧課程）

放射線の透過力や不可視性，シーベルトや人体への影響に関する認知が高かったが，イオン化や，自然放射線の存在およびその起源については低かった。また，ラドンに関する項目も低かった。新課程と旧課程で有意差が確認されたのは透過力とイオン化に関する項

目のみで，何れも新課程で学んだ学生の方の認知度が高かった。なお，理系学生と文系学生，県内と県外で，多くの項目で有意差が確認され，理系学生と県外の高校出身者の方が認知度は高かった（図 1）。

2.2.3 放射線の利用に関する認知度

放射線の利用についてはエックス線撮影やがん治療，空港の手荷物検査に関する認知度は約 7 割を超えた。しかしながら，その他の放射線利用に関する認知度は低く，沖縄県の農業に多大な恩恵をもたらした害虫駆除 [2]ですら，認知度は僅かであった。属性間比較を行ったところ，全ての利用について，新課程と旧課程に有意な差はみられず，学習指導要領の改訂による効果は確認できなかった。一方で，出身高校の県内・県外については，県外出身者の方が農作物の品種改良，タイヤの強度改良，医療用器具の滅菌，文化財の調査に関する認知度が有意に高かった（表 2）。

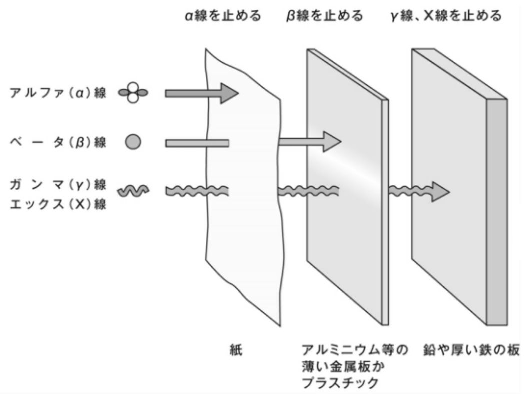
表 2. 放射線の利用に関する認知度（新課程・旧課程）

Question	Method of Analysis	Curriculum	Know (%)	Unknown (%)	P-value
1.じゃがいもの発芽防止	Chi-squared test	New	10.10	89.90	n.s.
		Old	14.73	85.27	
2.害虫駆除		New	15.15	84.85	n.s.
		Old	15.18	84.82	
3.農作物の品種改良		New	24.24	75.76	n.s.
		Old	19.20	80.80	
4.タイヤの強度改良		New	1.01	98.99	n.s.
		Old	2.23	97.77	
5.X 線撮影		New	92.93	7.07	n.s.
		Old	97.77	2.23	
6.がん治療		New	85.86	14.14	n.s.
		Old	83.93	16.07	
7.医療用器具の滅菌		New	30.30	69.70	n.s.
		Old	31.25	68.75	
8.文化財の調査		New	27.27	72.73	n.s.
		Old	33.48	66.52	
9.空港の手荷物検査		New	68.37	31.63	n.s.
		Old	66.96	33.04	

2.2.4 放射線の透過力と危険認知

放射線の透過力を説明する図を提示し（図 2），5 段階で危険度の評価を問うたところ，すべての属性においてアルファ線，ベータ線，ガンマ線・エックス線の順に危険度認知（平均値）が高くなった（表 3）。なお，危険度の評価は「危なくない」を 0 とし，「危ない」を 4 とし，数値化した。

放射線被ばくには外部被ばくと内部被ばくがあるが，放射線の透過力を示す図は外部被ばくからの影響を無意識にイメージさせ，透過力の高いガンマ線やエックス線に対する危険認知を高めたと考えられる。アルファ線の放射線荷重係数は光子の 20 倍もあり, 放射線被ばくを議論する際には，アルファ線による内部被ばくを無視することはできない。放射線の透過力だけではなく，放射線被ばくの形態と放射線種の関係を示す適切な解説が必要である。



原子力・エネルギー図面集 2015

図 2. 放射線の透過力

表 3. 放射線の透過力と危険認知（新課程・旧課程）

Question	Method of Analysis	Curriculum	Average	P-value
alpha ray	Chi-squared test	New	1.79	n.s.
		Old	1.28	
beta ray		New	3.29	n.s.
		Old	3.56	
gamma, X-ray		New	3.00	n.s.
		Old	3.49	

3. まとめ

学習指導要領の改訂後に中学校で放射線教育を受けた学生の方が，放射線に関する知識が高い傾向が一部を除き見られたが，統計学的に明確な効果は見られなかった。また，学習指導要領で明記された放射線の利用については，新旧課程の有意差が全ての項目で見られなかった。福島第一原子力発電所事故が収束しない状況で，社会の関心が放射線の環境や人体への影響に集まる中，放射線利用が授業でどの程度扱われたのか，疑問が残る。特に，害虫駆除や建物内のラドン [3]など，沖縄と関係が深い項目について，県内出身の学生の認知度は極めて低かった。地域の実情に合わせた放射線教育が今後求められるとともに，放射線を教える教師への支援も必要と思われる。他方，放射線の透過力を表す図のみの説明では，自然放射線による被ばくの約半分を占めるラドンガス（アルファ線）の影響を過小評価する可能性もある。放射線被ばくの形態と放射線種の関係を示す適切な解説が必要である。今回の調査では，理系と文系で放射線に関する認知に有意差が多くみられた。調査時点では，新課程の学生は 1 年前期の講義を履修中であり，大学での学習ではなく高校での学習が影響したと思われる。中学校のみでなく，継続的な放射線教育が必要と考えられる。

謝辞

本研究の一部は，JSPS 科研費 26350239 の助成を受けて行われた。

参考文献

1) 文部科学省: 中学校学習指導要領解説理科編. 大日本図書 2008
2) Kakazu Hiroshi, A new frontier of Okinawa's Agriculture: An economic evaluation of the melon fly eradication project. *Journal of Agricultural Development Studies* **17**, 21 (2006)
3) 沖縄県農林水産部病害虫防除技術センター: ウリミバエ根絶防除事業概要 2008
4) Inspector General U.S. Department of Defense: Military Housing Inspections–Japan. Report No. DODIG-2014-121 2014

Development of Teaching Materials for Radiation Education Using CR-39

固体飛跡検出器 CR-39 を用いた放射線教育教材の開発

Yumeto NAKAHODO and Eisaku HAMADA
仲程 夢斗，濱田 栄作
Faculty of Education, University of the Ryukyus
琉球大学 教育学部
1 Senbaru, Nishihara-cho, Nakagami-gun, Okinawa 903-0213, Japan
〒903-0213 沖縄県中頭郡西原町字千原 1 番地
E-mail: e-hamada@edu.u-ryukyu.ac.jp

Abstract

For visualization of radiation damage to the solid track detector, it must be etched with a high concentration of sodium hydroxide solution or potassium hydroxide solution. Since the use of these solutions is accompanied by danger, it is difficult to do in elementary and junior high school. In order to use the solid track detector CR-39 in the education field, we have investigated a safe etching method for CR-39.

When a low concentration sodium hydroxide solution (5%) was used for etching at room temperature, etched pits could be observed by etching for 3 days. If etching could be performed at 90 ºC using a hot water bath, the etch pit on CR-39 appeared in just a few hours. By irradiating CR-39 with UV, it became easy to observe the etch pits. In particular, the size of the etch pits of CR-39 irradiated with UV before and after α-ray irradiation has expanded. By partially irradiating alpha particles, we were able to observe the presence or absence of radiation damage without using a microscope. By combining these methods, it can be safely utilized CR-39 in the school.

1. はじめに

現行の中学校学習指導要領理科に「放射線の性質と利用にも触れること」が明記され [1]，学校現場では放射線に対する理解を高めるために，霧箱や放射線測定器の利用など様々な工夫がされてきた [2－4]。一方で，医療，農業，工業分野での放射線利用や，放射線の人体への影響を理解するためには，放射線と物質の相互作用，すなわち放射線が持つエネルギーを実感し，理解することが重要であり，放射線損傷を眼で確認できる固体飛跡検出器の放射線教育教材としての活用が望まれる。

固体飛跡検出器は，荷電粒子が入射した際に形成される放射線損傷を化学薬品によるエッチングで拡大し，光学的に観察できる検出器である [5]。特に，プラスチック材料の PADC（Poly-Allyl-Diglycol-Carbonate, CR-39）は荷電粒子に対して高い感度を持ち，放射線損傷を観察しやすく，宇宙飛行士の線量評価など，その取扱い性から様々な分野で利用されている [6]。また，軽量で衝撃に強く割れにくい一般的な CR-39 は優れた光学性能も有していることから，偏光レンズや溶接カバーとしても利用されており，生徒にとっても馴染みのある材料である。

プラスチック板 CR-39 に荷電粒子が入射すると，飛跡に沿って放射線損傷（潜在飛跡）を与える。その損傷は極めて小さいが，化学薬品でエッチングすることで，損傷された場所の方が損傷を受けていない場所よりもエッチング速度が速いため損傷が拡大され，光学顕微鏡で観察できるようになる（図 1）。このように，放射線による損傷を観察できる CR-39 は，学校現場での教材としての活用が期待されるが，CR-39 の放射線損傷の可視化には，高濃度（30 %）の水酸化ナトリウム水溶液や水酸化カリウム水溶液によるエッチングが一般的で，教育現場で使用するためには取扱いに注意が必要となる。また，昨今の放射線教育のニーズの高まりから，簡単に放射線損傷を可視化できる実験キット（サンルックス，Sun9）も市販されているが，30 %の水酸化ナトリウムを沸騰させ，徐冷しながらエッチングしており，中学生の生徒実験としては，安全面から特段の配慮が必要である [7]。

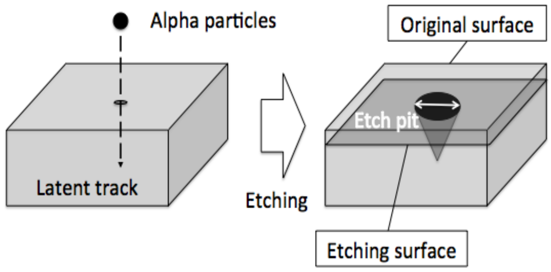


図 1. エッチピットの形成過程

そこで，本研究では CR-39 の教育現場での活用を目的に，エッチング溶液の低濃度化を中心に検討を行った。

2. 教材化のための検討

本研究では，市販の CR-39（長瀬ランダウア，BARYOTRAK，$t = 0.9$ mm）を用いた。また，教育現場での活用を考慮し，「毒物及び劇物取締法」に該当しない 5%の水酸化ナトリウム水溶液をエッチング溶液として主に利用した。なお，放射線源（アルファ線）には，硝酸トリウムを含侵させたマントルの芯を用いた。以下，①エッチング溶液の低濃度化，②紫外線照射効果，③超音波照射効果について述べ，最後に④光学顕微鏡を利用しない方法について述べる。

2.1 エッチング溶液の低濃度化

一般的に，エッチング溶液の液温を上昇させることで，エッチピットをより早く拡大できる。しかしながら，教育現場ではウォーターバス等の恒温装置が無いのが現状である。そこで，低濃度エッチング溶液による室温でのエッチングを試みた。図 2 に，高濃度（30% NaOH (aq)）および低濃度（5% NaOH (aq)）エッチングによる，エッチピット径の時間変化を示す。高濃度エッチングの場合，数時間後にはエッチピットを観察できたが，低濃度エッチングでは，3 日目から小さなエッチピットが観察でき，20 日目に明瞭なエッチピットを観察することができた。

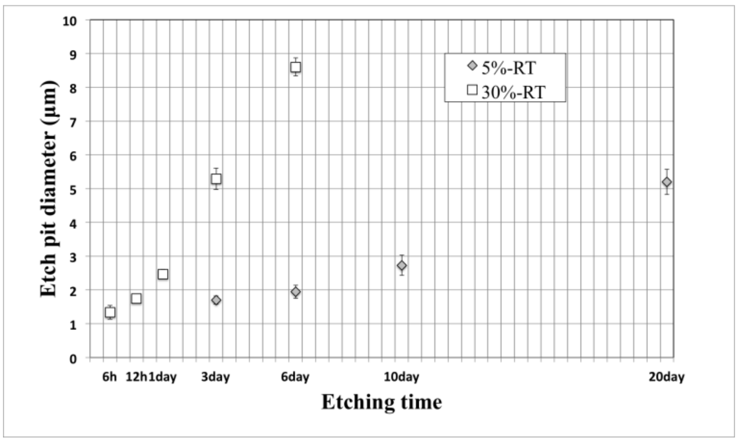


図 2. エッチング時間とエッチピット径の関係（室温，NaOH (aq)）

2.2 紫外線照射効果

CR-39 に放射線を照射する前または後に，紫外線を照射することでエッチング速度が大きくなることが報告されている[8]。そこで, 本研究では, 波長 254 nm の紫外線（UVP，3UV-34，4 W）を以下の条件で照射し，エッチピットの拡大について調べた。【pre-UV】予め紫外線を照射した CR-39 に放射線を照射し，その後エッチングを実施。【post-UV】放射線を照射した CR-39 に紫外線を照射し，エッチングを実施。【pre-post-UV】放射線を照射する前と後に紫外線をそれぞれ照射し，エッチングを実施。

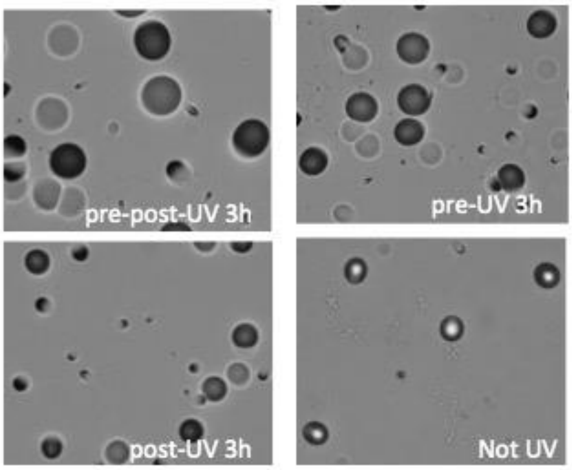


図 3. エッチピット画像

図 3 は，紫外線照射によるエッチピットサイズの変化を示したもので，紫外線を照射することでエッチピットの拡大が確認できた。図 4，5 は紫外線をそれぞれ 1 時間（図 4）又は 3 時間（図 5）照射した際のエッチピットサイズの時間変化である。両条件とも，エッチング時間が 3 時間を超えると，エッチピットの大きさに変化が現れ，特に，放射線照射の前後に紫外線を照射すると，その効果は顕著であった【pre-post-UV】。

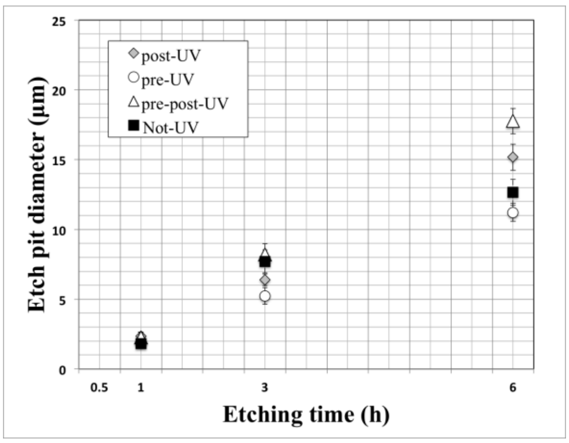


図 4. 紫外線を 1 時間照射したときのエッチピットの時間変化（90 ℃，5 % NaOH (aq))

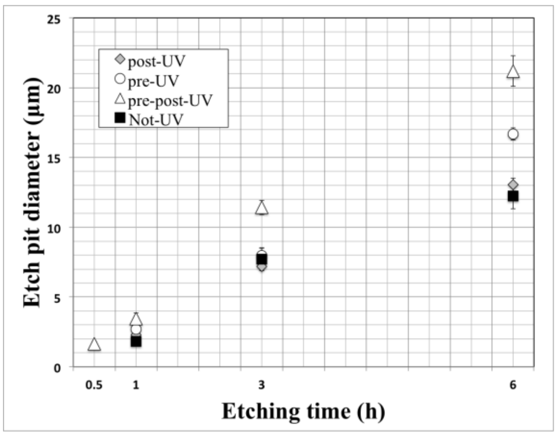


図 5. 紫外線を 3 時間照射したときのエッチピットの時間変化（90 ℃，5 % NaOH (aq))

2.3 超音波照射効果

エッチング反応の効果を高めるために超音波（本多電子，HM-303N，超音波発振周波数 2.4 MHz）を照射しながらエッチングを行ったところ（室温，5% NaOH (aq))， 24 時間後には直径約 2.3 μm のエッチピットを観察することができ, 5 日目には 17 μm となり, エッチピットの拡大が確認された (図 6, 7)。しかし，超音波発生時に，溶液温度の上昇（50℃）も確認されており，更なる研究が必要である。

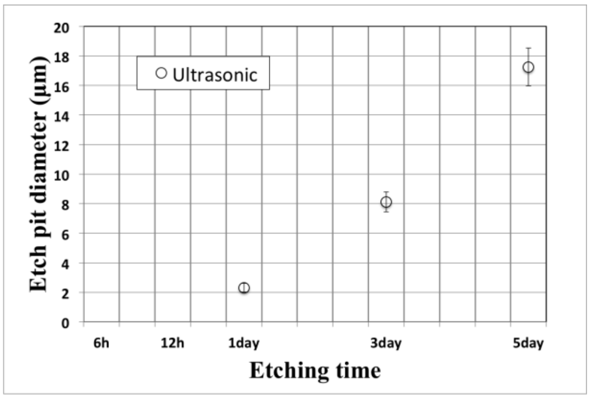


図 6. 超音波照射時のエッチング時間とエッチピットの関係（室温，5 % NaOH (aq)）

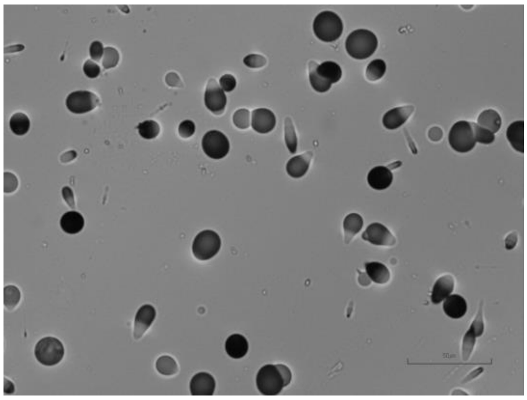


図 7. 超音波照射時のエッチピットの例　(5 日目)

2.4 顕微鏡を使用しない観察手法

CR-39 の損傷から放射能分布を肉眼で観察する方法が報告されている[2, 9]。本研究でも，約 4cm 四方に切った CR-39 に放射線を遮蔽するための紙を置き，その上から放射線源としてマントルを 1 日静置した。その後，30 % NaOH 水溶液を使用し 90 ℃で 20 分間エッチングを行った結果，放射線を遮蔽していない部分のみが白く濁り，模様を観察することができた（図 8)。同様の実験について，低濃度のエッチング溶液（室温，5% NaOH (aq)）でも試みたが，観察可能な大きさまでエッチピットが拡大するためには長時間（30 日超）のエッチングが必要であった。

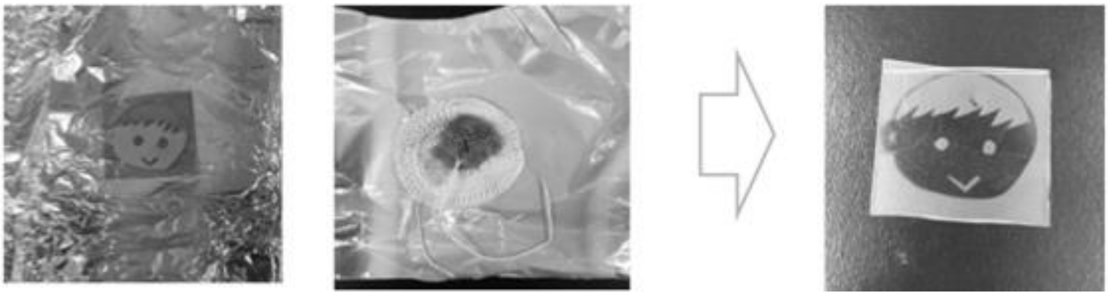


図 8. 放射線の遮蔽方法と結果

3. まとめ

本研究では，固体飛跡検出器である CR-39 を放射線教育用教材として，安全に利用するための手法について検討した。「毒物及び劇物取締法」に該当しない 5 %程度の NaOH 水溶液を使用する場合，90 ℃で液温を一定にできれば，1 時間のエッチングでエッチピットを観察することができた。また，液温を室温にし，5 %濃度で長時間エッチングを行えば観察も可能であった。さらに，紫外線照射や，エッチング中に超音波照射することで，エッチング速度の増加が確認された。顕微鏡を使用しない観察手法では，放射線照射による損傷部分とそうでない部分の状態の違いを肉眼で観察できるので，放射線がエネルギーを持つことについての理解が容易になる。これらの手法を組み合わせることで，より安全に CR-39 を教育現場で活用できると思われる。

謝辞

本研究の一部は，JSPS 科研費 26350239 の助成を受けて行われた。

参考文献

1) 文部科学省: 中学校学習指導要領解説 理科編. 大日本図書 2008
2) 森千鶴夫: 学校教育における放射線実験に関する提言. 放射線教育 **16**, 3 (2012)
3) 佐伯英人, 宇宿公紀: 秋芳洞, 大正洞, 景清洞の放射線に関する基礎研究と教材化に関する一考察. 理科教育学研究 **56**, 355 (2015)
4) 濱田栄作, 松田翔: WebGIS を活用した放射線教育実践. 放射線教育 **17** , 3 (2013)
5) G. F. NOLL: 放射線計測ハンドブック. 日刊工業新聞社 1982
6) B. G. Cartwright, E. K. Shirk, P. B. Price: A nuclear-track-recording polymer of unique sensitivity and resolution. *Nuclear instruments and methods* **153**, 457 (1978)
7) 石川一平, 清原修二: 放射線飛跡を可視化するプラスチック教材を用いた教育方法の実践, 応用物理教 **40**, 101 (2016)
8) K. C. C. Tse, D. Nikezic, K. N. Yu: Effects of UVC irradiation on alpha-particle track parameters in CR-39. *Radiation Measurements* **43**, 98 (2008)
9) Nobuhito Ishigure: Application of CR-39 plastic to rapid and quantitative macroautoradiography of alpha-emitters in a whole body section of an experimental animal. *Radioisotopes* **34**, 101 (1985)

ISRE2016 (2017) 99-102

HATO Project / Practice of Radiation Education through Partnership of Teacher Education Universities

HATO プロジェクト/大学間連携による放射線教育の実践

Kazuko ONISHI[1], Akio HIRATA[2], and Masahiro KAMATA[2]
大西和子 [1]、平田昭雄 [2]、鎌田正裕 [2]
[1]Center for Teacher Education Development through Partnerships, Tokyo Gakugei University
東京学芸大学　教員養成開発連携センター
[2]Faculty of Education, Tokyo Gakugei University
東京学芸大学 教育学部
4-1-1, Nukuikitamachi, Koganeishi, Tokyo 184-8501, Japan
〒184-8501　東京都小金井市貫井北町 4-1-1
E-mail: onishi@u-gakugei.ac.jp

Abstract

Teacher training to produce junior high school science teachers who can teach radiation/radioactivity based on scientific perspective has become an urgent task in Japan. Since 2012, four Teacher Education Universities (**H**okkaido University of Education, **A**ichi University of Education, **T**okyo Gakugei University（TGU）, **O**saka Kyoiku University) have been engaged in the “HATO Project”. Under this big project, Tokyo Gakugei University (TGU) has managed a sub-project; “HATO Radiation Education Project” whose objective is pre-service teacher training of radiation education for junior high school science. In this project, we started two new subjects “Radiation Education I” and “Radiation Education II” in TGU from 2014. The former one is for the students of the four universities, and is made of lectures and educational experiments. The latter “Radiation Education II” is for the students of TGU, and is made of lectures and practical work such as practice teaching at junior high school. In addition, we have developed teaching materials of radiation education (Video contents and “Teaching Materials Package for teachers”).

Outline of “HATO Project”

In Japan, curriculum guideline (Course of Study) for junior high school science was revised in 2008, and radiation education was added in the guideline of school science. After Fukushima Daiichi nuclear power plants accident of 2011, scientific literacy on radiation/radioactivity is socially demanded.

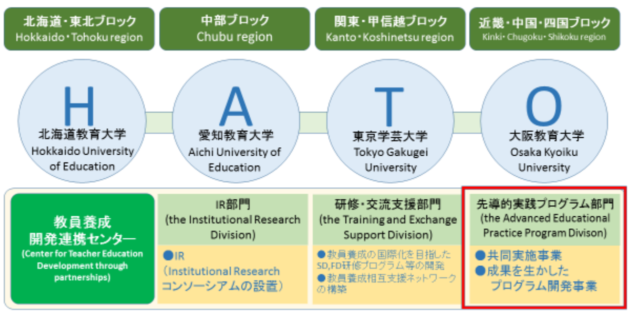


Fig. 1. The Organization of HATO

Under the circumstance described above, teacher training to produce junior high school science teachers who can teach radiation/radioactivity based on scientific perspective has become an urgent task in Japan.

The HATO Project is implemented to build a support system for advanced teacher education through university partnership. The project was established in 2012. Four Teacher Education Universities (Hokkaido University of Education (H), Aichi University of Education (A), Tokyo Gakugei University (T), Osaka Kyoiku University (O)) have been engaged in the “HATO Project” (Fig. 1). Under this big project, Tokyo Gakugei University (TGU) has managed a subproject; Radiation education project. The objective of this project is to develop junior high school teachers of science who can teach radiation and radioactivity based on scientific perspective.

Radiation Education Curriculum

In this project, we have developed a curriculum and materials for radiation education, and have started two new subjects “Radiation Education I” and “Radiation Education II” for university students since 2014.

Table 1. Curriculum of “Radiation Education I”（2016）

Day	Schedu	No.	Title	Teacher
2016 9/2(Fri.)	9:00	01	Guidance	Masahiro Kamata(TGU), Akio Hirata(TGU)
	10:40	02	Basics of radiation physics	Masahiro Kamata(TGU)
	13:00	03	Science of Radiation	Masahiro Kamata(TGU), Kazuko Onishi(TGU)
	14:40	04	Nuclear fission and nuclear reactor	Shu Matsuura(TGU)
9/3(Sat.)	9:00	05	Natural nuclear fission reactor, uranium deposits and deep geological repository	Masataka Nakata(TGU)
	10:40	06	Separation of radionuclides using ion exchange and solvent extraction method	Hisao Kokusen(TGU)
	13:00	07	Effects of radiation on living organism	Fumi Nakanishi(TGU)
	14:40	08	Molecular mechanism of Cs specific adsorption	Kiminori Sato(TGU)
9/5(Mon.)	16:00 16:20	09	Guidance(for students of three other universities) Basics of radiation physics	Masahiro Kamata(TGU), Akio Hirata(TGU)
9/6(Tue.)	9:00	10, 11	Measurement of natural radiation, Visualization of radiation by cloud chamber	Masahiro Kamata(TGU), Kazuko Onishi(TGU)
	13:00	12	Experiment of model waste fluid processing using ICP and AAS (1)	Hisao Kokusen(TGU)
		13	The effect of radiation on biological systems (1) Model experiments using ultraviolet light The effect of ultraviolet light on E. coli and Drosophila	Kazuo Harada(TGU), Hisaki Takamori(TGU)
9/7(Wed.)	9:00	14	Principles of IP, CT, and radiation detectors	Etsuo Arakawa(TGU)
	12:50	15	Elementary particles observed in Photographic Emulsion	Koichi Kodama(AUE)
		16	Experiment of model waste fluid processing using ICP and AAS (2)	Hisao Kokusen(TGU)
9/8(Thu.)	9:00	17	Radiation effect of foods	Hideo Nakamura(hue)
	10:40	18, 19	Measurement of the natural radioactivity of mineral rocks Identification of radionuclides in mineral rocks	Masataka Nakata(TGU), Akio Hirata(TGU)
9/9(Fri.)	13:00	20	The effect of radiation on biological systems (2) Model experiments using ultraviolet light The effect of ultraviolet light on E. coli and Drosophila	Kazuo Harada(TGU), Hisaki Takamori(TGU)

In “Radiation Education I” (Table 1), students learn about radiation systematically through lectures and experiments. In “Radiation Education II”, students design some classes of radiation for junior high school science. They actually try in junior high school what they designed, and confirm the responses from the junior high school students.

Since “Radiation Education I” was held intensively for four days (16 school hours) in September, students of three other universities came to TGU and learned about the basic of radiation, radiation measurement, radiation effects on living things through experiments with TGU students. In 2016, professors from Hokkaido and Aichi University of Education participated in the class as lectures, and the students’ impressions were very positive (Photo 1).

Photo 1. Scenes from “Radiation Education I” (2016)

1) The effect of radiation on biological systems（1）

2) Elementary particles observation using Photographic Emulsion

3) Experiment of model waste fluid processing using ICP and AAS(2)

4) Students from four universities.

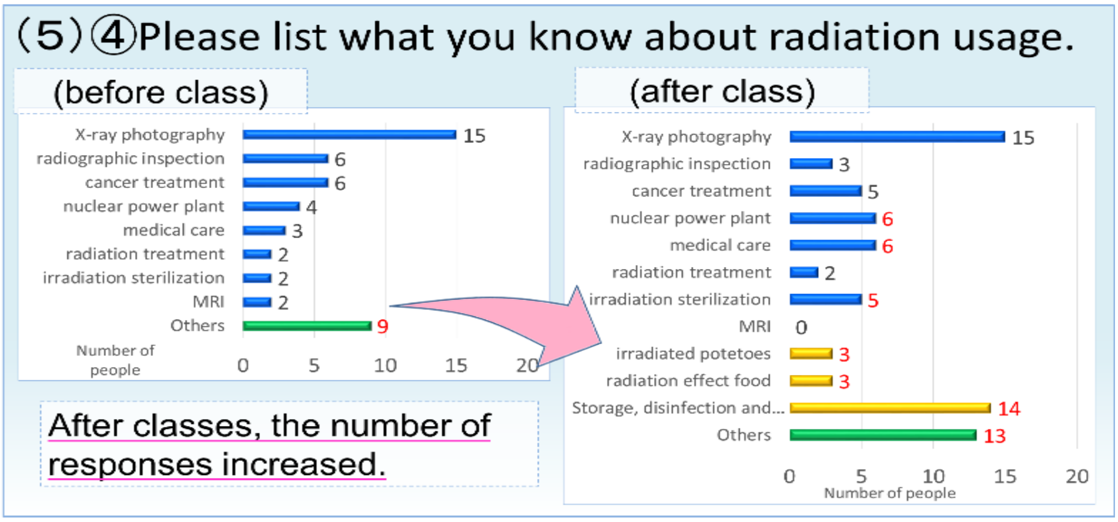
Class questionnaire

Before and after the class “Radiation Education I”, we asked 26 students of the four universities to answer our questionnaire. Before the class, we asked the reason why they took part in the class. The results indicate that they could not find enough opportunities to learn about radiation while they understood the knowledge is important when they become teachers in future.

After the class, we asked them if the contents of “Radiation Education I” were useful for teaching science classes in future. The students who choose “Very useful” and “Useful a little”, were 96% (Fig. 2).

Students’ opinions

- In future, we will teach science in junior high school. But we have not learned about radiation. So I think the class is very useful.
- Although radiation is harmful to a human body, it is used for various purposes in our lives. In future, I would like to teach correct knowledge about radiation to my students.



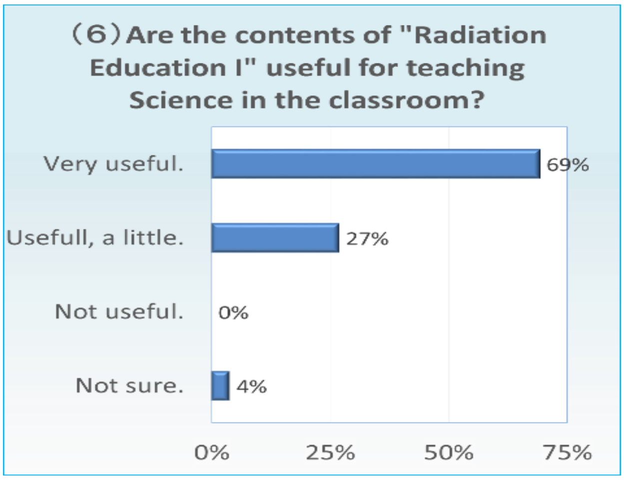


Fig. 2. Results of questionnaire before and after "Radiation Education I"

Developed materials

In 2016, we developed teaching materials for radiation education; "Video contents" and "Teaching Materials Package for teacher training". The materials have been uploaded on the website of HATO Project, and can be used for free in any university for preservice and in-service teacher training.

(Top page) http://hato-project.jp/index.html

(Contents) http://hato-project.jp/product/post_10.html

(2017/2/16)

*This research was supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology through the Grant for Strengthening National University Reforms for the "HATO Project/Teacher Training Renaissance: Building a Support System to Advance Teacher Education through University Partnership".

ISRE2016 (2017) 103-106

Effects of the Thoron Spa or Bath on the Anaplastic Carcinoma of Thyroid

Kimiko HORIUCHI, Atsuhiro KISHIMOTO, and Koji YAMAMOTO
Healthypeople Co.,Ltd

1. Introduction

It is generally received that the low dose irradiation emitted by the radioisotope such as radon (^{222}Rn) and thoron (^{220}Rn) is effective for the improvement of the condition of the lifestyle diseases such as cancers and diabetes. In this meeting, we reported about the effects of the thoron spa or bath on the anaplastic carcinoma of thyroid.

2. Materials and Methods

The thoron hot water was prepared using our devices based on the weak acid leaching method. The cancer patient took a bath in the thoron hot water from six to eight times a day for each ten minutes every day. We judged the evaluation from a blood test and so on.

3. Results

Comparison of the thoron and the radon hot spring

The thoron is an isotope of the radon. The radon is a member of the Uranium-238 decay series and is the α decay product of Radium-226 then becomes stable Lead. On the other hand, the thoron is a member of the Thorium-232 decay series and is the α decay product of Radium-224 then becomes stable Lead (Fig. 1).

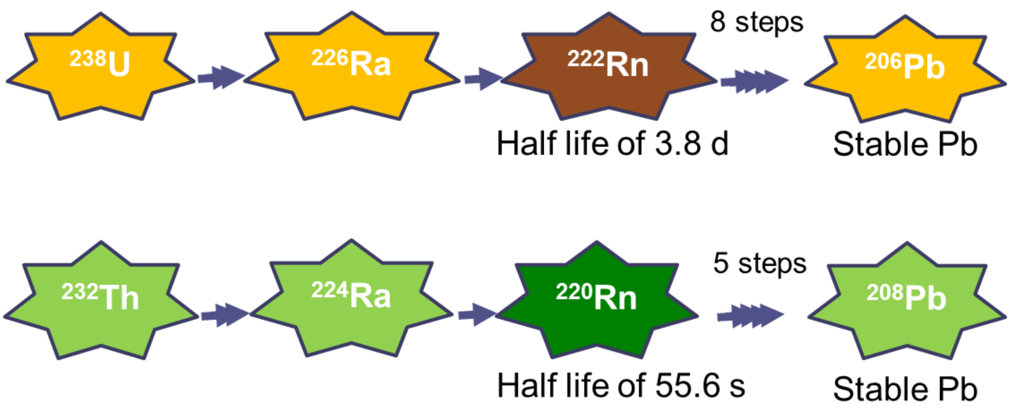


Fig. 1. Summary of the Uranium-238 and the Thorium-232 decay series. The Uranium-238 and the Thorium-232 become radon (^{222}Rn) and thoron (^{220}Rn) each.

As the radioactive material, the half-life of radon is about 3.8 days, and it takes more than 20 years for the radon to become the Lead. On the other hand, the half-life of thoron is about 55.6 seconds, and it takes around 11 hours for the thoron to become stable Lead. Thus, because the period when the thoron exists as radioactive material is shorter than that of the radon, it is thought that the negative effect of thoron on human body is small. For the thoron hot water, it is easy to obtain the radioactive effects stably and to investigate various conditions such as the concentration and the component of the water because of preparing artificially. On the other hand, for the radon hot water, it is difficult to maintain the radioactive effects and to study more effective conditions because of the natural hot water. As the location of the radon hot spring, it is difficult to move the place of spa facility because of the natural hot spring. As the location of the thoron hot spring, it is easy to build the spa facilities in the various places because of the artificial hot spring. Thus, the thoron hot spring is useful as the radioactive spring (Table 1).

Table 1. Comparison of the thoron and the radon hot spring

Item	Radon hot spring	Thoron hot spring
Safety of radioactive material	The half-life of radon is about 3.8 days, and it requires more than 20 years until it becomes stable ^{206}Pb.	The half-life of thoron is about 55.6 seconds, and it requires around 11 hours until it becomes stable ^{208}Pb.
Radiation intensity	5.4×10^6 MeV	6.3×10^6 MeV
Hot water	Because of natural hot water, it is difficult to maintain the radioactive effects and to study more effective conditions. It is difficult to move the place of spa facility because of the natural hot spring.	To prepare hot water artificially, it is easy to obtain the radioactive effects stably. It is easy to build the spa facilities in the various places because of the artificial hot spring.

Radioactive component of the thoron hot water

A stock solution immediately after the thoron preparation was measured by the liquid scintillation counter. We could detect the thoron even after 4 hours of elution. (Table 2).

Table 2. Radioactive component of thoron hot water

Elapsed time (h)	^{228}Ra (bq/l)	^{228}Ac (bq/l)	^{224}Ra (bq/l)	^{220}Rn (bq/l)	Total radioactivity (Bq/l)
0	7.43	0	9.70	0	17.13
0.24	7.43	0.19	9.68	9.68	26.78
2.4	7.43	1.76	9.52	9.52	28.23
4.0	7.43	2.74	9.39	9.39	28.95

Case

The patient was diagnosed with undifferentiated carcinoma of thyroid, which is a high grade of malignancy and is one of intractable cancers, in June 2014, and the surgery was performed in the same year on August. The treatment of taxol, which is an antitumor agent to prevent the microtubule organizing and produces the serious side effects, was started from September of the same year. Bathing in the thoron hot spring (every day, 6 to 8 times a day, and bathing of each ten minutes) began just before the second taxol treatment (Fig. 2).

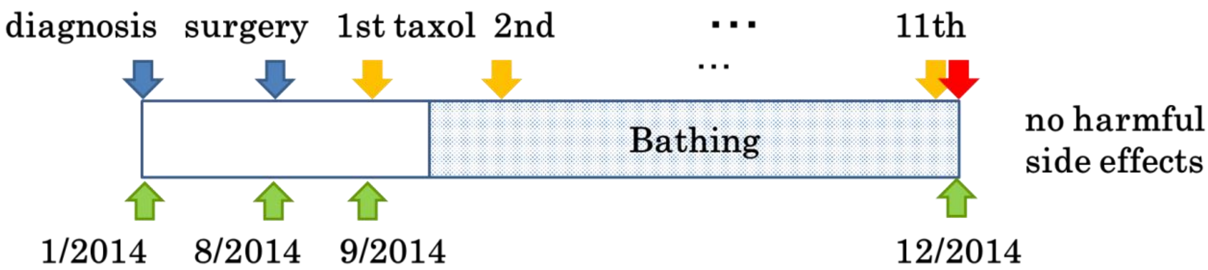


Fig. 2. Time table of the therapy of the patient

The number of white blood cells sharply decreased after the 1st time of taxol treatment, and it has become less than the normal value. Thus, the 2nd taxol treatment was canceled. But it recovered after the thoron bathing, and it was fall within the normal range. It was possible the administration of 11 consecutive weeks. The peripheral neuropathy, which is observed generally in the taxol treatment did not appeared (Fig. 3). On the other hand, the recurrences of the thyroidal anaplastic carcinoma were caused four times by August 2016. However, only the removal operation was carried out because the progress was very slow unlike normal anaplastic carcinoma.

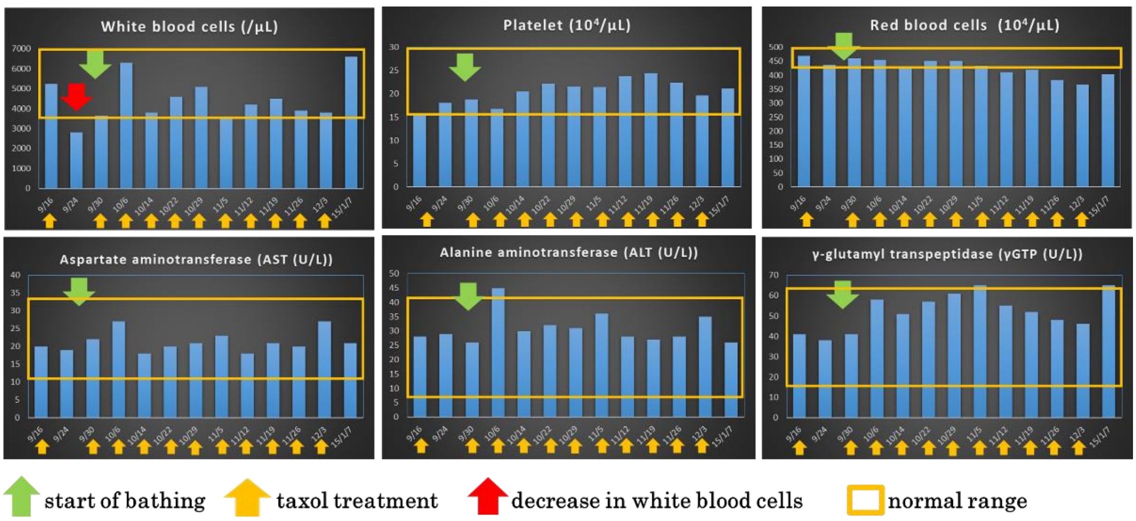


Fig. 3. Data of blood test. These graphs show the white blood cell count, the red blood cell count, the platelet count, AST, ALT and gamma-GTP from September 16, 2014 to January 7, 2015.

Discussion

It was suggested that the thoron hot spring possibly reduced the side effect of the anticancer drugs. Furthermore, the possibility that the thoron hot water affected the malignancy of cancer was suggested. The mechanism of the effectiveness of the thoron spa or bath was still unknown, but it would be suggested of the good results for the improvement of the cancer.

References

1) Atsuhiro Kishimoto, Kimiko Horiuchi, Koji Yamamoto. Effects of the Thoron spa or bath on the

anaplastic carcinoma of thyroid. The 49th Annual Meeting of Japanese Society of Thyroid Surgery (October 2016, Kofu)

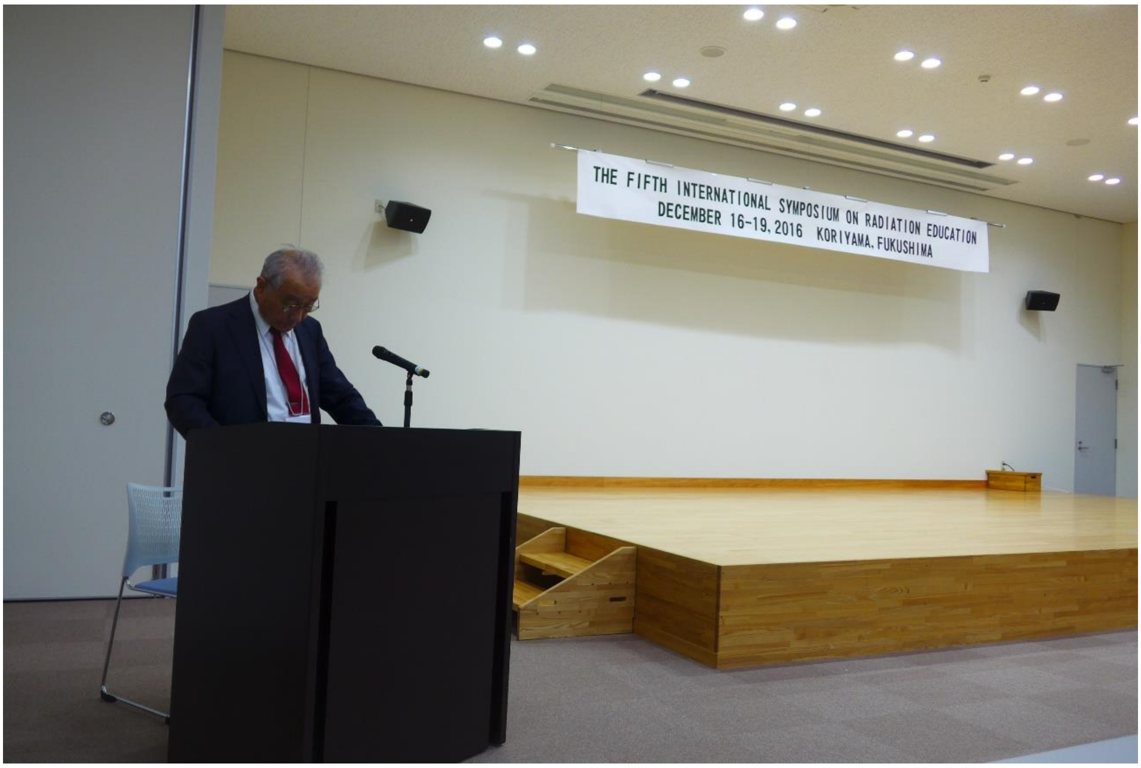
2) Atsuhiro Kishimoto, Kimiko Horiuchi, Koji Yamamoto. Effects of the Thoron spa or bath on cancer patients. The 41th ISMH World Congress (May 2016, Bucharest)

3) Atsuhiro Kishimoto, Kimiko Horiuchi, Koji Yamamoto. Effects of the Thoron spa or bath on cancer patients. The 81st Annual Meeting of The Japanese Society of Balneology, Climatology and Physical Medicine (May 2016, Shibukawa)

Appendix

Author Index

ISRE2016 Photo



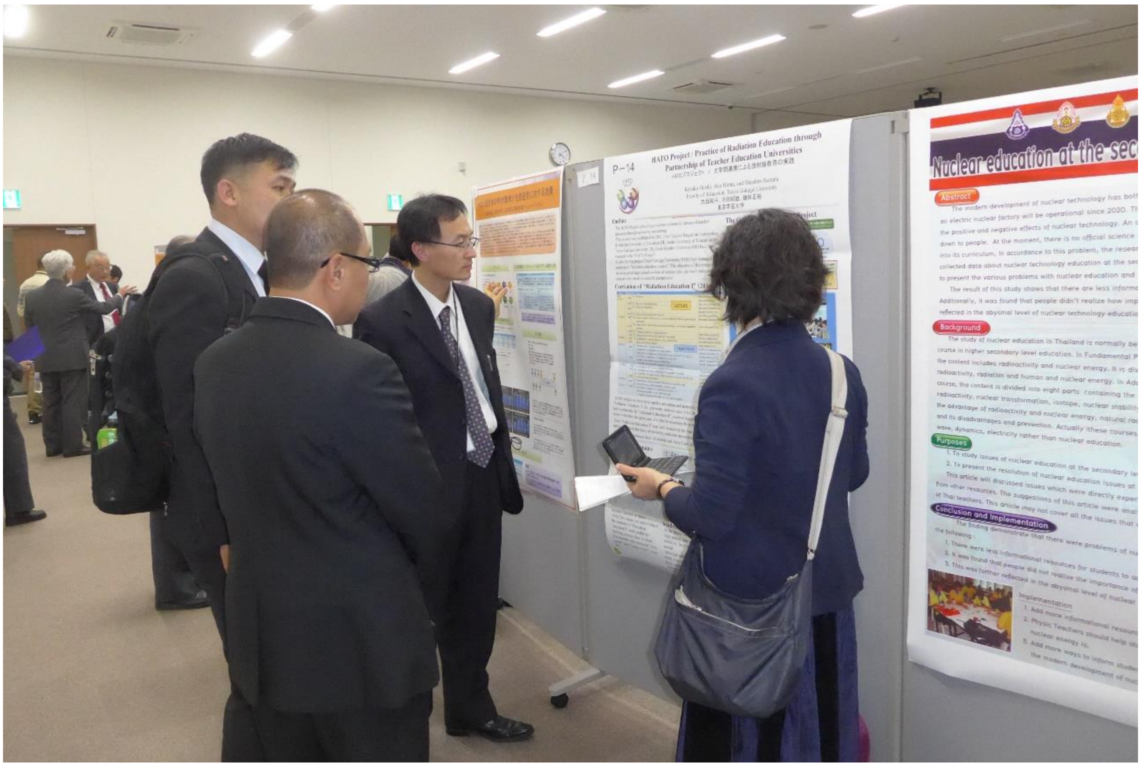
Opening Address by Prof. Hasegawa (President of NPO Radiation Education Forum)

Group Photo of Symposium Participants

Keynote Lecture by Prof. Arima (President of Japan Radioisotope Association)

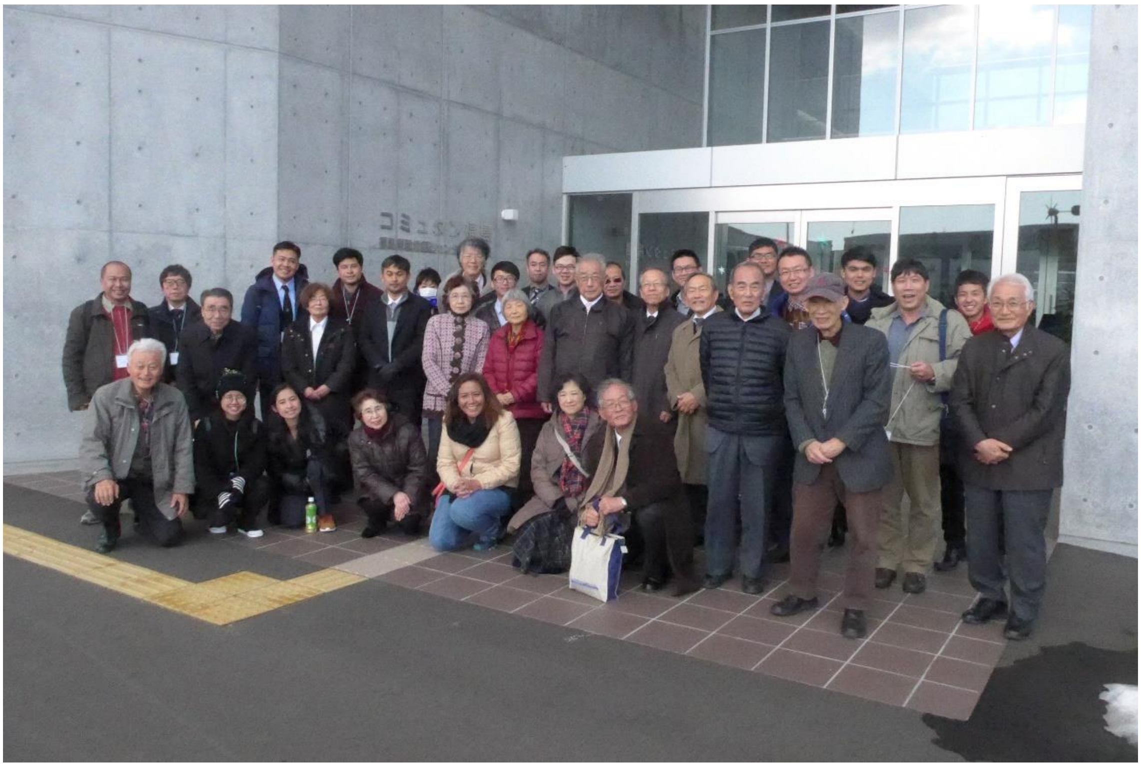
Keynote Lecture by Prof. Yamashita (Vice President of Nagasaki University)

Oral Presentation by Prof. Horiuchi (The Jikei University School of Medicine)



Poster Session

Tour to Fukushima Environmental Creative Center



Group Photo at Fukushima Environmental Creative Center