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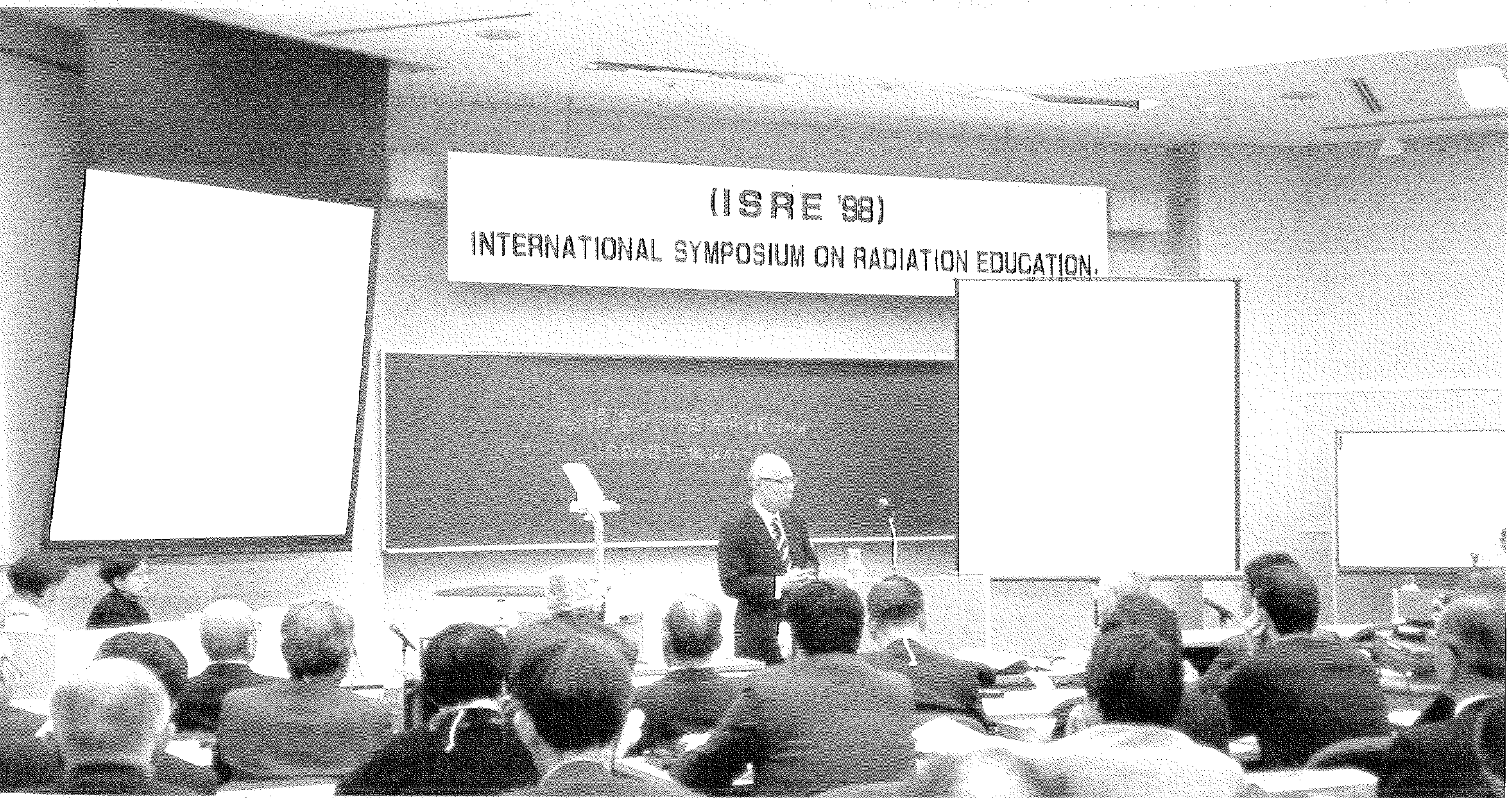

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Japan Atomic Energy Research Institute

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and
Radiation Education Forum

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PREFACE

The discovery of radium and polonium in 1898, that of x rays in 1895, and that of radioactivity in 1886 were major events which contributed very much to the fundamental understanding of the nature of matter and to subsequent diverse developments in science and technology in the twentieth century. At present, radiations and radionuclides are not only indispensable in medical diagnosis and treatments, but also are widely used in fundamental research and in industry. Nuclear fission for power production is also playing an important role in saving the nonrenewable natural energy resources, without producing the potentially hazardous carbon dioxide.

However, the fact that the first use of nuclear energy appeared as the disastrous weapon in 1945 has resulted a profound after-effect in a socio-psychological sense. In addition, the accidents of nuclear power plants in the 1980's have been repeatedly reported in mass media with undue sensationalism. As a consequence of these circumstances, a majority of people, including many intellectuals, have an excessive concern about radiation and radioactivity even in very minute quantities.

In the present civilized society, it is evident that the sound acceptance of science and technology by general public, based on full understanding and confidence, is needed to maintain the stability of society and to improve the quality of human life. It is particularly desirable that the level of both SCIENCE LITERACY and RADIATION LITERACY is elevated throughout the world. Otherwise, not only the proper use of radiation and radionuclides in medicine and in many scientific areas will be obstructed by the shortage of working personnel, but it is also probable that the mankind may soon find difficulty in their existence in the event of a serious global energy crisis resulting from the exhaustion of fossil fuel.

Radiation and radionuclides have existed around us since the birth of Earth, and we all human beings have continuously received some small amount of radiation doses. According to the recent studies, the premise that the risk of radiation were the same throughout the whole ranges of the dose and dose rate is no longer valid; indeed, a small amount of radiation might be even indispensable for the existence of life in general, according to a school of thought. Thus, although the idea of "radiation education" seems to have been focused on the hazard of radiation even at a minor dose, it should be shifted to teaching not only its hazard at high level but also the possible existence of a threshold level below which the hazard is actually negligible, and to emphasizing its important benefits in various applications used in our present civilization.

This symposium, which commemorates the centenary of the discovery of radium by the Curies, aimed to promoting the right knowledge about radiation and radioactivity and about various risks accompanied with the living in the civilized society, by discussing how to improve education of the public in general and young generations at schools in particular, and by exchanging newest scientific information relevant to the education. As seen in this volume, it is our great pleasure that many participants, from 15 countries and one district, have presented many valuable papers, which contribute to improving the present situation. We believe that a next symposium following up this one will be held in a very near future.

The Organizing Committee of this Symposium sincerely thanks several organizations, including the Japanese Government and a few international ones, many companies and individuals, including the distinguished invited speakers and participants, who have very kindly understood the purpose of this Symposium and cooperated with us in various ways for producing the proceedings in the present form.

December 1998

Tatsuo Matsuura
Secretary General, Organizing Committee of
International Symposium on Radiation Education

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Division of Planning and Analysis

Nuclear Safety Research Center
Tokai Research Establishment
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(Received September 8, 1999)

The International Symposium on Radiation Education, which commemorates the centenary of the discovery of radium by the Curies, was held on December 11 - 14, 1998 in Kanagawa, Japan. At present, radiation and radioactivity are not indispensable in medical diagnosis and treatment, but also are widely used in scientific research and industrial activities. Nuclear power generation is also playing an important role in saving nonrenewable natural energy resources, and without producing the potentially hazardous carbon dioxide. However, a majority of people has a insufficient knowledge or information about radiation and radioactivity. The symposium intended to generalize the scientific knowledge about radiation and radioactivity and also about various aspects of risks associated with the life in the civilized society, by discussing how to improve education in general and young generations at schools in particular, and by exchanging the newest scientific information relevant to the education.

The symposium consisted of 5 sessions with 61 submitted papers, and involved about 170 participants from Australia, Bangladesh, France, Germany, Hungary, Indonesia, Korea, Philippine, Pakistan, Thailand, Turkey, UK and USA.

Keywords: Radiation, Radioactivity, Nuclear Power Generation, Education, Scientific Knowledge, Risk

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放射線教育国際シンポジウム報文集 (ISRE 98)

日本原子力研究所東海研究所安全性試験研究センター
計画調査室

(1999 年 9 月 8 日受理)

放射線教育国際シンポジウムは、キュリー夫妻によるラジウム発見の百年記念として、1998 年 12 月 11～14 日にかけて神奈川で開催された。現在、放射線及び放射能は医療診断及び治療に不可欠であるのみならず、科学的研究活動や産業活動において広く利用されている。また、原子力発電は、潜在的に有害な二酸化炭素を発生させることなく、再生できない天然エネルギー資源を節約する上で重要な役割を果たしている。しかし、多くの人々は放射線や放射能について十分な知識や情報を有していない。本シンポジウムは、公衆、特に若い世代の学校における教育をいかに改善するかを議論すると共に、教育に関する最新の科学的情報を交換することにより、放射線・放射能、さらには文明社会での生活に起因する種々のリスクに関する科学的知識を普及することを意図したものである。

シンポジウムは 5 つのセッションから構成され、発表論文は 61 件、参加者は約 170 名（オーストラリア、バングラデシュ、フランス、ドイツ、ハンガリー、インドネシア、韓国、フィリピン、タイ、トルコ、英国、米国）であった。

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Contents

WELCOMING ADDRESS

Professor Kodi Husimi
(Chairperson of the Organizing Committee, International Symposium on Radiation Education, and President of Radiation Education Forum)

Good morning, ladies and gentlemen! As Chairman of the Organizing Committee, I have a pleasure of welcoming you all, and want to say a few words of welcome.

It is needless to say that the present civilized world is supported essentially by the advancement of science and technology. Opinions are divided as to welcome or not the further development of science and technology. There are recently increasing opinions stressing the ill aspects of science and technology. However, it is impossible to deny the progress of science and technology.

To encourage or to stop the further development : that is the question. This question depends totally on the power of human reason : that is the power of education.

It is a duty of scientists to pursue truth in science and to create innovative ideas, but simultaneously, they have to act with social ethics and have to educate the general public.

There seems to be a gap between the views of general public and the scientists toward the safety of radiation and radioactivity.

Now, it is time for us, scientists, to make a coming out of the academicians' ivory towers and try to think with the general public, to talk with them, and to educate people if you find them suffering from pain and damage because of their ignorance. We, the scientists, should not be reserved when it is necessary for us to stand up and straighten the incorrect information.

Especially when we see people using the scientific knowledge in a wrong way, like the application of atomic bomb, we should not keep silent. It was a wrong example of abusing the science, and it should never happen again.

On the other hand, of course, it is encouraged to utilize the atomic energy for peaceful purposes for the human kind of today and tomorrow.

Participants of this symposium are those who are interested in science education and radioactivity. I hope that you will discuss about how to educate people in society who just hate even to listen to a word like "radioactivity."

Concerning the attitude of people against radioactivity, I would like to cite an interesting phrase by late Prof. Torahiko Terada, who lived from 1878 to 1935. He said, "It may be easy either to take it seriously dangerous or to dismiss it as entirely safe, but it is pretty difficult to admit its danger properly. " This phrase by the famous Japanese physicist, late Prof. Terada, whose lecture I was happy enough to listen to during my university years, is particularly important when it comes to radiation and radioactivity. But it can be applied to all cases of " risk-related scientific matters.

Presently, correct knowledge about radiation and radioactivity is learned only by those who wish to be specialists in these fields but I think that everybody in the society should learn about these matters properly.

Today, in the advanced countries like Japan, materialistic civilization seems to have reached to the utmost level and materialistic dreams of the people come true everywhere everyday. This is possible just because everybody has the tight knowledge about how to use the electric or electronic appliances in daily life. This is the great results of education.

Thus, in a sense, we are well educated, but whether or not we are properly educated or not is a different matter. We need to educate children so that they could nurture a sense of justice, in addition to learn the three R's : reading, writing, and arithmetic. Children should be taught how to think scientifically as well as to understand the phenomena.

The role of education is becoming more and more important and complicated because the life of people is advanced, expanded and getting complicated. As the population of the world increases, our environment becomes worsened. In the mid-21st century, the world population will reach 10 billion and people may destroy natural environment more than now.

For the existence of humankind, we may develop the land further. But, however true "rules of Entropy" may be, we must try our best not to worsen the natural environment. We must try our best to stop the deterioration of our beautiful earth for the sake of our descendants.

For the betterment of our human life and for the improvement of our real quality of life, let us appeal to teach wisdom with scientific knowledge for children and people. Let the wisdom flourish all through the earth !

Without wisdom, our knowledge, creativeness, ideas, goodwill, wishes and dreams will be of no use.

To maximize the potential ability of all the humankind, the direction of our path should be integrated with the same vector. Here again, we have to rely on the power of education.

Quite fortunately, here is Prof. Arima, Minister of Education, Science, Sports and Culture, working hard in the Diet. Let us join forces to encourage Prof. Arima to improve the Japanese education system.
We have assembled here to build up a new educational system : an activity which needs human wisdom and courage. I am expecting brilliant success of this meeting !
Thank you.

歓迎のあいさつ

伏見康治（放射線教育フォーラム会長）

皆さんお早うございます。組織委員会委員長として、一言皆様を歓迎するご挨拶を申し上げます。

言うまでもないことですが、今日の文明社会は、科学技術の進歩に大きく支えられております。科学技術の今後のさらなる発展を否定することはできません。しかし、それが歓迎すべきかどうかについては意見の分かれるところであり、科学技術の悪い面を強調する論調が最近増えております。

科学技術の更なる発展を促進すべきかあるいは停止すべきか、それは問題です。この問題はすべて人間の力にかかっています。それは教育の力です。

科学者の義務は科学における真理を追求し、斬新な着想を生み出すことであります。しかし同時に、社会的な倫理観をもって行動し、一般社会人を教育しなければなりません。

放射線と放射能の安全性に関しては、一般の社会人と科学者との間に考え方の隔たりがあるように思われます。

さて、いまや科学者がアカデミックな象牙の塔から足を踏み出して、一般大衆とともに考え、これらの人々と話し、もし彼らが事実を知らないが故に苦痛や損害に悩んでいるのを見れば、かれらを教育すべく努力すべき時であるように思われます。

特に、原子爆弾への利用のように、科学的知識を悪用する人々がいたとき、我々は沈黙していてはなりません。原爆は科学を悪用する悪い実例であり、このようなことは決して二度と起こしてはなりません。もちろん、一方において原子力を今日と将来の人類のために平和的に利用することは、これは進めてよいことであります。

このシンポジウムの参加者は、科学とりわけ放射能に関する教育に関心のある方々であります。社会には「放射能」という言葉を耳にすることさえ嫌うような人々がいるわけですが、このような人達をどのように教育すればよいかについて皆さんが議論していただきたいと希望します。

人々の放射能に対する態度というものについては、私は 1878 年から 1935 年まで生存した有名な日本の物理学者故寺田寅彦の興味ある言葉を引用したいと思います。それは「ものを怖がり過ぎたり、怖がらな過ぎたりすることは易しいが、正当に怖がることはなかなか難しい」ということです。私は幸いにも大学生であった時代に寺田先生の講義を聞くことができるという幸運に恵まれましたが、寺田先生のこの言葉は、放射線・放射能に関して、またリスクに関連のある科学的現象を理解し教育するのに、たいへん重要な意味を持っている

ものであります。

現在、放射線と放射能に関する正確な知識は将来この分野の専門家になろうとする学生だけに教えられているようです。しかし私は、社会のすべての人々がこの分野の正しい基本的知識を持っているべきであると思います。

今日、日本のような先進国では、物質的文明が行き着くところまで達して、昔は夢であったことが日常いたるところで可能な現実となりました。これを可能にしているのは、すべての人々が日常生活において電気や電子的製品をどのよう使用するかという正しい知識を持っていることに他なりません。

このように、われわれはある意味では教育が行き届いているわけですが、あらゆる面で正しく教育がされているかどうかについては問題があると考えざるをえません。われわれは子供たちに、３つのＲ、すなわち「読み・書き・算数」を学ばせることに加えて、正義感を育成するよう教育せねばなりません。また、科学的現象をいかに理解するかとともに、科学的なものの見方を身につけるよう、教育が行われねばなりません。

教育の役割はますます重要となり、また複雑なものとなっています。それは、人々の生活が進歩し、行動範囲。来世紀の半ばには、世界人口は 100 億人に達し、自然環境の破壊がますます進むことになるでしょう。

人類の生存のためには、さらなる土地の開発は必要かもしれません。しかし、「エントロピー増大の法則」は真理であるとしても、われわれは何としてでも自然環境をこれ以上悪化させないようにせねばなりません。そしてわれわれの後の世代のために、この美しい地球の荒廃がこれ以上進まないように、最大の努力を試みねばなりません。

人々の生活をより良いものにし、われわれの真の生活の質の向上に向けて、子供たちや人々に、正しい科学的知識に基づいた英知を教えることを訴えようではありませんか。この地球全体に英知の花を開かそうではありませんか。

英知というものがなかったら、われわれの知識も、想像力も、着想も、善意も、希望も、夢も、すべて何の役にも立たなくなります。

すべての人々のもっている潜在的な力を最大限に発揮させるためには、われわれの個々の努力のベクトルを目的とする同じ方向に集めることが必要です。ここでも、教育という力に頼らねばなりません。

幸いなことに、ここに文部大臣として政府・議会で活躍されておられる有馬先生がおられます。われわれの力を集めて有馬先生を応援し、日本の教育システム改善のためにご協力申し上げようではありませんか。

われわれは新しい教育システムを確立するためにここに集まりました。この活動は人間の英知と勇気を必要とします。私はこのシンポジウムの輝かしい成功を期待しています。

どうも有り難うございました。

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1. Lectures

（招待講演及び依頼講演）

JP0050061

1.1 理科教育の問題点に関する考察

有馬　朗人

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要旨

学童の理科に関するテスト結果の国際比較の資料に基づいて、わが国の理科教育の傾向と特異点を探る。また最近発表された一般成人の科学知識に関する国際比較の結果から、理科教育の在り方を考察する。

１．はじめに

わが国の理科教育の現状は必ずしも楽観を許すものではない。いくつかの問題が存在する。それを学童の数学、理科に関する学力、並びに一般成人の科学知識の国際比較によって考察したい。

２．学力は優秀

根拠になる材料は１９６４から９５年までの間の、３回にわたる学童の数学ならびに理科についての理解度に関する国際比較によるもので、対象はそれぞれの国の１４才、中学２年の生徒で無作為に選ばれている。そして全員同じ問題に回答する方法で、１０００点満点で比較したものである。

まず、数学の成績では、９５年に日本は３番をとり、その１０年ほど以前の８１年では１番で、３回の国際比較で１番、２番、３番という極めて優秀な成績を収めている。その限りでは申し分がない。

つぎに理科の成績の点数の上位１０か国について、その順位を第１表に示す。日本の児童は、９５年が３番、８１年は２番というように、常に１番、２番、３番といった地位にある。これによる限り、日本の児童の理科の理解度は非常に優れているといえる。理科離れをいわれながらも、１９９５年において日本の子供

は、学力の上では優れた成績を残していることは明らかである。単純な平均点では、アジアのシンガポール、日本、韓国という順で上位を占め、アメリカは７位、１９位、一番最近の１９９５年は１７位と、ずっと下方に位置する。

それでは問題がどこにあるか。第１図は、日本が３番であった９５年の調査での点数の分布を示したものである。ここでの問題点は、日本の学童の成績の分布があまりにもシャープなことである。つまり分布の幅が極めて小さい、成績がそろい過ぎている、ということに尽きる。

上位のシンガポール、また下位のアメリカはその幅がかなり広いが、日本と韓国は場合は極端に狭い。特に日本は狭い。つまり皆同じくらいの成績をとり、隣の子ができることは、うちの子もできる。うちの子ができないことは隣の子もできない。実は数学でも同じような分布を示すことが明らかになっている。

これはいい面もないわけではない。全員が似たような力を持っているということであって、将来企業や職場で採用しても、どんな人間でも使いものになる。こういった画一性は今日まで日本の産業を大いに発展させるのに役立ってきたことであろう。

しかし欠点は、多様な人間が育っていない。あまりにも画一的過ぎる。それこそ桁外れの、ノーベル賞を狙うような人物が出にくいということを意味する。

３．応用問題で劣る

さらに残念な事実を明らかにしなければならない。近年二酸化炭素という物質名は、地球温暖化問題が議論される機会の多い日本では、新聞紙上やテレビなどによく用いられて来た用語ではある。

先に述べた、９５年の理科の国際比較に採用された、化学の領域の問題の一つが「二酸化炭素はある種の消火器に使用されている物質です。二酸化炭素はどのようにして火を消すのか説明しなさい。」という問題であった。

その正解率と標準偏差の国際比較を第２表と第２図に示す。学校教育の中で二酸化炭素の性質は習っていたはずである。そこでこの解答の成績がどうであったかをみると、日本の学童の場合、ずっと下位に、つまり２８番目で下から三分の一くらいのところに位置する。この時アメリカは１１番であって、上から三分の位置くらいの順位にあった。

ところで日本の子供たちに「二酸化炭素というのは何か」という質問をすると、「炭素が一つに酸素が二つついてCO_2だ」と答が返ってくる。二酸化炭素は炭素を燃やすとできるということは知っているが、それがどういうふうに利用されたり、どのような害を及ぼすか、どういうよい性質を持っているかを理解していない。つまり応用力に関しては弱いことを示している。

しかもその成績の分布を見ても、やはり幅が狭い。他の国の場合に比べてシャープであることは、成績の悪い応用問題についても、成績優秀な理科の学力の分布と同じ傾向にある。つまり皆ができるか、皆ができないかの、画一性をここでも見ることができる。

以上のような統計資料から、次のように論点をまとめることができよう。日本の学童の数学や理科を対象にした理解度・学力は、国際的に見ても最上位にある。しかし応用面が不得意だということ。どちらにしても平均点のまわりに揃い過ぎるということ。

そしてさらに悪いことに、高等学校に進んだ頃から、理科嫌いが増える傾向にある。これは見過ごせない問題点で、成人になってからこれがどのような傾向をもたらすか、慎重な分析が必要であろう。

４．成人は科学に弱い

その一つが１９９８年７月に発表された全米科学財団（ＮＳＦ）の調査結果であって、ＯＨＰ－５に示す通りである。これは一般成人を対象にした科学の理解度、あるいは科学知識の国際比較である。

アメリカの発表は、アメリカの２千人を対象に１９９７年に調査を実施した結果である。「分子」の意味を答えられたのは１１％、「ＤＮＡ」を知っていたのが２２％にとどまったが、平均点では５５点を獲得した。同財団ではこの成績を、他の先進国で実施されたほぼ同内容のテスト結果と比較したものである。それによるとアメリカの５５点はデンマークと並んで１位となった。

しかしそれに引き換え、日本の成人はほとんど最下位といってもよい。１５００人を対象にした日本でのテスト結果は、平均点３６点で、１４か国中１３位にとどまった。問題は深刻である。

もっともアメリカ以外のデータは、１９９６年に東京で開催されたＯＥＣＤシ

ンポジウムで発表されたもので、国によって質問の細部や実施時期は異なっているが、大まかな国際比較には役立つだろうという大方の認識ではある。

アメリカでの調査の場合、２０項目に及ぶ様々な領域の質問が用意されたが、これらの一つ一つの質問に対する正解率は、ここでは明らかにされていない。ただし「放射線」と「放射能」に関する質問も３件含まれていたことを付け加えておきたい。

とにかく日本の一般成人の科学に対する理解度、あるいは彼等が持っている科学知識は、国際的にみても最低に近いというのである。これらの事実を踏まえて、学校教育における理科教育と、大学の教養課程あるいは一般成人に対する科学教育の在り方を再検討しなければならないだろう。

それならば日本人はおしなべて、科学の分野でずっと立ち遅れて来たかというと、そのようなことはない。キュリー夫人のラジウム発見百年に因んで、放射線と原子核に関する科学史を振り返るとき、長岡博士の原子核モデル、湯川博士の中間子理論、それに仁科博士のサイクロトロン建設等の業績は、決して他の国の科学者に劣るものではなく、むしろ先端を行くものであったことを認識したいものである。

５．おわりに－多様な理科教育の場を

このような状況のなかで、２１世紀に社会人となる青少年関にする、理科教育、科学教育の現場での取り組みは、一層重要なものとなるであろう。しかしそれは学校の理科教育に限られたことではなく、各地にある研究機関や、研修機関、科学技術館といった場で、教員や研究者を含む、広い意味での科学者の指導の下に、本物の自然や実生活に則した科学の現場で、地域の特色を生かした、様々な興味ある青少年向けの活動が要請されることになろう。

第１表　理科の得点順位

1964		1981		1995	
JAPAN	31.2	HUNGARY	72.2	SINGAPORE	607.3
HANGARY	29.4	JAPAN	63.7	CZECH REP	573.9
AUSTRALIA	24.6	HOLLAND	65.8	JAPAN	571.0
NEWZEALAND	24.2	CANADA	61.9	KOREA	564.9
GERMANY	23.7	ISRAEL	61.9	BULGARIA	564.8
SWEDEN	21.7	FINLAND	61.7	HOLLAND	560.1
U.S.A.	21.6	SWEDEN	61.4	SLOVENIA	560.1
SCOTLAND	21.4	POLAND	60.4	AUSTRALIA	557.7
:		:		:	

第２表　応用問題の正解率

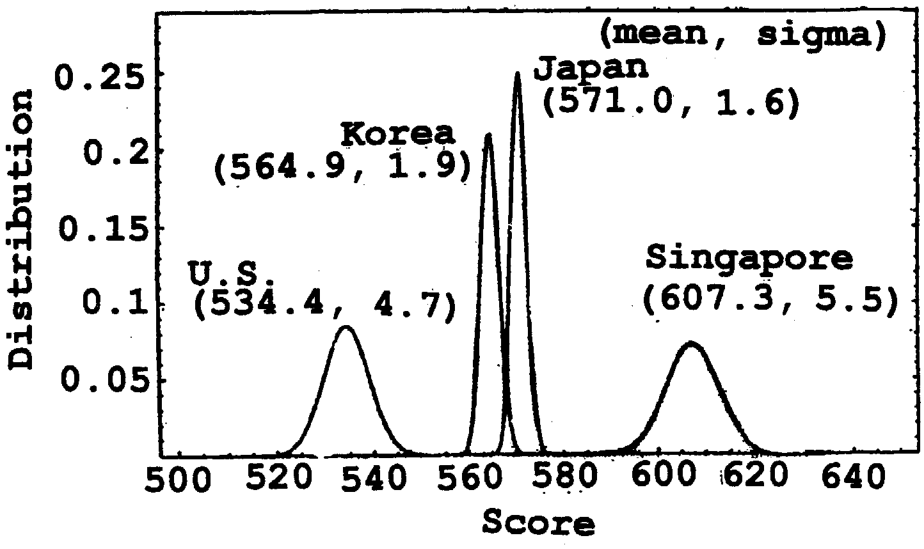
化学の領域　(1995)

順位		正解率	標準偏差
1	AUSTRIA	74.5	2.9
2	U.K.	71.2	3.1
3	SWEDEN	69.9	2.3
4	SINGAPORE	69.8	2.3
	:	:	:
11	U.S.A.	62.1	2.7
	:	:	:
22	KOREA	53.8	2.5
	:	:	:
28	JAPAN	44.8	2.0
	:	:	:

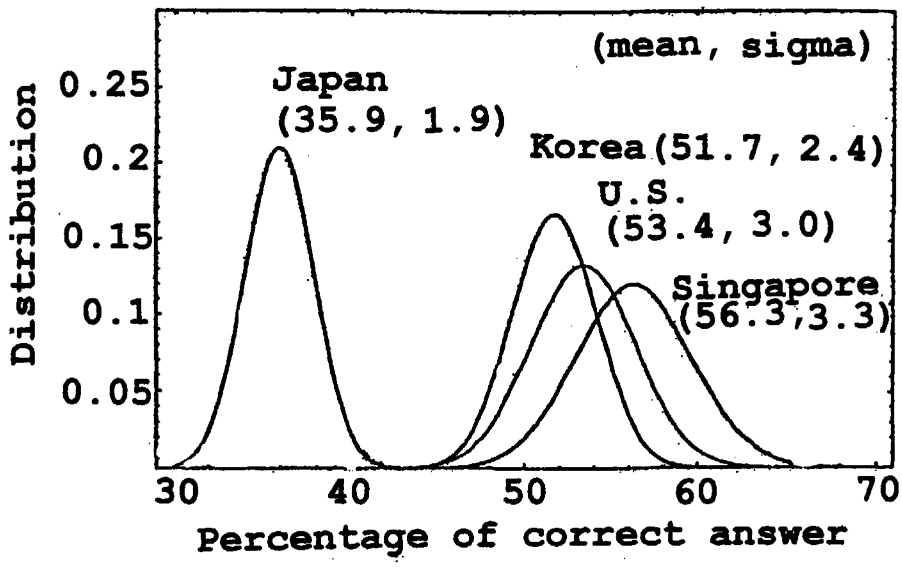
第３表　一般成人の科学知識

NSF 1998･7･1　発表

順位		平均点
1	U.S.A.	56
2	DENMARK	56
3	HOLLAND	54
4	U.K.	53
5	FRANCE	52
6	GERMANY	51
	:	:
13	JAPAN	36
14	PORTUGAL	33



第1図　理科の成績



第2図　応用問題の成績

1.2 THE DISCOVERY OF RADIUM 100 YEARS AGO AND THE IMPACT ON THE EARLY HISTORY OF NUCLEAR SCIENCE

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ABSTRACT

One hundred years ago, Pierre and Marie Curie reawakened the topic of uranic rays and discovered two radioelements, polonium in July 1898 and radium in December. The circumstances of these events which announced the beginning of radiochemistry are reviewed at the light of the laboratory notebooks and the publications of the authors. The role of radium in the early history of radioactivity and nuclear sciences is emphasized.

1. Introduction

In 1891 Maria Sklodowska (1867-1934) moved to Paris from her native Poland to undertake scientific studies. In 1895 she married Pierre Curie (1859-1906), a physicist renowned for his work on magnetism and his theory on symmetry in physical phenomena. After concluding her studies at the Paris University, Marie Curie was thinking of a subject for a thesis. X-rays were still a current topic, but had lost the charm of novelty. On the other hand, the uranic rays discovered in 1896 by Henri Becquerel raised a puzzling problem. The uranium salts appeared to maintain an undiminished ability to blacken a photographic plate over months. The law of energy conservation was solidly established since 50 years. What was the origin of this inexhaustible energy which apparently violated the Carnot principle, the first principle of thermodynamics, which states that energy can be transformed, but can never been created nor destroyed ?

Pierre Curie had a presentiment that the phenomenon discovered by Becquerel was extraordinary and helped Marie in the decision. Marie Curie confirmed later *we felt the investigation of the phenomenon very attractive, so much the more the topic was quite new and required no bibliographical research.*

The couple settled in a small room in the Parisian School for Physics and Chemistry. Pierre Curie was involved in a work on crystal growth and had opened a laboratory notebook. The writing of Marie Curie appears in the diary on December 16, 1897. This day is the beginning of her research on uranic rays first alone, later joined by Pierre, a prelude to two Nobel prizes.

Two sources of information are available in order to reconstitute the progress of the work during the memorable year 1898: three laboratory notebooks and three publications in the *Comptes Rendus*, the weekly report of the French Academy of Science [1].

2. The strategy

At the end of 1897 all knowledge on uranic rays was contained in nine short Becquerel publications in the *Comptes Rendus*, mostly during the first semester of 1896. After an initial excitement, the interest of scientists in the new rays faded rapidly and the topic was moribund when Marie Curie entered the scenery.

How undertake the subject chosen for Marie's thesis? A new topic required a new strategy with its own tool and methodology. The blackening of the photographic plate was useful to detect uranic rays but provided no information on the intensity of the emission. But the rays also rendered air conducting for electricity. This property was much more amenable to quantitative determination of the action of rays. However, a convenient measurement of very small intensities had still to be imagined. At this point the genius of Pierre Curie was decisive. He invented a device based on piezoelectricity which he had discovered in 1880 (Fig.1). For the first time, the emission of uranic rays could be quantified on the basis of the ionization current produced under controlled conditions.

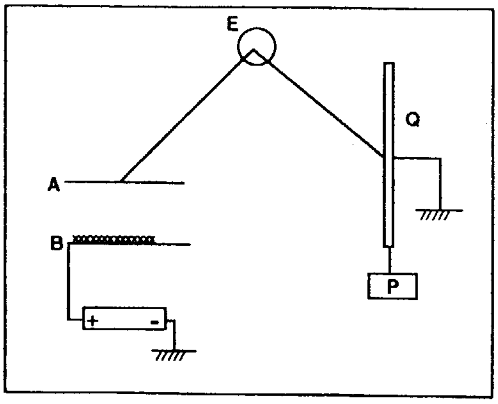


Fig.1. The charges produced in the ionization chamber AB by the active substance laid on the plate B are compensated by opposite charges calculated from the weight P applied to the piezoelectric quartz Q and the time of application. The compensation is controlled with the electrometer E.

On the 12 of February the equipment was ready and Marie Curie now had an invaluable tool for routine measurements and knew how to prepare the samples for reproducible measurements. The systematic search for elements which may impart electric conductivity to air was a logical procedure since there was no reason that the spontaneous emission of rays should be limited to uranium. Within a few weeks Marie Curie tested a large number of samples at hand or borrowed from various collections. The activity of metallic uranium prepared by Henri Moissan was used as a reference for comparing the relative strength of active substances.

The most important result was obtained a few days later. A sample of pitchblende, a black mineral from Joachimsthal in Bohemia with a high content of uranium oxide, was four times more active than metallic uranium. This was quite unexpected since no uranium containing substance ought to be more active than the metal which has the highest concentration of uranium atoms. It was not commented in the notebook, but numerous tests of the equipment which followed immediately show that Marie Curie was extremely preoccupied by the result. The same peculiar property was observed for other uranium minerals such as chalcolite, a copper uranyl phosphate, which was twice as active than uranium.

It had been found earlier by Becquerel and confirmed by Marie Curie that the emission of rays was a specific property of uranium atoms, independent of the chemical combination of the element. Accordingly the excess of activity of the minerals had an unequivocal origin which Marie Curie stated in following terms: *This fact is quite remarkable and suggest that these minerals may contain an element much more active than uranium itself.* Initial evidence in favor of this hypothesis appears in the next sentence since Marie Curie knew how to prepare artificial chalcolite: *I have prepared chalcolite with pure products; this artificial chalcolite is not more active than other uranium salts.* Marie Curie then concluded that the unknown element exists only in the uraniferous minerals which are more active than uranium.

She discovered at the same time than Gerhardt Schmidt that thorium and its compounds were active, reported a feeble activity for potassium salts and probably was the first to record without knowing it the natural radioactivity of potassium.

The results acquired in two months and published in Marie Curie's first paper on April 12 are impressive[2)]. Tens of chemicals and natural compounds with activities down to a hundredth of that of uranium were measured. Numerous experiments on the absorption of the rays led to a further important observation: the rays from uranium minerals were less absorbed than those of uranium compounds, and this confirmed the hypothesis that the minerals may contain an active substance different from uranium.

The search of this element was now a matter of highest priority. Pierre Curie fascinated by Marie Curie's findings abandoned his own research projects and joined his wife in the adventure.

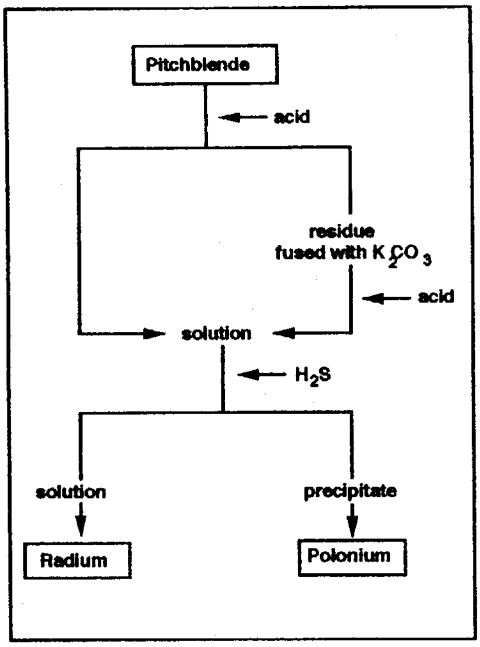
Research on uranic rays now turned from physics to chemistry. The obstacles were immense: separate and identify a substance whose chemical properties were completely unknown. The Curies who were not much familiar with chemistry were helped by Gustave Bémont, an analytical chemist at the Parisian School for Physics and Chemistry. The team introduced a new methodology which marks the beginnings of radiochemistry[3)]. Marie Curie explained: *The method we have used is a new one for chemical research based on radioactivity. It consists in separations performed with the ordinary procedures of analytical chemistry and in the measurement of the radioactivity of all compounds separated.* In this way the chemical behavior of the radioactive element can be recognized and the element can be characterized by its intensity and the absorption of its rays. The fractions in which it concentrates become increasingly radioactive.

Marie Curie added *radioactivity acts like a specific analytical reagent with a high sensitivity* but she could not imagine that the limit of sensitivity was a few atoms.

3. The discovery of polonium

The second publication, this time signed Pierre and Marie Curie appeared on July 18[4)]. The title *On a new substance, radio-active, contained in pitchblende*, is eloquent for two reasons. It announces that the search for the element much more active than uranium was successful and it is also the first appearance of the word radioactive (with the hyphen).

The first chemical treatment began on April 14, whereby 100 g of Joachimsthal pitchblende was ground and attacked by an acid. (Fig. 2). The residue was fused with an alkali salt and the treatment of the acidic solution with hydrogen sulfide was a significant step since the insoluble sulfides and the remaining solution were both active. This could mean that each fraction contained a different radioactive substance. In fact the Curies will discover during the following months a new element in both fractions: polonium in the precipitate of sulfides and radium in the remaining solution. The authors focused their attention first on the sulfides because it seemed easier to search for the activity concentrated in a solid.



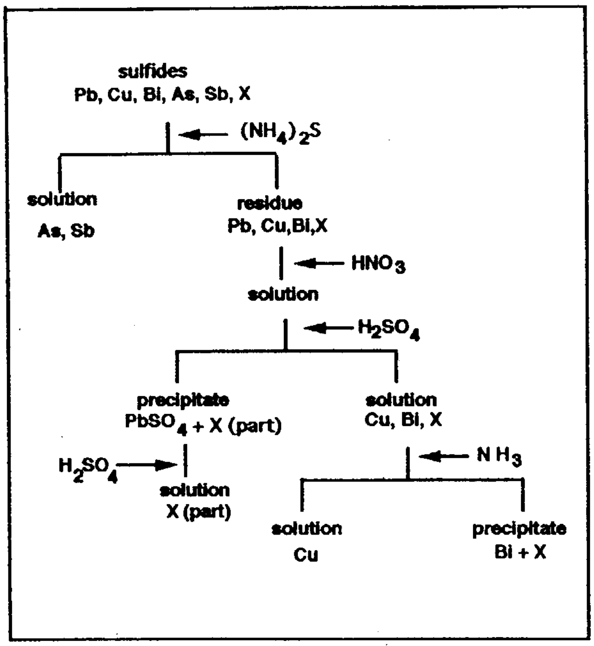


Fig.2 (left): Simplified scheme of the first treatment of pitchblende.

Fig. 3 (right): Treatment of the precipitate of sulfides. X is the radioactive substance (polonium)

The activity carried with the sulfides was insoluble in ammonium sulfide and thus could be separated from arsenic and antimony (Fig. 3). Now it became clear that the sought substance was associated with lead, copper and bismuth. These three elements could be easily separated and eventually most of the activity remained with bismuth. The authors wrote *we have not yet found an accurate wet method for separating the radioactive substance from bismuth*. A partial concentration was obtained by precipitation with water: the first fractions are the more active.

Pierre Curie more inclined to physics undertook the analysis of pitchblende by sublimation. Already in the first trial it was found that a very small amount of substance about 10 times as active than uranium could be separated and this method was pursued in parallel with the chemical treatment.

Suddenly on July 13, without further comment, the symbol of polonium appears in the notebook. Pierre Curie had proceeded to the sublimation of sulfides concentrated by Marie and a fraction 400 times more active than uranium was isolated. This success was the result of the joint efforts of the two scientists.

The second notebook ends on July 16 with a final test for activity on a large variety of compounds. This was a last precaution before the discovery of a new element could be claimed with confidence. Two days later it is announced, however cautiously... *We believe that the substance we recovered from pitchblende contains a heretofore unknown metal, similar to bismuth in its analytical properties . If the existence of this new metal is confirmed, we propose that it be named polonium in honor of the native land of one of us.* The designation of polonium had a provocative significance since as a state Poland had disappeared in 1795, being parceled out between Prussia, Russia and the Austrian Empire.

For the first time in the history of chemistry the existence of an element was claimed which could be identified solely on the emission of its rays. Pierre and Marie Curie had invented the "chemistry of the invisible"

On the other hand, the caution was founded. Eugène Demarçay, the leading spectroscopist of the time, analyzed the most active sample of bismuth sulfide. To the disappointment of the discoverers, he could not distinguish any new characteristic line apart those of bismuth and impurities. The authors admitted *this fact does not favor the idea of the existence of a new metal.*

4. The discovery of radium

The title of the third publication on December 26, with Gustave Bémont as co-author, is identical to that of the previous one with addition of one single word: *On a new strongly radio-active substance contained in* pitchblende [5]. The chemical behavior of the second radioactive substance was strikingly different from that of polonium: it did not precipitate with hydrogen sulfide but coprecipitated with barium carbonate and sulfate.

Once it was sure that the radioactivity was contained in barium it remained to prove that it was not barium, but a new element. This important demonstration was based on three tests. First Marie Curie verified that natural barium is not radioactive and contains no radioactive substance. Next the radioactive substance could be separated from barium by fractional precipitation with alcohol. The operation was repeated until the activity of barium chloride was 900 times higher than that of uranium. At this point the authors had to cease the concentration because the amount of material was too small.

The third argument was decisive. Demarçay found in the spectrum of the radioactive barium chloride several lines which could not be assigned to any known element. The intensity of the most intense new line increased with the radioactivity of the substance, from very weak with the first sample up to notable for the sample 900 times more active than uranium. Pierre and Marie Curie concluded *we think this is a very serious reason to attribute the new line to the radioactive part of our substance. The* *various reasons which we have enumerated lead us tot think that the new radioactive substance contains a new element to which we propose to give the name radium.*

Besides the spectroscopic analysis, a second official proof for the existence of radium was the determination of the atomic weight. On December 20 Marie Curie obtained for the atomic weight of the metal in radiferous barium chloride a value of 142.8 on a sample 227 times more active than uranium. This value was slightly higher than that of barium which is 137, but still within limits of errors and not significant. Obviously the amount of radium was too small to change the apparent atomic weight of barium.

Polonium and radium could excite the fluorescence of a screen of barium platinocyanide. The authors conclude their publication stating *a source of light which requires no energy can thus be obtained in contradiction, at least apparently, with the principle of Carnot.* It is precisely this puzzle which prompted the investigation of uranic rays by Marie Curie. However, the discovery of radium gave no immediate clue to the origin of the mysterious energy. On the other hand, it proved that radioactivity was a more general phenomenon than it was thought at the time of Becquerel's discovery since the phenomenon of spontaneous emission of radiation was now shared by four elements. The latter had only one property in common: they were heavy elements in the terminal part of the periodic chart.

In spite of these prodigious discoveries, at the end of 1898 nothing was known about radioactivity itself. But now time was ready for blooming of the new science.

5. Radium after 1898

The news of the discovery spread out very rapidly. The translation of the full paper appeared end of January 1899 in the journal *Scientific American*. Six months later, a German company which produced uranium for the glass industry followed the procedure established by the Curies and offered radium preparations for sale. Pierre and Marie Curie never sold radium, but delivered the precious radioelement free of charge. They never made the slightest personal benefit nor granted patents for their numerous inventions and discoveries.

Continuation of the research on polonium, radium and they rays required much larger quantities of the radioelements. When the Curies ran out of material they were aware that vast amounts of pitchblende would be necessary in order to prepare visible quantities of radium. They could not afford the purchase of this expensive material. But they supposed correctly that the residues of the ore, which had no longer a commercial value after extraction of uranium, should contain the new elements. The Austrian government, proprietor of the Joachimsthal mines, offered free of charge a first batch of 100 kg followed by additional shipments of several tons of low price residues, five times more active than uranium.

The tedious processing of the residues under primitive conditions with the handling of 20 kg batches of the material has been widely popularized. The procedure is described in Marie 's Thesis submitted in 1903, the year when she became the first woman honored with a Nobel Prize. The Herculean task is modestly expressed in the sentence *we succeeded in extracting from thousands of kilograms of starting material a* *few decigrams of products.* This was a quite astonishing achievement considering that one ton of uranium is in equilibrium with 377 mg of radium and 74 μg of polonium. Ernest Rutherford, when he received the Nobel Prize for Chemistry in 1908 wrote *the bigger problems of radioactivity can only be solved by people with lots of radium.* This justified a posteriori the immense efforts of Marie Curie. The preparation of a macroscopic amount of radium was her obsession, not only for the determination of the atomic weight, but also to convince the scientific community that radium was a new and real element. The atomic weight 225.9, practically the present value, was obtained in 1902, on 122 mg of pure radium chloride, one million times more active than uranium.

Marie Curie knew that the treatment of large amounts of ores and ore residues could only be achieved on an industrial scale. She helped in the development of a first plant in Nogent near Paris. The production of radium continued with ups and downs until artificial radioelements become available in large quantities and supplanted radium in all applications. In the best years the top price of one gram was 170 000 $.

In the years following the discovery of radium, Pierre and Marie Curie made further important discoveries. They found that radium can transfer radioactivity to other substances and observed physical and chemical changes which announced the rise of a new field of research, that of radiation physics and radiation chemistry. The β rays were identified with the electrons discovered by J. J. Thomson in 1897. Pierre Curie evidenced the physiological effects of radiation by applying on his arm during 10 hours a source 5000 times more active than uranium. He described the ensuing erythema and concluded to therapeutical applications of radium. He informed immediately the medical world, a step which may be considered as the beginning of health physics and radiotherapy.

The mystery of the source of the energy carried by the rays began to be lifted. In a prophetic publication Pierre Curie indicated that radium salts were always warmer than their surroundings: one gram of radium gave off heat at about 100 calories per hour, and melted an amount of ice larger than its own weight. This observation gave a clue to the immense reserves of energy contained in heavy atoms. Pierre Curie commented *so great an evolution of energy can be explained by no ordinary chemical reaction as radium remains unaffected for years. The evolution of heat might be attributed to a slow transformation of radium atoms; we should be led to conclude that the energy generated exceeds all that is so far known.* He ended his Nobel Conference with a warning: *it may be conceived that in criminal hands radium may become highly dangerous,* but added *I am one of those who think that humanity will gain more good than evil from the new discoveries.*

Marie Curie pursued untiringly the investigation of radioactive matter during the nearly 30 years which followed Pierre Curie's tragic death. The Nobel Prize for Chemistry in 1911 was attributed tardily for the discovery of polonium and radium. With the increasing use of radium in therapy it become urgent to establish a metrology of radioactivity. In 1912, on behalf of the Committee of Radiology, Marie Curie prepared an international standard of 22 mg of very pure radium chloride. The Committee also adopted the curie as unit of radioactivity.

During the first world war Marie Curie interrupted her scientific work and together with her daughter Irène introduced mobile X-ray equipment in the field hospitals behind the front lines and taught the techniques of radiology to medical assistants. She had a great interest in the application of radium and radon for the cure of cancers. But she never lost the enthusiasm of her youth for fundamental science. Her last work dealt with α spectroscopy and the correlation of the energy of particles with nuclear structure.

The role of radium was not restricted to the early history of radioactivity. Main discoveries in nuclear science were achieved with sources of polonium, radium and its daughters. The α particles were first recognized by Rutherford in 1899 from their strong ionization power, and this was confirmed by Becquerel and Curie using magnetic deflection. Ten years later, the particles were identified with helium. In 1911 scattering of α particles led Rutherford to the concept of the atomic nucleus. The field of radioactivity was now progressively replaced by that of nuclear physics and nuclear chemistry. 20 years after the discovery of radium, Rutherford realized the first nuclear reaction by bombarding nitrogen with the α particles of a radium daughter. The neutron was discovered with polonium and the first neutron sources were constituted by a mixture of beryllium with polonium, radium or radon. These sources in turn were used in the discoveries of artificial radioactivity, fission, nuclear chain reaction and the synthesis first transuranium element. The advent of nuclear energy is the direct consequence of the centenary discoveries of Pierre and Marie Curie.

Conclusion

Polish by birth, French by heart, Marie Curie is a mythical figure of science which belongs to humanity. Her glory obscured the greatness of her husband, teacher and collaborator not only in the eyes of the general public, but regrettably also in the mind of scientists. One hundred years after the discovery of radium it should be recalled that Pierre is associated to all *Curie* denomination: curietherapy, the former unit of activity curie, the element curium, the innumerable elementary and high schools, Universities, associations bearing the names. The two scientists were definitely honored in 1995 when their ashes were solemnly transferred to the Panthéon, the national burial place for the most illustrious French compatriots.

Acknowledgment. Madame Hélène Langevin-Joliot is thanked for providing a copy of the notebooks of Pierre and Marie Curie.

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JP0050063

1.3 CURIE'S HYPOTHESES CONCERNING RADIOACTIVITY AND THE ORIGIN OF THE ELEMENTS

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In his Nobel Lecture entitled "Radioactive substances, especially radium",[1] which was delivered on June 6, 1905, Pierre Curie stated: " At the beginning of our investigations we stated, Mme.Curie and I, that the phenomenon could be explained by two distinct and very general hypotheses which were described by Mme. Curie in 1899 and 1900. --------1. In the first hypothesis it can be supposed that the radioactive substances borrow from an external radiation the energy which they release, and their radiation would then be a secondary radiation ------- 2. In the second hypothesis it can be supposed that the radioactive substances draw from themselves the energy which they release -------".

He then went on to remark " ------- The second hypothesis has shown itself the more fertile in explaining the properties of the radioactive substances properly so called -------." Consequently, the first hypothesis mentioned above became more or less forgotten. It appears, however, the Curies were well aware of the fact that the first hypothesis should play an important role in explaining the phenomena concerning the origin of the elements.

Ten days before Pierre Curie delivered his 6 June 1905 Nobel Lecture[1], one of the most important events in the history of Japan took place.[2] On 27 May 1905, the Imperial Japanese Fleet under the command of Admiral Togo-Heihachiro destroyed the Russian Baltic Fleet in the famous battle of the Japan Sea.

A young boy named Chester Nimitz born in Texas graduated from the U.S. Naval Academy in Annapolis in June 1905. He and his classmates sailed across the Pacific Ocean for the first time in the summer of 1905, and while in Japan, Nimitz was fortunate enough to meet and shake hands with Admiral Togo. Nimitz became a great admirer of Admiral Togo after that and he carefully studied all the naval tactics used by Admiral Togo for many years. Four decades later, Admiral Nimitz and his U.S.Pacific Fleet destroyed Japan's Imperial fleet during WWII.

Mme. Curie and Admiral Togo died in 1934 and in the same year Jean Frederic Joliot and Irene Curie discovered artificial radioactivity. In his 12 December 1935 Nobel Lecture entitled "Chemical evidence of the transmutation of elements", Joliot stated[3]:
" -------- Astronomers sometimes observe that a star invisible to the naked eye may become very brilliant and visible without any telescope ------ the appearance of a Nova. This sudden flaring up of the star is perhaps due to transmutations of an explosive character like those which our wandering imagination is perceiving now

------- a process that the investigators will no doubt attempt to realize while taking, we hope, the necessary precautions."

It thus appears that the Joliots were aware of the importance of the first hypothesis of the Curies in explaining the phenomena occurring at the time the synthesis of the heavy elements, such as uranium and thorium, were taking place in nature.

The crucial first step toward achieving this goal was taken by an Italian physicist Enrico Fermi and his co-workers in 1942. The following words are written on a plaque at the football stadium of the University of Chicago: "On December 2, 1942, man achieved here the first self-sustaining chain reaction and thereby initiated the controlled release of nuclear energy".

In 1956, the speaker made the prediction that natural reacters should have existed on the earth about 2 billion years ago.[4,5] Although this prediction was not taken seriously by scientists of the 1950's, sixteen years later in 1972, French investigators discovered the remnants of natural reactors at the Oklo uranium mines located in the Republic of Gabon, Africa.

Until the middle of the 20th century, scientists believed that chemical elements were synthesized only in stars, but the discovery of the Oklo Phenomenon has demonstrated that a nuclear fire had once existed on our planet earth and formation of heavy elements was occurring in nature.

The reason why most investigators during the 1950's believed that natural reactors could never have formed in nature was briefly as follows: when it is attempted to apply Fermi's pile theory to a natural assemblage of uranium, such as a large uranium ore deposit a certain assumption has to be made. The infinite multiplication constant(k_∞) is

$$k_\infty = \underline{\epsilon}\ \underline{p}\ \underline{f}\ \underline{\eta} \qquad)1),$$

where $\underline{\epsilon}$ is the fast fission factor, $\underline{p}$ is the resonance escape probability, $\underline{f}$ is the thermal utilization factor, and $\underline{\eta}$ is the number of fast neutrons available per neutron absorbed by uranium.
It so happened that investigators in the U.S. during the 1950's were using a model, in which it was assumed that a large uranium ore deposit has suddenly appeared on the surface of the earth at a certain time during the geological history. This model leads to an erroneous conclusion as shown in Table 1.

Table 1.
Models used in the calculations and the consequences

No.	Model	Consequence
(1)	A large uranium ore has suddenly appeared on earth at a certain geological time	k_∞ has never exceeded unity at any time in the past

No.	Model	Consequence
(2)	Trace amounts of U had to be leached from the rocks with water, transported to a certain place, and finally deposited and dried	k_∞ could have exceeded unity some 2 billion years ago

What the speaker realized in 1956 was that Model 1) was over-simplification of the natural phenomena, because a large uranium ore deposit never appears in its present form on the surface of the earth. A somewhat more complicated, but geochemically reasonable model would be to assume that trace amounts of uranium had to be first dissolved from rocks and transported by water to a certain locality and then finally deposited and dried(see Model(2), which leads to the conclusion that natural reactors should have operated some 2 billion years ago.

In his book entitled "The transuranium elements", Glenn Seaborg[6] wrote: " ------ The search for transuranium elements, a quest born of scientific curiosity, was destined to be the trigger for a series of events, which, within a decade, were to rock the world and burst upon the consciousness of every literate human being. These events were the discoveries that led to the exploitation of nuclear energy, particularly as a weapon of mass destruction. Other fundamental scientific discoveries in the past undoubtedly have had an equal, if not greater, effect on man's mode of existence, but no other exploded in his face as has this one: the announcement to the world of the existence of plutonium was in the form of the nuclear bomb dropped over Nagasaki".

It is to be noted here that the element 94 (plutonium) discovered by Seaborg and co-workers was a "man-made" element and hence the speaker has initiated a long-range research project to look for the occurrence of ^{244}Pu in the early solar system.

In 1960, John Reynolds[7] at the University of California, Berkeley, made the important discovery that the xenon extracted from the Richardton meteorite was heavily enriched in ^{129}Xe and he concluded that this isotope almost certainly was formed from the radioactive decay of ^{129}I with a half-life of 16 million years, now extinct as a natural radioactivity, but not so at the time of formation of the meteorite:

$$^{129}I \xrightarrow{\beta^-} {}^{129}Xe(\text{stable}) \qquad (2).$$

The speaker[8] then proceeded to point out that ^{244}Pu with a half-life of 82 million years should have been also present in the early solar system and the experimental evidence for its presence could be secured by searching for the presence in meteorites of excess heavy xenon isotopes ^{131}Xe, ^{132}Xe, ^{134}Xe and ^{136}Xe, which are produced by the spontaneous fission of ^{244}Pu.

It is important to note here that in his classic paper entitled "Xenology", Reynolds[9] wrote, in 1963,: " ------ Xenology means to us the detailed study of the abundances of xenon isotopes evolved from meteorites by heating or other means and the inferences that can be drawn from these studies about the early history of the meteorites and the solar system. To the classicists Xenology means study of a strange substance, which is also appropriate ----------. In this paper we discuss xenology in the context of theories of the origin of the heavy elements by Burbidge _et al_[10] and Cameron[11], and a theory of the xenon isotope anomalies in meteorites by Kuroda[8] and Cameron[12]. These theoretical ideas provide a convenient framework for our discussion, even though it is certain that ideas in this field will require frequent revision as the experimental side of the subject develops --------."

Reynolds[9] called large variations of relative abundances of ^{129}Xe the _special anomalies_, and the less spectacular variations observed at all mass numbers, except 129, _general anomalies_. He then went on to state that the general anomalies are explained by two processes: (a) relative abundances at mass numbers 131, 132, 134 and 136 will be enhanced by the addition of the spontaneous fission product of ^{244}Pu, according to Kuroda[8] and (b) xenon in the sun has been exposed to neutron irradiation during the deuterium-burning phase of the evolution of the sun and hence the transfer of solar xenon to earth would have the effect of enhancing the relative abundances at mass numbers 128, 130 and 132, according to Cameron[12] ----------".

The effect of spallation reactions was unknown in 1963, but it was soon discovered that the relative abundances at mass numbers 124, 126, 128, 130, 131 and 132 should be enhanced by this process. The effect of the spontaneous fission decay of ^{244}Pu at mass numbers 131, 132, 134 and 136 was also discovered at about the same time.

The importance of the effect of stellar temperature neutron-capture reactions, which had been predicted by Cameron in 1962 was not clearly understood until the Apollo 11 landing on the moon in the summer of 1969. Soon thereafter in 1971, the speaker[13] pointed out, however, that the differences in the isotopic compositions of xenon found in meteorites, lunar samples and in the earth's atmosphere can only be explained as due to the alterations of the isotopic compositions of xenon by a combined effect of (a)mass-fractionation, (b)spallation and (c)stellar temperature neutron-capture reactions.

In 1972, Manuel et al[14] reported, however, that the effects of the above-mentioned processes(a), (b) and (c) were negligibly small and the carbonaceous chondrites contain two isotopically distinct components of trapped xenon, which could not be explained by the occurrence of nuclear or fractionation processes.

The method of treatment of the xenon isotopes used by Manuel *et al*[14] in 1972 was essentially the same as the one used during the 1960's, but their arguments seemed to lead us to a new concept that the *r*- and the *p*- process nucleosynthesis products may have not been initially well mixed within the solar nebula. Moreover, the fact that another strange xenon component(*s*-type xenon)was added to the list of strange xenon components six years later[15], seemed to strengthen the case for Manuel *et al*[14] (see Model(1) in Table 2.

Table 2.

Models used in the study of ^{129}I and ^{244}Pu in the early solar system

No.	Model	Consequence
(1)	These isotopes have suddenly appeared in space 4.6 billion years ago	Carbonaceous chondrites contain strange xenon components -*HL* and the *s*-type xenon
(2)	These isotopes were created in a supernova and hence the abundances of all the xenon isotopes existing in its vicinity must have been subjected to a combined effect of (a)fractionation (b) spallation and (c)neutron-capture reactions.	Xenon-*HL*is a mixture of ^{244}Pu fission xenon and the xenon whose isotopic composition is altered by the processes(a),(b) and (c), while *s*-type xenon is the xenon, which was exposed to a very high neutron flux.

It is to be noted here, however, that the use of an overly simplified model often leads to erroneous conclusions, as we have seen in the case of the Oklo Phenomenon(see Table 1). The speaker therefore decided to use a more complicated Model(2)(see Table 2) to interpret the same set of the xenon isotope data.

Meanwhile, the field of studies on the origin and nature of the strange xenon components found in carbonaceous chondrites was reviewed by Anders and Zinner[16] in 1993. According to these investigators, primitive meteorites contain a few ppm of pristine interstellar grains that should provide information of nuclear and chemical processes in stars. Diamond grains contain anomalous noble gases including xenon-HL, which shows the signature of the *r*- and *p*-processes and thus apparently is derived from supernovae. Silicon carbide grains, on the other hand, shows a signature of the *s*-process and apparently comes mainly from red giant stars.

It is worthy of note, however, that one encounters great difficulties in the interpretation of the xenon isotope data by the use of this over-simplified model(1), as evidenced by the fact that Anders and Zinner[16] were forced to conclude: " ------- The most pristine, unaltered interstellar grains provide little information on the early solar system, bearing no memory of their gentle arrival ----- ".

Results from our latest calculations reveal, however, that the strange xenon components are not isotopically pure substances. Instead, the former is a mixture of the ^{244}Pu fission xenon and the xenon whose isotopic compositions is severely altered by a combined effect of the processes (a), (b) and (c) mentioned above, while the so-called s-type xenon is the xenon, which was simply exposed to an extremely high neutron-flux.

These results also indicate that the C1 carbonaceous chondrites, which are generally regarded as the most primitive sample of the solar system material, began to retain its xenon 5.1 billion years ago, when the plutonium to uranium ratio in the solar system was as high as almost 0.6(atom/atom), while the C2 carbonaceous chondrites began to retain their xenon about 150 million years later and the ordinary chondrites and achondrites about 500 to 600 million years later. This means that the birth of the solar system began soon after the last supernova exploded about 5.1 billion years ago, and the generally accepted 4.55 billion year-age of the solar system is likely to be the time of the breakup of the meteorite parent body[17].

It is important to note here that Pierre Curie[1] remarked in 1905: " -------- It is not absurd to suppose that space is constantly traversed by very penetrating radiations which certain substances would be capable of capturing in flight -------- ". The very penetrating radiations which he had in his mind in 1905 turned out to be the neutrons. It so happened that the neutrons involved in the case of the Oklo Phenomenon were the reactor-temperature neutrons, while those in the case of the supernova explosion were the stellar-temperature neutrons.

In the speaker's highschool days, two most respected and admired living persons in the world were Mme.Curie in France and Admiral Togo in Japan. On the occasion of the 100th anniversary of the discovery of radium and polonium, the speaker wishes to express his deep gratitude to Professor Tatsuo Matsuura for his kind invitation to this memorable International Symposium.

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1.4 放射能に関するキュリー夫妻の仮説と元素の起源

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1905 年6月6日に Pierre Curie[1]が行った、『放射性元素、とくにラヂウム』と題するノーベル賞講演の中で、彼は次のようなことを述べた：『われわれの研究のはじめにおいて、放射能という現象は、次のような極めて漠然としたところの、キュリー夫人が 1899 年と 1900 年に発表した２つの仮説によって説明ができるであろう。‐‐‐‐1. 第１の仮説によれば、放射性物質はそれが放射するエネルギーを外部の放射線から借用するもので、すなわち、その放射能は２次的放射線であろう。‐‐‐‐2. 第２の仮説によれば、放射性物質はそのエネルギーは、自分たち自身の中から引き出すものであろう。』

そして、彼は次のような言葉を追加した：『第２の仮説の方が色々のことを説明するのにより役立つように思われるから、放射性の物質の諸性質はそうであると考えてよかろう』。その結果として、第１の仮説は一般にはほとんど忘れられてしまった。しかし彼は、第１の仮説が、後になって元素の起源という問題の説明をするのに、重要な役割を演ずるようになるだろうということを充分承知していたように思われる。

Pierre Curie が 1905 年6月6日に行ったノーベル賞講演の 10 日前に、日本の歴史上極めて重要な事件が起こった。[2] 1905 年5月 27 日の日本海海戦で、東郷平八郎元師の大日本帝国海軍がロシアのバルチック艦隊を撃滅したのである。

同じ頃、1905 年の６月にアメリカの海軍兵学校を卒業した Chester Nimitz というテキサス生まれの青年は、はじめて遠洋航海に出て太平洋を横断し東京に着いた時、運よく東郷元師にお目にかかり握手をした。

そして、それ以来 Nimitz は東郷元師の崇拝者となり、東郷元師の海軍の戦術をよく勉強して、40 年後の第２次世界大戦で日本の太平洋艦隊を撃滅することになった。

1934 年にキュリー夫人と東郷元師がこの世を去られた年に、Jean Frederic Joliot と Irene Curie が人工放射能を発見した。Joliot が 1935 年 12 月 12 日に行った『元素の転換の化学的証拠』と題するノーベル賞講演の中で、彼は次のようなことを述べている。『天文学者たちは、今まで肉眼で見えなかったような星が急に明るくなって、望遠鏡なしで見えるようになることを知っている』。これが、いわゆる客星の出現(appearance of a Nova)である。このように星が突然明るくなる現象は、現在のわれわれが漠然と考えているように、将来の研究者たちが疑いなく実現させるであろうが、その時は充分注意するように希望するものである。

このような目的に対する極めて重要な第一歩は、イタリーの物理学者 Enrico Fermi によって、1942 年に成就された。シカゴ大学のフットボール・スタヂアムにある記念碑に、次のようなことが記されている：『‐‐‐‐1942 年 12 月２日、人類はここにはじめての連鎖反応をつくり出して、核エネルギーを制御しながら取り出すことに成功した』。

1956 年になって、講演者[4, 5] は原子炉が約 20 億年前に地球上に存在した筈であると発表した。この

予言は当時の科学者たちから問題にされず無視されたのであるが、16 年後の 1972 年になってフランスの原子力科学者たちによって、アフリカのガボン鉱山のウラン鉱床の中にその『化石』が発見され、『オクロ現象』として有名になった。

20 世紀の後半になるまで、科学者たちは科学元素というものは、星の中だけで合成されたものであると信じていたが、オクロ現象の発見により、地球上でも大規模の元素合成が起こっていることが明らかになったのである。

1950 年代の科学者たちが、天然原子炉が存在しないと考えたのは、簡単に説明すれば次のような理由からである。Fermi の原子炉の理論を天然ウランの大鉱床に適用する場合、何らかの仮定をたてる必要がある。

無限の広がりをもつ原子炉に対する『無限増倍率 (k_∞) 』は、

$$k_\infty = \in \cdot p \cdot f \cdot \eta \qquad (1)$$

ここに、$\in$は速中性子核分裂係数、pは共鳴脱出確率、fは中性子利用率で、ηは有効中性子数である。そこで 1950 年頃の科学者たちは、ウランの大鉱床がそのままの形で地球上に、あるは地質年代に忽然と出現した、という一つのモデルを使って計算してみると、第１表に示すように、k_∞の値は決して１以上にはならなかったという結論が出てくる。

第１表　計算に使ったモデルと、それから得られる結論

No.　　モデル	結　論
(1)大きなウランの鉱床が、ある地質年代において地球上に忽然として出現した。	k_∞の値は過去において、１より大きくなることは決して無かった。
(2)微量のウランが母岩から水で浸出され、ある所に運搬され、沈殿して、乾燥されて、鉱床が生成した。	k_∞の値は 20 億年ばかり前までは、容易に１より大きな値となった。

一方、私は第１表のモデル (1)は、あまりにも簡単化しすぎたものであると気付いた。そこで、モデル1)よりいささか複雑であるが、第１表に示すモデル (2)を使って計算をして、k_∞の値は 20 億年ばかり前には容易に１より大きな値となった。つまり、原子炉は天然に作動していた筈だという、モデル (1)の場合と正反対の結論を出したのである。

それから２年後に、Glenn Seaborg[6]は『超ウラン元素』と題する彼の著書の中で、次のように述べている：『- - - - 科学的好奇心から生まれた、超ウラン元素の研究は、10 年も経たぬうちに世界人類のすべての良心を直撃するような事件を引き起こした。他の基礎科学の分野における発見は、過去において少なくも同等の影響を人類の生存様式に与えたものがあったであろうが、人の面前に文字通りに爆発したものは過去になかった。プルトニウムの存在の世界に対する発表は、長崎に於ける原爆投下という形でなされたのである』。

Seaborg 等が発見したプルトニウムはしかし、人工的に合成されたものであった。そこで私は 1950 年代の終の頃、プルトニウムの天然における存在を証明するという、遠大な長期研究計画をたてたので

あった。

β⁻2年後の1960年に1960年に、カリフォルニア大学のJohn Reynolds[7] はRichardtonという隕石の中に含まれるゼノンの中に、^{129}Xeが著しく濃縮されているという重要な発見をして、これは現在は『消滅核種』となっている、半減期が1,600万年の^{129}Iが隕石が出来た頃には天然に存在していたためであろうと説明した。

$$^{129}\mathrm{I} \xrightarrow{\beta^-} {}^{129}\mathrm{Xe}\ (安定) \qquad (2).$$

そこで私はその直後に、それなら半減期が8,200万年の^{244}Puも天然に存在していた筈であると指摘し、その実験的証明は、いろいろの隕石の中に^{244}Puの天然核分裂生成物である^{131}Xe, ^{132}Xe, ^{134}Xe及び^{136}Xeが存在するかどうかを調べることによって得られるであろうと発表した。

一方、Reynoldsは1963年に『ゼノロジー』という重要な論文を発表し、その中で次のように述べた。『‥‥ゼノロジー(Xenology)とは、隕石を加熱した際、あるいは隕石から何らかの方法で放出される、ゼノンの同位元素の相対的存在比を測定して、それから隕石や、太陽系の古い歴史を知ることを目的とする学問である。古典学者にとっては、ゼノロジーは奇妙な物質を研究する学問であるといっても差し支えない。この論文においては、我々は重い元素の起源に関するBurbidge等[10]とCameron[11]の論文に基づき議論する。そして、Kuroda[8] とCameron[12]が発表したゼノン同位元素の理論をも考慮する。これらの理論的アイディアは、我々の議論の構想の骨組となるが、実験の分野が進展するにつけ、変更することが必要となってくるであろう。

Reynolds[9] は、^{129}Xeの存在量の大きな変動を『特別同位体異常 (Special Anomalies)と呼び、他のすべての同元素について見られるそれ程際立たぬ異常を『一般同位体異常 (General Anomalies)と名付けた。そして彼は後者は2つの過程でおこると述べた。(a)質量数の131,132,134及び136は、Kuroda[8]がいうように、^{244}Puの天然核分裂によって大きくなる筈であるが、(b)太陽の中に存在するゼノンは、太陽が重陽子を燃料として使っていた頃に起きた中性子照射のために、質量数128,130及び132の存在量が増大するであろう (Cameron[12])。

宇宙線照射による核破砕反応の影響は、1963年当時にはよく知られていなかったが、間もなくそれは質量数124,126,128,130,131及び132の存在量を増大することが判った。^{244}Puの天然核分裂の影響もやがて明らかとなってきた。

1962年にCameron[12]が予言した *stellar temperature* (星の温度でおこる) 中性子捕獲過程の影響は、1969年夏のApollo 11の月面上陸の頃までには、はっきり判っていなかったが、間もなくして、1971年に私[13]は、隕石や月試料及び地球大気中に存在するゼノンの同位元素組成が、それぞれ異なっているのは (a)質量分裂と、b)核破砕反応と、(c) *stellar temperature* (星の温度でおこる中性子捕獲という、3つの過程による変化の組合せによるものであると発表した。

ところが、1972年になるとManuelたち[14] は、上述の (a), (b)及び (c)の3つの過程による同位体組成の変動は無視できる程に小さいものである。 そして、炭素質コンドライト中には2つのtrapped xenon(もとから存在したゼノン) が存在すると考えるべきであると発表した。

Manuelたち[14]の考えは、1960年代からあったゼノンの同位体組成の取扱いと同じものであるが、彼

らが太陽系をつくった星雲の中では、r－過程とp－過程で生成した物質が均一に混合していないという考え方は、魅力的であると一般の人には思われた。そして6年後にs－type xenon の発見が報告されて[15]、Manuel たち[14]の説は広く認められるようになった。

第2表　^{129}I と ^{244}Pu の初期太陽系における存在に関するモデル

No.　モ デ ル	結　論
(1)ゼノンの同位元素は 4.6 億年ばかり前の空間に突然出現した。	炭素質コンドライトは2つの Strange xenon (-*HL* 及び *S*-type ゼノン) を含む。
(2)ゼノンの同位元素は超新星の中で合成されたから、すべてのゼノン同位元素はその時3つの過程、つまり上述の (a), (b), (c)によって、その組成が変動した筈である。	ゼノン -*HL* は ^{244}Pu 核分裂ゼノンと (a), (b), (c)の3過程により組成が変わったゼノンの混合物であり、一方s－type ゼノンは、極めて高い中性子の線束によって照射されて出来た。

しかし乍ら、オクロ現象の場合に、第1表に示した様に、単純すぎるモデルを使って計算をすると、往々にして間違った結論が出てくる。そこで私は第2表に示すような、より詳細なモデル (2)を使って計算をして、全く違った結論を出した。

1993 年になって Anders と Zinner[16] は、炭素質コンドライト中に存在すると考えられる、奇妙なゼノン成分に関する研究分野の総合論文を発表したが、それによると原始的な隕石の中には、数 ppm の星間物質の粒子が含まれているから、星で起こっている原子核的、そして化学的過程を知ることが出来る筈である。ダイヤモンドの粒子の中にはゼノン -*HL* が濃縮されており、r－過程とp－過程の指紋を示すから、恐らく超新星から来たものであろう。一方、SiC の中のゼノンは、s－type の指紋を示すから、多分『赤い巨人 (Red giants)』から来たと思われる。

しかし、ここに注目すべきことは、かような簡単すぎるモデルを使ってゼノンの同位元素組成を解釈しようとすると、色々の難しい問題に直面する結果となることは、Anders Zinner[16] が次のような結論に到達せざるを得ないことで判る：『- - - - 最も純粋な、変化をうけていない星間粒子は、太陽系の初期の歴史に関する情報を、我々に全く提供しない。それは、太陽系の中に静かに黙って到着したからである。』

一方、私が主張するような、いくらか複雑なモデル (2)を使ってゼノン同位元素のデータを解釈すると、ゼノン -*HL*やs－type Xenon は、同位元素的に純粋な(isotopically pure) 物質ではないという結論が出てくる。すなわち前者(-*HL*) は ^{244}Pu 核分裂生成物と、前述の過程 (a), (b), (c)によって、同位元素組成が大きく変動したゼノンの混合物であり、一方、後者 (s－type Xenon) は、極めて高い中性子の線束(flux)の影響をうけたゼノンである。

そして、このような計算の結果から、太陽系物質の組成を代表すると考えられている、C1炭素質隕(Carbonaceous Chondrites)は、約 51 億年前に太陽系の中のプルトニウムとウランの比が、約 0.5 から 0.6 (原子比) の時にゼノンを保持しはじめ、C2炭素質隕石といわれる種類の隕石は、それから約1億年ばかり経ってからゼノンを保持しはじめ、普通のコンドライトやエコンドライトは、それから約5億乃至6

億年後にゼノンを保持しはじめたという結果となる。つまり、一般に信じられている 45.5 億年という太陽系の年齢は、隕石の母体であった惑星がこわれた時に相当するものであるという結論となる。

Pierre Curie[1] は 1905 年に、『宇宙の中には極めて透過力の大きい粒子が常に通過していると考えても、馬鹿げたことではなかろう』と言ったが、彼が 1905 年に考えていた透過力の大きい粒子は、中性子だったのである。そして、オクロ現象の場合は、その中性子は *reactor-temperature* neutrons(原子炉の温度の中性子) で、超新星の場合は *stellar-temperature* neutrons(星の温度の中性子) だったのである。

私が高校生だった頃、フランスのキュリー夫人と日本の東郷元帥は、世界中で生存する最も尊敬され、敬愛された人物であった。ラヂウムとポロニウム発見の 100 年記念の年にあたり、私をこの記憶すべき国際シンポジウムにお招き下さった松浦辰男教授に深く感謝する次第である。

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1.5 NATURAL RADIATION AND RADIOACTIVITY IN EDUCATION

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ABSTRACT

To understand radiation and radioactivity, it is important to recall the history of their investigation. At first, the works made by Elster and Geitel with a leaf electroscope about 100years ago are introduced. Then the variations of enviromental radiation level are shown by the results obtained with a large volume NaI(Tl) detector on my car travelling all over Japan and the data with a pocket dosimeter during my tours in Europe. Among environmental radioactivity, radon and tritium are specially remarked from the historical and educational points of view, with various methods for their measurements.

1. INTRODUCTION

Though radiation and radioactivity have been exisisting in the nature from ancient times, they can not be recognized only by five sences of human beings. The following poem was made for invisible air or wind in the last century by an English poet, Christian Rosseti (1830-1894).

Who has seen the wind? Neither I nor you:
But when the leaves hang tremblimg, the wind is passing through.
Who has seen the wind? Neither you nor I:
But when the trees bow down their heads, the wind is passing by.

In order to recognize invisible radiation and radioactivity, we have to replace the leaves or the trees with some scientific instruments. As seen in the two lower columns of Table.1 showing the main historical events in the studies of radioactivity, our informations on radiation and radioactivity have developed very much according to the development of detectors and various chemical methods to be applied for the identification of radioactive nuclides,

On the other hand, a famous Italian chemist, Cannizzarro (1826-1910) once said as follows, " It often happens that the mind of a person learning a new science has to pass through all the phases which the science itself has exibited in its historical evolution ". Furthermore, Ernst Heinrich Haeckel(1838-1919), German biologist and natural philosopher stated " Ontogeny simulates phylogeny " that is, in the growing process of individual lives, the stage of historical development of the species are repeated. From psychological and educational point of view, it is considered valuable and effective for young generations in

Table 1. Historical events and the development of methods.

18 95 | 19 00 | 05 | 10 | 15 | 20 | 25 | 30 | 19 33

X Ray, U Rad. (X R a y, U R a d.) Th.Tn. RaA.RaTh ・Atomic Nucleus ・Auger Effect ⇩
Ra. Rn. "B.C. Io. ・Isotope. Diplacement law Neutron
Po.Ac. RaD. MsTh. UY. ・Artificial trans. of element
UX.ThX "F. UX $_2$. Pa. UZ. Sm.
from Radioactive Minerals

Environmental Radioactivity ・The Mineral Spring of Japan pub.
・Rn and its shot-lived daughtetrs ・Rare Earth Mineral in
・K-40. ・Atomosph. Dep.(Comet"Halley") Japan
・Rb-87. ・"Hokutolite"(Radioact. Sinter Dep.)
・Cosmic Ray ・Radioactive Dating

[CHEMICAL METHOD]
Co-precipitation, Law of Coprecipt.,
Solvent Extraction(with Ether), Radiocolloide, Aerosol,
Chromatography, Electr. Migration and Deposition,

[PHYSICAL METHOD] IM Fontacto-
Gold Leaf Electrometer, Wilson Chamber, Auto-rdiography, Scope,
Quadrant Electrometer. GM Tube,
Photography, Spinthariscope[ZnS(Cu)], Coincident
Emission Spectrography, X-ray Spectrography, Circuit,

1935 | 40 | 45 | 50 | 55 | 60 | 65 | 19 70 | 72

・Artificial Radioactivity,
Tc. Np.Pu. Cm.Am. Pm. Bk. Es. Md. Lr.
Fr.At. Cf. Fm. ‡Nucl.Syn. in Star(B^2 FH theo.)
・Induced Nuclear Fission.. ・Atomic Power Station. Apollo-11△
・Spontaneous Nuclear Fission. ★SNAP-9A Acc.
・Nuclear Reactor(CP-1). ★Palomares A.
・Atomic Bomb Expl. Thule A.★
★ Nuclear Test Expl. in the Atomosphere
‡ H-3 Activity. ※ Environmental H-3. 1963 Partial Test Ban Tr.
※ C-14. ☆proposed[Natural Nucl.R.]found☆

[CHEMICAL METHOD] (TBP,)(TTA,) (HDEHP,) (DBDECMP)
Ion Exchange Resin, (High Mol. Amine,) --Solvent Ex.--
Alumina Chromatography, Partition Chromatography,
Paper Chromatography,

[PHYSICAL METHOD] Low BG Counting(C-14),
Lauritsen Electroscope, GI Chamber, Fission Track,
Nuclear Emulsion, Bubble Chamber, α Track, α Recoil Tr.
Pulse Counting Tech.& Electronic Circuit, Multi Ch. PHA,
Naphthalene Scintillation,
NaI Scin., Si(Au)Semi-cond. Det., HpGe,
Liquid Scin,. Ge(Li), LEPS,

1973
'76. 3. ※ Kirin Meteorite fall.
'76. 8. ☆ Eu-152 found in Hiroshima
'78. 8. ★ Nucl. R. Satellite Acc.
'79. 3. ★ Three Mile Island R. Acc.
'80. 5. ※ St. Helens volcano expl.
'81. ★ Co-60 release at Tsuruga
'86. 4. ★ Chernobyl R. Acc.
'87. 2. ※ Super Nova SN1987 expl.
1991 ※ Volcanic Activity in Asia
Future ⟶

Problems

‡ Dose Assessment for Risk Factor:
‡ Effective Dose Equivalent Estm.:
‡ Nuclear Reactor Safety:
---- Emergency Monitoring:
‡ Risk - Benefit Analysis:
‡ Radioactive Waste Disposal
---- Natural Analogue Study:
etc.

their growing process to trace the historical processes and also to learn the definite results of experimental works made previously. In order to understand radiation and radioactivity, it is significantly important to recall the history of various studies since the discovery of radioactivity by H. Becquerel in 1896 follwed by the Curie's discovery of new radioactive elements, Po and Ra.

2. PIONEERING STUDIES BY ELSTER AND GEITEL

Pioneering works on natural radiation and radioactivity in the environment were made by two German physicists, Julius Elster (1854-1920) and Hans Geitel (1855-1923), by using a simple leaf electroscope. They were both close friends since their childhood and remained as teachers of a Gymnasium "Großen Schule" at Wolfenbüttel throughout their lives publishing many papers jointly. It must be mentioned that, based on their experiments for Becquerel ray made in a vaccum environ and a deep underground tunnel in the Harz mine, they sugested at first the disintegration of atom itself as the possible origin of this ray on 19th of January in 1899 at the scientific meeting at Braunschweig, although Marie Curie expressed the same concept soon later on 30th of January, 1899 independently.

They were measuring the electric condictivity of air, that is, the degree of ionization of atomosphere and invented a photo-cell to measure faint light. We can see now their some memorial instruments at their school. Elster used a portable leaf electroscope set on a stick during his tour. He made tours in 1900 to the Mediterranean areas in spring and also to the North Sea areas in summer. During these tours, he carried out totally 390 measurements at various points. The data in his report[1] include the data on several high mountain tops showing the higher ionozation contribution of cosmic ray even before its discovery by Victor F.Hess (1883-1964) in 1911.

Another paper[2] shows the variation of air electric conductivity during the total solar eclipse at Algier on May 28th in 1900. Such variations are nowadays explained as the accumulation of radioactive gas radon on the ground surface due to the atomospheric inversion layer during solar eclipse.

They also found that the electric conductivity of the air is rather high [3] in the underground room of the congress hall of their city and in the cavern of neighbouring Harz district where I visited this summer. By collecting aerosol particles on the wire charged with high electric potentialand measuring its radioacrivity decay, they proved in 1902 [4] that the high electric conductivity of airis due to the existence of accumulated radon which had been discovered at the laboratoty of Halle university in 1900 by Friedrich Dorn (1847-1916).

After such first finding of natural radioactivity in the environmental, Elster and Geitel extended their studies on natural spring sediments and soil. Famous scientist E. Rutherford wrote in his book [5] appreciating their works, that "The pioneers in this important field of investigation were Elster and Geitel and no researcher has contributed more to our knowledge of radioactivity of the earth and atmosphere than they have".

3. CONTINUOUS CARBORNE MONITORING OF RADIATION

Although opaque ZnS powder had been used since 1903 for α ray scitillation counting, detector using scintillation in transparent solid material developed since 1947 when its first observation made by β ray in naphthalene was found by H.Kallmanand. And then P.R,Bell found in 1948 that anthrathene gave larger pulse than anthrathene and for γ r ay detection R.Hofstadter prepared sodium-iodide scintillator activated by adding thallium in the same year. Now the large volume sodium-iodide detector with photo multiplier tube become commercially available. I carried out continuous carborne monitorings of radiation over Japan by setting on the back side of my car such a large volume (4"$\phi\times$4") detector enough to secure a good counting statistics even at fairly high speed driving [6]. Electric powers are supplied from 12 volt car battery through a survey meter unit having 4 channel pulse height discriminators. The relationship between each level and the energy of gamma ray was examined on an integral curve obtained by changing the lower discrimination level as shown in Fig.1. In our carborne monitoring, channel 1 and 2 were used to estimate terrestrial gamma ray levels and other two channel (3 and 4) were used for the estimation of cosmic ray contribution.

Though the counting rates of cosmic ray contribution increase according to the altitude of road above sea level (Fig.2), its decrease in tunnels owing to the shielding effect of mountain and the region of tunnel is easily identified by this effect Fig.3 (ⅰ). In some tunnels, abrupt change of terrestrial gamma ray is observed. An example is shown in Fig.3(ⅱ) for Ena-san tunnel with its geological cross section. Such abrupt change can be explained by geological features of rocks in the tunnel. Another example of such abrupt change was also observed for Sasaga-mine tunnel on the Kochi highway traversinge Shikoku Island in Japan. On the southern part of Kochi highway, rather lower levels of gamma ray radiation were observed even in the tunnels and this is understood by the fact that this area is mainly covered with calcite and dolomite rock.

Maps of Japan[6] were made with different colours of circles according to the gamma radiation levels to summarize the results in tunnels, while triangular signs were used to show the levels on flat open surface for several districts where only few tunnel exist. In a table [6], the radiation levels (40-160 nGy/h) of each tunnel is shown by deviding Japan into the following nine districts. (Ⅰ.Hokkaido, Ⅱ. Tohoku, Ⅲ.Kanto, Ⅳ,Chubu, Ⅴ.Hokuriku, Ⅵ.Kinki, Ⅶ.Chugoku, Ⅷ.Shikoku, Ⅸ.Kyushu). On the whole, rather lower levels in Hokkaido district and rather higer levels in Chubu, Kinki and Chubu districts are observed. After

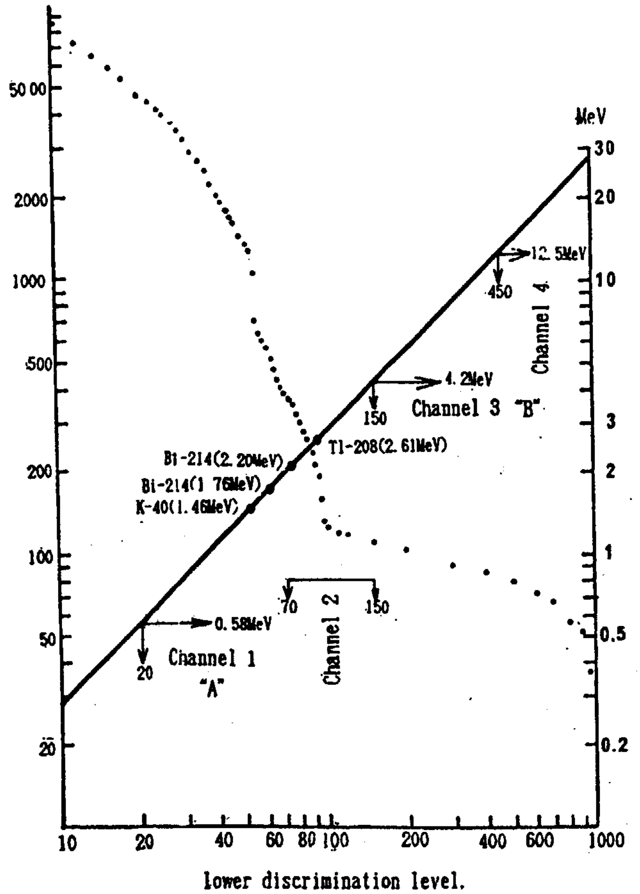


Figure 1:
Integral curve obtained by changing lower discrimination level, and relationship between pulse height discrimination level and gamma ray energy

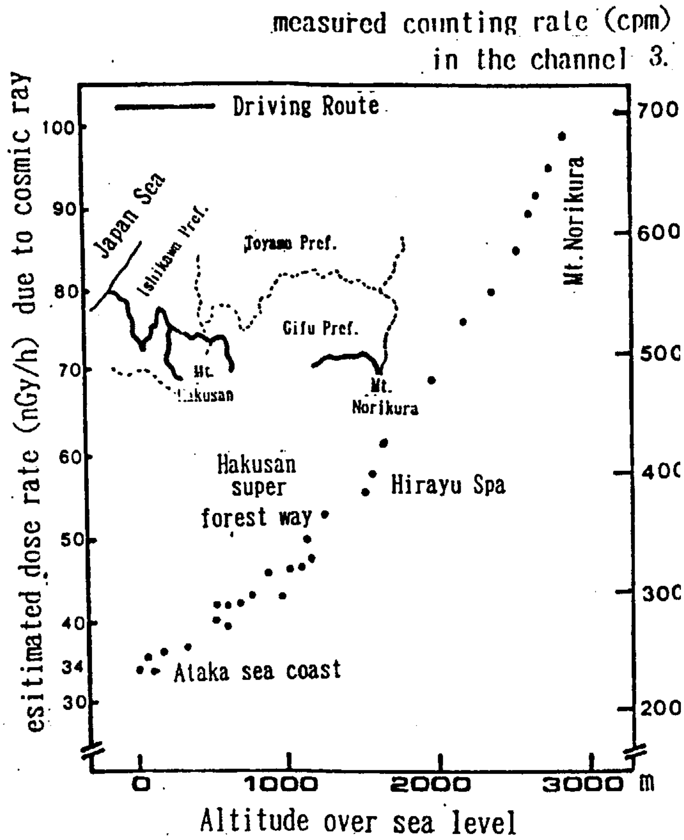
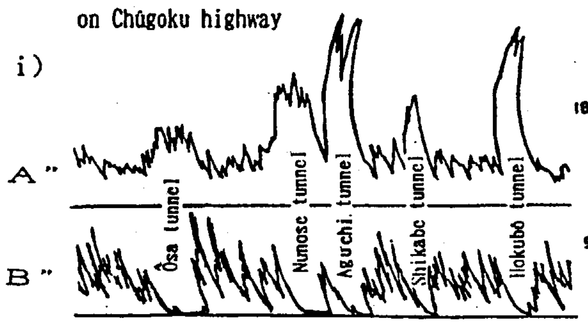


Figure 2:
Variation of counting rate due to cosmic ray with altitude during carborne survey



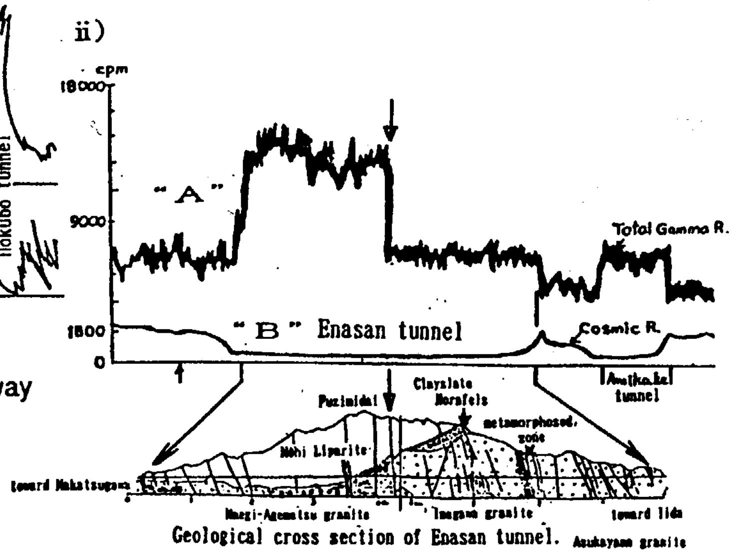


Figure 3:
Examples of variation of counting rates on recording charts, i) on Chugoku highway (ii) in Enasan tunnel with its geology

my retirement from university, I carried out with my wife for several years such radiation monitoring not only over Japan, but also in China [7] with Hong Kong, Malaysia[8] and Vietnam, when I was invited to these countries, the results being published in each country.

Furthermore, when I was invited and asked to make a lecture on radiation and radioactivity in 1990 at the junior high school (the former Kobe-ityu, now Kobe-kôkou) where I studied in my younger days, I measured a week beforehand radiation levels on the way to the gate of school campus and also in several school rooms with the cooperation of students belonging to the science club of this school. By showing in my lecture the results obtained with NaI detector and also explaining the scientific causes of these variations, many students hearing my lecture were much interested in various invisible radiation level outside and inside of the school which can not be known without any detector.

3. ENVIRONMENTAL RADIATION MONITORING WITH POCKET DOSIMETER

When I had a chance to go Europe in 1993, I brought with me a new pocket electric dosimeter having a pn-junction type silicon semiconductor("MYDOSE-mini" Model PdM-101,Aloka Comp.,Japan) and made radiation level studies on various routes during my tours as similarly as Elster made with a leaf electroscope. The data were obtained on various routs [9] including on flights from Japan to Europe, on the Adria Sea, at the underground laboratory of Gran Sasso in Italy, from Bohemia in Czech (Jachymov and Karlovy Vary) to Saxony in Germany (Schlema and Freiberg), at Berlin and Stuttgart, on the Rhein and Bodensee, at Chamonix and Mont Blanc in France and so on. The radiation levels are known by the slope of lines of accumulated dose. Rather high levels of about 500nGy/hr are observed even now at the memorial park in Jachymov with the Madame Curie's monument where the waste from uranium pigment factory had been piled up and used effectively to extract radium in Paris about 100 years ago. And in Jachymov, the unpaved road near the old uranium mine office show the fairly high levels, while the road paved with granitic rocks at the market place near Rathaus of Marktredwitz in germany shows also relatively high level. On the other hand, the radiation level on river and lake or sea show lower level and further lower level was observed at the Gran Sasso underground room.

As similarly as such radiation monitoring during travels, the presentation of comparative data on radiation levels along the route of school excursion will be effective to get the students interested in radiation.

4. MEASUREMENT OF RADON IN AIR

As for natural radioactivity, the measurement of radon in air around us which make a largest radiation dose commitment to man, provides students with familiarity to environmental radioactivity.

Aerosol particles to which various daughter nuclides of radon attach, can be collected by using an ordinary vacuum cleaner and a glass-fiber filter set on suction pipe. After sampling for about one hour, the filter is subjected to the radioactivity counting with Geiger Müller tube which was invented in 1928. The tube is shielded heavily with lead blocks to decrease the background counting. The analysis of radioactivity decay curves will give the estimate of levels of radon by ^{214}Pb [RaB] (its half-life:26.8 min.) and that of thoron by ^{212}Pb [ThB] (its half-life:10.6 hr.) in air respectively. This experiment is an appropriate educational subject to become familiar to uranium and thorium series nuclides. The comparisons of levels of these nuclides and also the ratio of daughter of thoron over that of radon at differrent locations (rather high levels in the space under the floor) are interesting to be studied at differrent times.

The concentrations of radon in air are also determined by alpha ray track method developed since 1960's. Plastic detectors for example CR-39(allyldiglycol carbonate film) are exposed to air for several months with filter for avoiding the attachment of dusts and the effect of thoron. For rough estimation, more simply naked plastic plates are also used without filter. Then the etching with warm sodium hydroxide solution (6.5mol/dm^{-3}, 70° C) is carried out for about 6 hours. The numbers of etch-pits counted by common optical microscope ($\times$100) inform the average concentration of radon in the indoor or outdoor environment. This method also a good educational trial for students to study environmental radioactivity in various rooms of their school and also their homes.

Other than these environmental radioactivity, tritium (H^3 , T), a soft β ray emitter, was discovered rather later in 1950 as HT from He-Ne fractions of Firma-Linde AG (Z.Naturforsch.5A, 438-439) and in 1951 as HTO from heavy water produced in Norsk Hydro-Elektrisk Kvoelstofaktierlskab (Science 113,1-2). The gas counting method was used in these discoveries. Cosmic ray produced tritium is widely distributed in the world. Soon after its discovery, rain water, snow and others are studied for their tritium in 1954 (Phy. Rev. 93,1337-1344) using gas counting. Now environmental tritium with artificial atomic bomb-broduced one can be measured by low background liquid scitillation counter directly or after the enrichment by electrolysis. The data on tritium in our environment including familiar drinking water will be informative for students. Interresting tritium data obtained by us on "Meisui-100sen", a hundred selected fresh water in Japan are presented with some waters in foreign countries for comparison.

5. EXHIBITION AT NAKATSUGAWA MINERAL MUSEUM

The mineral museum in Nakatsugawa, Gifu prefecture of central Japan where many earlier geochemical studies in Japan were conducted, was opened in May of

1998. And a special exibibition on " Mineral and Radioactivity " with various informations on environmetal radioactivity is held at this museum from 1st of October, 1998 through January 17th, 1999. Exibitions were carried out on the following five items from educational view points along with many instruments. (A)How Marie and Pierre Curiedscovered Polonium and Radium?(B)What extent of the atomic numbers chemical elements have been discovered?(C)Where radioactive rare minerals are found in Japan?(D)How much variation exist in natural radiation level? (E)What kind of natural environmental radioactivity have been studied?

Many visitors including students have enjoyed such exibitions.

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1.6 医学における放射線・放射能の最近の利用

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放射線あるいは放射能の医学・医療への応用の分野を放射線医学ラジオロジーと申します、この分野も最近ではかなり分化をしております。臨床放射線医学クリニカルラジオロジーとその分野だけでも大きく分けますと3つの領域がございます。

放射線診断学、最近では画像医学とも申しますが、治療学及び核医学という3分野で、特に最近の四半世紀の間に様々な技術の開発に支えられて目覚ましい進歩を遂げております。私が医者になりました三十数年前に比べますと、放射線医学の医療における役割は非常に重要性を増していると思います。一つの病院における診療の質は、現在では放射線診療の質に依存しているといっても過言ではないと思っております。この分野の最近の進歩の中で、本日は皆さまあまり馴染みがないかも知れませんが、核医学の分野のポジトロンエミッショントモグラフィー、PET というものと、現在、放医研、私どもの研究所で大きなプロジェクトになっております、放射線治療のなかの重粒子線治療・重イオン放射線治療に焦点を合わせてお話しを致します。

いずれも 1895 年のレントゲンによるX線の発見、1896 年ベクレルの放射能の発見、そしてちょうど 100 年前キュリー夫妻によるラジウムの発見、こういったおよそ 100 年前の物理学上の偉大な発見によって放射線医学は始まったわけでありまして、放射線医学はちょうど今2世紀目に入ったということができます。

レントゲンがX線を発見してその性質をいろいろ研究しておりますが、すぐにその物質透過性に気付いております。そして蛍光スクリーンあるいは写真看板とX線源との間に手を置きまして、X線ビームを当てると手の骨あるいは金属の指輪の写真ができるということを見いだしております。最初にレントゲンが撮った写真は奥様の手だと言われております。診察をするのに、打診、聴診と並んで、眼で見て観察をする視診は大事な技術であります。医療における視診の範囲を著しく拡大して、肉眼では見えないような体の奥の構造を、X線写真でみることができるようになったということであります。

キュリー夫人はX線カーを使って、第一次世界大戦の時に戦場をまわって多くの野戦傷病者の診療に当たられました。この写真は、やはり 20 世紀の初め米西戦争でフィリピンで負傷したアメリカの軍人さんですが、このあたりに傷

があるようですが、外から見るとあまりよく分かりません。頭のX線撮影を、横から撮りますと弾丸が脳の中に入っていることが分かります。このようにしてX線撮影が非常に多く使われたわけであります。ここでご注目いただきたいのはこのX線写真は頭部の写真ですが、写っているのはほとんどが骨、頭蓋骨でありまして脳の中の様子は分かりません。

X線が発見されて間もなく、米国で発明王のエジソンはこのX線撮影に非常に興味をもちまして、ウイリアムハーストという宣伝家と一緒になって、人間の脳のX線写真を見せると宣伝したということであります。それを聞いて多くの新聞記者たちが、エジソンの研究所に集まって、人の脳のX線写真を見るのを楽しみにしていた、しかし毎日毎日実験を繰り返しても当時撮れるのはこういう頭蓋骨の写真だったわけでありまして、失敗を繰り返すうちに記者たちも一人去り二人去りして、とうとう誰もいなくなってしまったというエピソードが記録に残っております。このエジソンの夢は 70 年後に叶えられるわけであります。それは 1972 年イギリスのハウンスフィールドが当時エミスキャン、現在ではコンピューテッドトモグラフィ、CTとよばれる技術を開発致しました。

これはX線ビームを頭あるいは体の周囲のいろんな方向から当て、これを反対側においた検出器で測定して、組織によるX線の吸収の度合いを測定して、それをコンピュータで計算して画像にするというものであります。ごらんのように脳の中の構造が分かります。これはあまりいい写真ではございませんが現在ではもっともっときれいな写真が撮れるようになっております。ただCTの欠点は骨が写りますので、骨のそばの病巣あるいは構造は分かりにくいということがあります。

これに対しましては、1980 年代に核磁気共鳴の現象を利用した、私どもが磁気共鳴画像MRI（マグネティクレゾナンスイメージング）とよんでいる技術が発達しました。これは骨から信号が出ませんので、骨に囲まれた場所でも良く画像化することができます。例えば、脊柱の中の脊髄の画像もとれますし、そういうところにある腫瘍が見つけられるということで、これも画期的なことであります。

このように体軸に対する断層像、輪切り像が撮れるようになったということも新しいことで、これ以後CTに限らずMRI、あるいは PET なども断層像が撮れるようになりまして、断層像の時代に入ったということができます。

今お話ししました骨の問題ですが、この患者さんは骨に囲まれている左側の、蝶形骨というところに腫瘍があるのですが、CTではあまりよく分かりません。

同じ患者さんに^{11}Cというラヂオアイソトープで標識したメチオニン、アミノ酸を静脈注射して、PET という撮影を致しますと、腫瘍が見えてまいり

ます(図 1)。これは腫瘍でタンパク合成が盛んに行われているために、その材料であるアミノ酸を腫瘍が取り込むためにこういう画がとれるわけです。先程のＣＴとペットと重ね合わせますとこの場所に腫瘍があることが分かります。このように病巣のもっている代謝の機能を画像化することが PET を用いてできるわけであります。

PET で脳の血流の状態を見ることができます。これは^{15}Oの炭酸ガスを吸入して、PET 撮影をして、局所の脳血流量を計算してそれを画として表しているものです。また、酸素ガスを吸入して酸素の消費率あるいは酸素の代謝率を同じように画にして表すこともできます。これはノーマルボランティアと書いてあります。ボランティアであることは間違いありません。私自身でございます。ノーマルかどうかというのは問題でありまして、私が群馬大学にいるころに撮った写真で、教室の者は左右差があるんじゃないかとか、もうすでに大脳皮質が少し薄いのではないかと大変心配してくれましたが、それからもう十数年経っておりますから、多分ノーマルといっていいのではないかと私自身は思っているところでございます(図 2)。

同じような脳血流の画像は ^{15}Oの水を静脈注射することによっても得られます。これは何度も繰り返して割合に短時間、20 分位の間隔で検査が出来ますので、いろいろな課題を与えてその課題を行っている時に、脳の局所のどこが賦活されているかを見るのに使うことができます。

例えば、目を開けて耳栓をした状態でとった ^{15}O水の PET つまり脳血流の分布を示したものでありますが、物を見ることの中枢、視覚領野というのは後頭部、脳の後の方にありますが、そこの血流量が増えている、そこの神経細胞が活動していることが示唆されるわけであります。

同じ被験者で今度は目を閉じて音楽を聞かせております。目をつぶっているので視覚領野の血流は減っております。それに対して物を聞く、聴覚の中枢というのは側頭葉にありますが、側頭葉の聴覚中枢と思われる場所が賦活されている様子が分かります(図 3)。

PET の賦活画像から安静時の画像を引き算した画像を MRI 三次元画像に重ね合わせた複合画像を示します。どういう課題を与えているかといいますと、片方の目の前に光を点滅致します。光が見えた時に目を反対側に動かす課題であり、交互に左右の目の前で光を点滅いたしますので、目を交互に左右に動かすことになります。そういうことを繰り返した状態でとったペットの画像から、目をつぶった安静時の画像を引き算してみますと、後頭葉の視覚領野が賦活されております。これは目を使って光を見ているので当然ですが、それだけでなくて前頭葉に目を動かす中枢がありますが、そこが賦活されているのも分かります(図 4)。いろいろな課題を与えながらこのような検査を致しますと脳の機

能の局在が分かるわけであります。

最近では、例えばいろいろな言葉を聞かせている時に賦活される場所、言葉を見ている時に賦活される場所、あるいは言葉をつくっている時に賦活される場所、そういう脳の高次機能の局在も見ることができるようになり、盛んに脳科学の分野で行われるようになっています。

もう一つ PET でできる面白いことは受容体画像であります。これは脳の中の情報伝達の機能を見るものです。二つの神経細胞の繋がる場所はシナップスといい、ここでは化学的な伝達が行われます。その化学的な情報伝達を行うのが神経伝達物質というもので、それを受け取るところに受容体があります。この受容体に結合する物質をラジオアイソトープで標識して投与しますと、受容体の存在する場所、及びどの位の量があるかということも調べることができます。

これは^{11}Cのエヌメチルスピペロンというドーパミンという神経伝達物質の受容体に結合する物質で、これを静脈注射いたしまして、PET で脳の画像を、経時的に見ているわけです。最初は血流の分布が見えるのですが、だんだんにエヌメチルスピペロンが特異的に結合する部位だけがはっきり見えてまいります(図 5)。

ここは線状体という場所ですがここにドーパミンのレセプターが存在することがわかります。いろいろな形で定量的な評価をいたしますと、例えばパーキンソン病という病気で変化することも分かりますし、ある種の脳腫瘍では、ドーパミンD_2レセプターが増えていますので、その診断とか治療効果の判定に使うことができます。こういったレセプターリガンドが、あるいはそれに関連した放射性トレーサーがたくさん出てきており、それによってこういうレセプターイメージングというのが盛んになってきております。近い将来、精神病あるいは精神活動とこういった化学物質との関連、あるいは神経伝達、情報伝達の機能の障害を解明するのに役立ってくると考えられます。

今申しあげましたように、PET により脳だけに限っても血流量、酸素代謝、糖代謝、アミノ酸代謝、それから様々なレセプターリガンドを使った受容体の局在と定量など脳局所機能の評価が出来るようになっています。

PET に使うポジトロン核種は、^{11}C，^{13}N，^{15}O，^{18}Fという４つの核種で、いずれもが大変半減期の短いものであります。半減期が２分から長いものでも 110 分というもので、製薬会社で作ってそれを病院に運んでくる間にはなくなってしまいます。　そこで病院の中に小型のサイクロトロンを置いて核種をつくり、それを様々な物質へ標識して診療に使うことになります。病院にとってはサイクロトロンを動かしたり、標識合成をするのに薬学あるいは化学の専門家を必要とします。現在では全国２７カ所で PET が実施されています。

特に密封されていない非密封の状態で使うラジオアオソトープで、放射性同位元素でいろいろな物質に目印をつけて診断とか治療とか医学研究に使う分野のことを核医学といいます。これはヘベシーが 1913 年に化学の分野で開発し、1923 年には生物学の分野に応用した放射性トレーサー法の人体への応用ということができます。

このトレーサー法の特徴をごく単純な例でもう一度復習をしたいと思います。これは小さなレジンの粒子であります。これを^{99m}Tc で標識して、鼻中隔に置きます。それから、鼻梁の上に 5 ㎝離して同じものをはりつけてマーカーと致します。それを、ガンマカメラで撮影しますと、鼻中隔におかれた粒子が鼻粘膜の繊毛運動によって外へ運ばれます。外というのは食道の方へ運ばれていきます。消化管は体の外につながっていますから、異物としてはいじょされるのです。食道の中に落ちると見えなくなります。このようにして鼻粘膜の繊毛運動の機能を画像として見ることができます。

今のは連続的に撮影したものですが、断続的に撮影して作図をすると、この粒子が 1 分間に平均 12.5 ㎜の速さで運ばれていくのを見ることができます(図 6)。すなわち、体の局所機能を人体に侵襲を与えずに非侵襲的に画像として表すこともでき、それをある程度定量的に評価できることが核医学の特徴であります。

実は核医学は、日常診療にたくさん使われており、1997 年の全国調査では、毎日日本中の約 1000 の施設で 7400 件の検査が行われています。特に癌の骨転移を見つける骨シンチグラフィー、虚血性心疾患、心筋梗塞とか狭心症などの診断をする心筋シンチグラフィー、腫瘍の存在を見る腫瘍シンチグラフィー、あるいは脳血流シンチグラフィーというものが極めて多く行われています。

話をまた 100 年前に戻します。X線が発見されますと、そのX線の生物学的効果が分かるようになり、それがいち早く治療に使われます。1901 年にX線で皮膚表面の難治性の潰瘍を治療したという例であります。また、ラジウムを使って子供の血管腫を治療したという例があります。1895 年のX線の発見から間もなく治療への応用が行われています。

この様に、放射線治療の中で外部から放射線を当てて病気を治療する方法を外照射と言っています。その他にも放射線治療にいくつかあるのですが、その外照射は現在はライナックを使って、非常に高いエネルギーのX線が用いられています。最初は体の表面の治療から始まりましたけども、だんだんにエネルギーの高いX線、あるいはガンマー線が使えるようになり、体の深部の病巣、特に悪性腫瘍、癌の治療に用いられてきています。ごく最近粒子線を使った治療が試みられています(図 7)。私どもの放医研では HIMAC(Heavy Ion Medical Accelerator in Chiba)という大型加速器を作り、現在この重粒子治療の臨床試

行を実施しています(図7)。

従来使われているガンマー線やX線は、体の表面で多くのエネルギーを失いますので、深い病巣に当てようとすると、健常の組織により多くの放射線が当たってしまうという問題があります。陽子線、重粒子線、私どもは炭素イオンを使っているのですが、それはブラッグピークを示しますので、そのブラッグピークの場所にちょうど癌の病巣を上手く合わせますと、そこに多くの放射線を照射して癌細胞を破壊して、その前、あるいは後ろの健常組織にほとんど放射線を当てないですますことができます（図8）。

特に炭素の重粒子線の場合には陽子線やX線に比べて生物学的効果が2倍ないし3倍ぐらい強いといわれておりますので、従来のX線治療に比べて、難治性の非常に抵抗性の強い癌にも効果が期待されるわけです。

重粒子線の場合には病巣に集中してその周辺、健常組織への放射線量を著しく減らすことができるわけです。先程申し上げました HIMAC という加速器の主体はシンクロトロンで半径約 40mのものです。加速されたビームを3つの治療室に導き、その3つの治療室で重イオンの放射線治療をしております。現在これは臨床研究であり、第一相、第二相の臨床試験、安全性を確かめつつ、腫瘍への効果をみているところであります。過去5年間におよそ 500 例余りをこれまで治療して、安全性に関しても十分な自信をつけてきておりますし、腫瘍に対する効果、特に普通の放射線治療では効きにくい腺癌、悪性黒色腫、肝細胞癌でも効果が得られるという感触を得ております。以上、放射線あるいは放射能の医療、医学への応用の一端をご紹介して、最近の医療への応用の状況をある程度ご理解いただければと思います。ご静聴ありがとうございました。

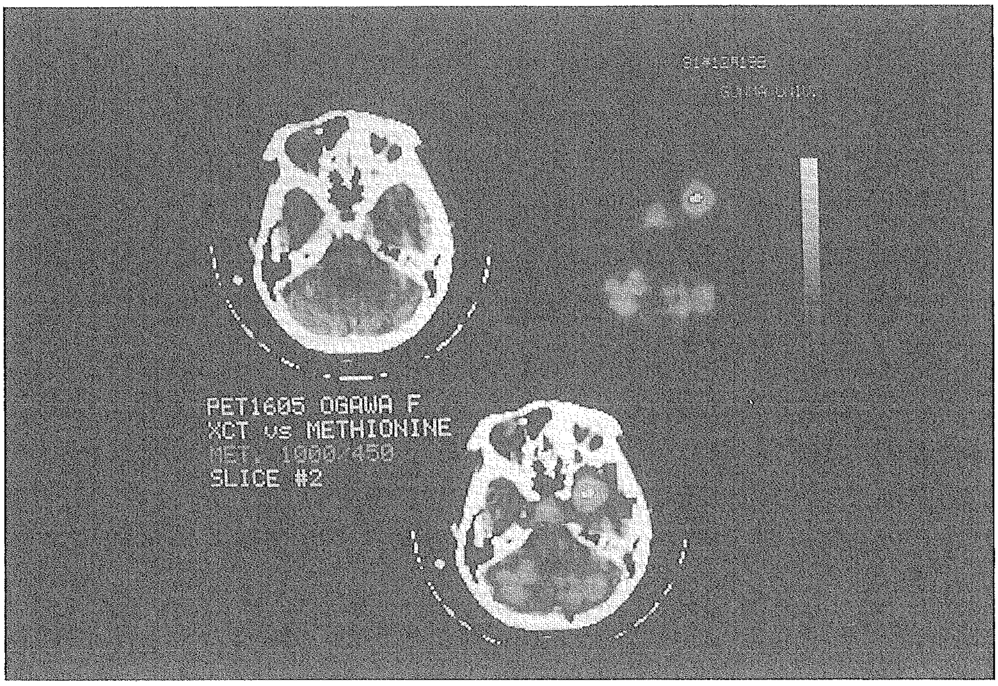

図1　蝶形骨翼部の脳腫瘍（矢印）、CT(左上)
^{11}C-メチオニン PET(右上)、
CT と PET の複合画像(下段)

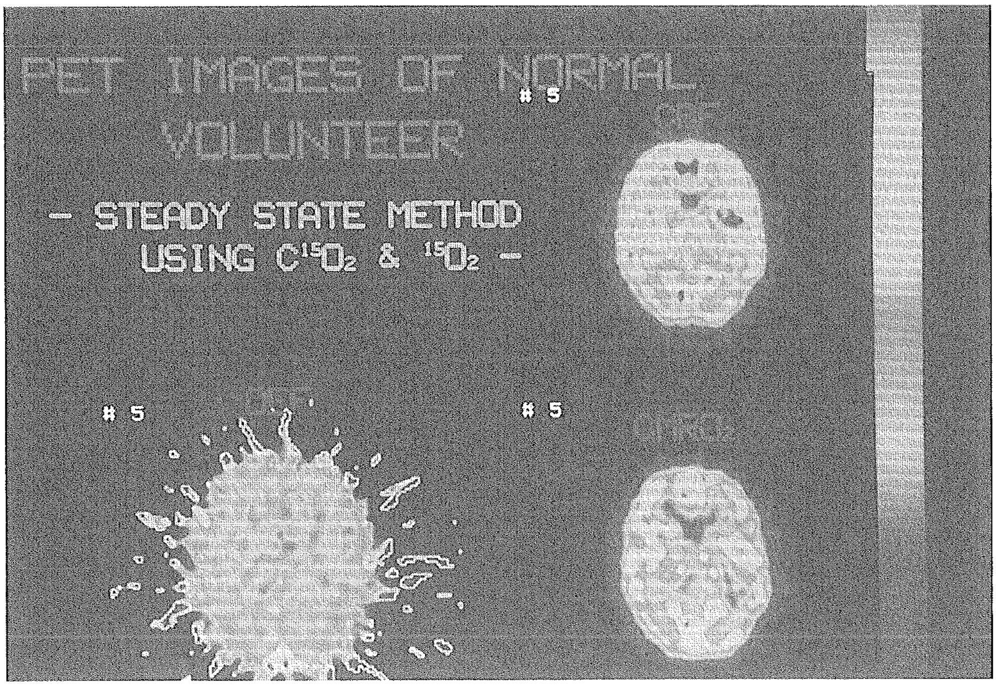

図 2　^{15}O－炭酸ガス吸入後の PET 局所脳血流量(rCBF)を示す機能図(functional image)(右上)と ^{15}O-酸素ガス吸入後の PET 局所酸素代謝率($rCMRO_2$)を示す機能図(右下)

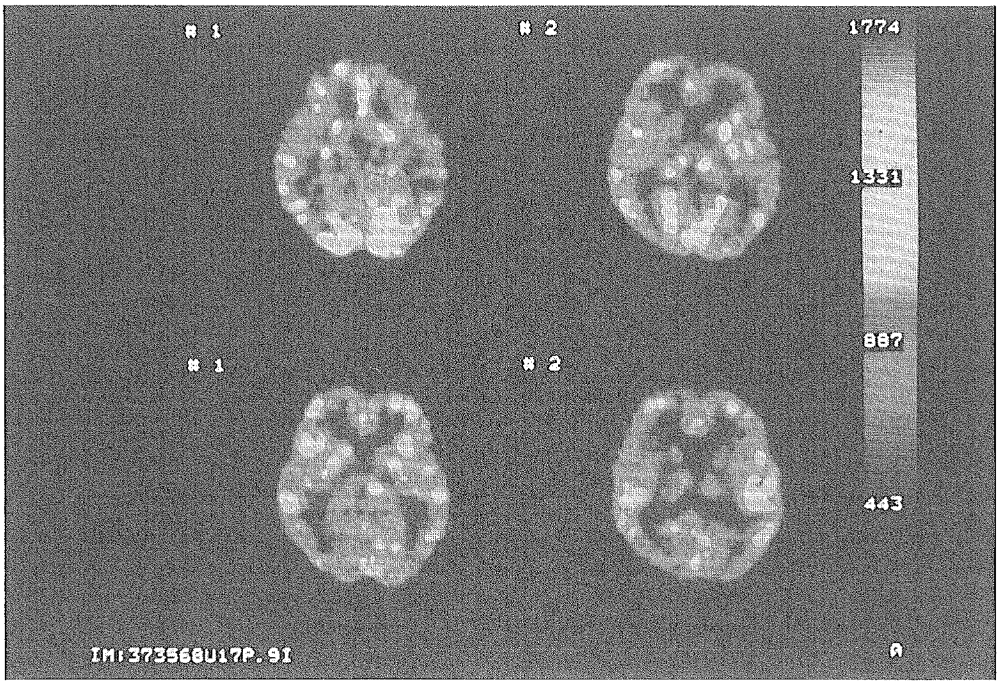

図 3　^{15}O 水 PET による脳賦活試験

上段：開眼，耳栓。後頭部の視覚中枢が活性化している（矢印）。

下段：閉眼、音楽を聴いている。側頭部の視覚中枢が活性化している（矢印）。

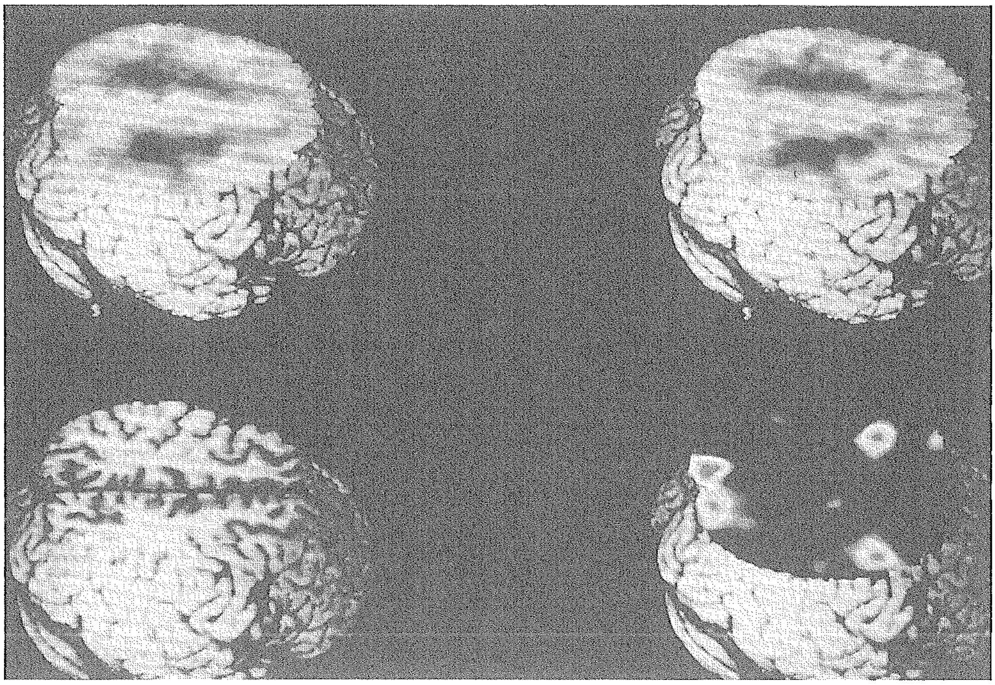

図 4　脳賦活試験中の ^{15}O 水 PET(右上)から安静時脳血流 PET(左上)を引き算したサブトラクションイメージ(右下)。後頭部視覚領野（矢印）と前頭眼野（矢頭）が活性化している。PET 画像は 3 次元 MRI(左下)に重ね合わせてある。

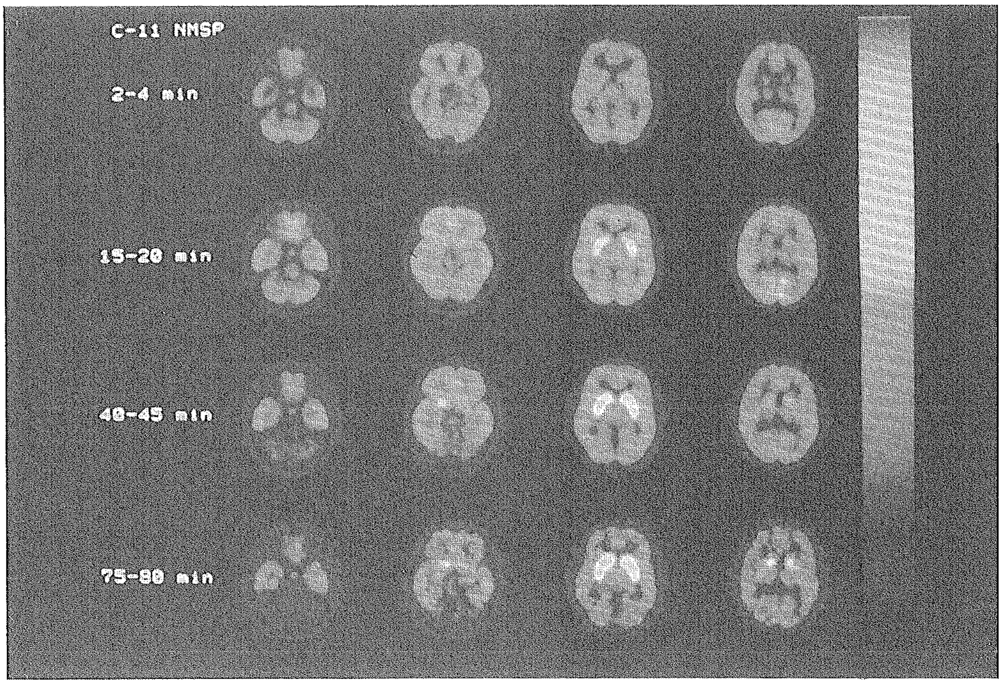

図５ ^{11}C-N-メチルスピペロンとPETを用いたドーパミンD2受容体画像、75分後に線状体の受容体部位が描出されている(矢印)。

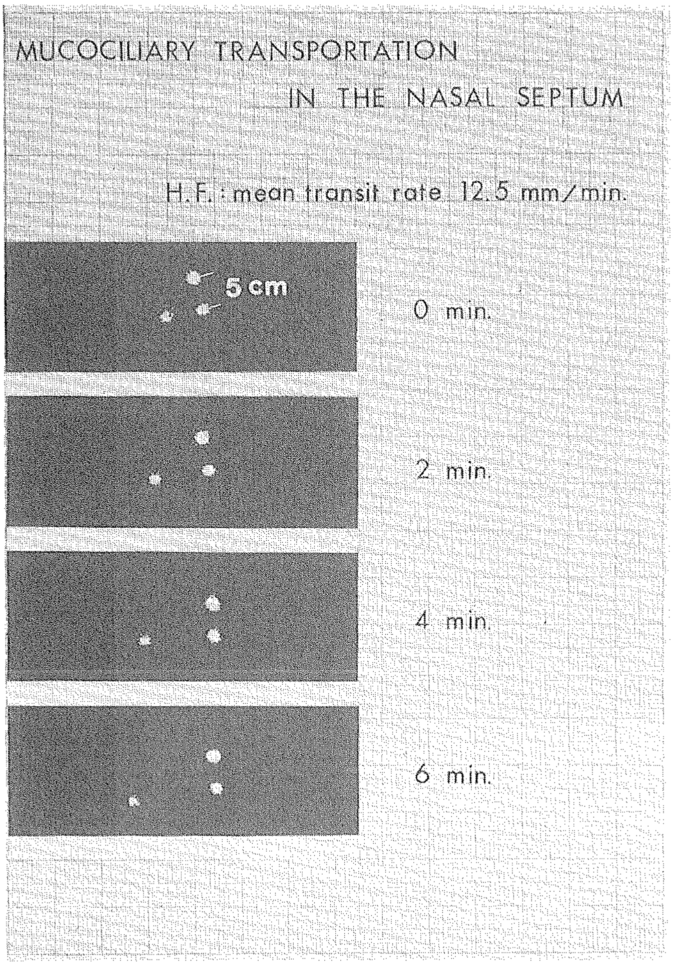

図６ シンチカメラによる
鼻粘膜線毛機能の測定

鼻中隔に置いた ^{99m}Tc-レジン（矢印）が時間経過と共に後方に移動し、食道内に排出される。

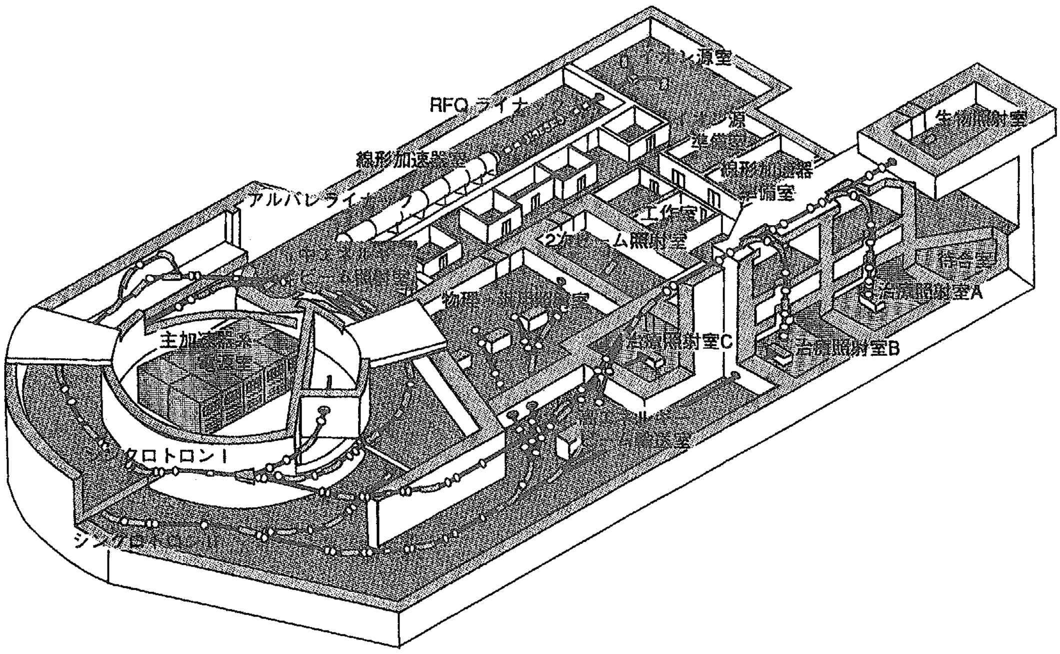

図 7　HIMAC(Heavy Ion Medical Accelerator in Chiba)の模式図

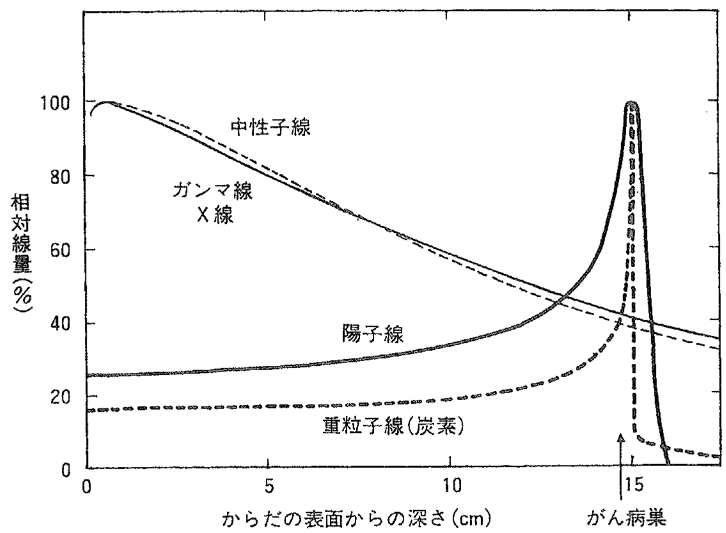

図 8　光子（X 線、ガンマ線）、中性子線、陽子線、重イオン（炭素）線の体内線量分布を示す模式図

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1.7 原子力科学技術の社会への貢献

CONTRIBUTION TO THE HUMAN SOCIETY FROM THE NUCLEAR SCIENCE AND TECHNOLOGY

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概要

人々は、日の光、空気、水、山の緑、海の碧等を自然の恵みと受け取る。それと同様に、原子力・放射線もまぎれもなく自然の恵みである。日の光は、太陽での核融合反応で生まれるものであり、地熱のかなりの割合は自然放射能によるものと考えられている。自然放射線が生物の進化に及ぼした影響は計り知れない。全体、この宇宙自体が核反応に由来するものと理解されている。しかし、核反応や放射線は目で見、耳で聞くことはできず、人間の感覚、感性で認識することができない。核反応や放射線の認識は知性による理解と測定器による検出が不可欠である。このことが原子力や放射線に対する違和感や恐怖心の原因となっている可能性がある。これに類することは他にもあり、バクテリアやウイルスなどもその例であろう。文明の近代化の過程を回顧するに、感覚や感性のみではなく、「知性と測定器」を用いて初めて認識し得るものを利用して、人間の生活を豊かにしてきたということが近代文明社会の最大の特徴の１つであろう。19世紀末に発見された放射線と放射能、その発見に触発されて急速に核物理学、そしてそれに基礎を置いて発展した原子力科学技術は20世紀の世界に大きな影響をもたらした。この特徴は、21世紀には人間の社会により広く、深く普及するであろう。原子力科学技術は既に、学術研究の分野において、エネルギー源として、また産業や医療の分野において、大きな役割を果たしている。さらに、21世紀に予想されるエネルギー・環境問題の解決に貢献できるように、原子力科学技術の多様な可能性を引き出す研究開発が行われている。一方、水や風にも災厄があるように、原子力にも災厄がある。最大のものは核兵器によってもたらされるものであり、原子力施設や放射線源も管理を謝ると災厄がもたらされる可能性がある。原子力科学技術の役割は、原子力や放射線のリスクを最小限に止めつつ、その恵みを最大限に発揮するための「知と技」を社会に供給することである。

Abstract

All of us living on this planet feel a hearty gratitude for our being endowed with natural blessings like sunshine, atmosphere, water, green of the mountains and blue of the ocean, etc. From the same point of view nuclear power and radiation are also precious blessings from the nature. To begin with, sunshine originates from the thermonuclear reactions in the sun, and a considerable portions of geothermal energy is assumed to be from natural radioactivity. The effects of natural radiation onto the evolution of life is considered as immeasurably great. The creation of this universe is, in the first place, thought to owe to certain nuclear reactions. The process of the nuclear reaction or radiation itself can not be perceived by human senses and feelings such as eyesight or hearing. In order to recognise them we must possess powers of understanding, or intelligence, as well as detectors of that specific purpose. However, this may have caused among people the feelings of alienation and fear. Some can be said for cases of bacteria, virus, electricity, and many others. There seems to be good grounds to say that the greatest characteristic of the modern civilization is that it has evolved, so far, the quality of human life adopting what man can recognise by means of "intelligence and detectors" combination, in addition to his senses and feelings. Typical

examples of this are radioactivity and radiation both of which were discovered in the end of the 19th century and, provoked by this, the nuclear physics achieved an immense progress in consequence. Based on these, the nuclear science and technology have been developed with a giant step and exerted their powerful influence on all over the world in this century. This characteristic is supposed to permeate into the human society of the 21st century more widely and deeply. The nuclear science and technology have become to play a significant role in science research, as an energy source and in industry and medicine. In the century to come, while greater possibility is expected for its exploitation, it must contribute to the solution of issues like energy shortage or global environmental problems. Still, we need to admit, just the same that even water or wind involves hazards, the nuclear energy has its own curses; the biggest of which, of course, is the nuclear weapon. Besides it there are several other possible hazards when a nuclear facility or a radiation source is wrongly operated. The real role of the nuclear science and technology shall be so defined that it will provide the society with "knowledge and ingenuity" so as to maximise its blessings to mankind while reducing the risks associated with the exploitation of the nuclear power and radiation to a minimum level.

1. 原子力の見方

原子力という言葉を人々が聞いた場合、エネルギー源として、要するに電力源としての原子力が頭に浮かぶか、あるいは現代社会の懸念として、事故、放射性廃棄物、あるいは核兵器の拡散等が頭に浮かぶであろう。しかし、原子力の研究開発に携わる筆者をはじめ、日本原子力研究所（原研）の研究者の多くは、核反応によるエネルギー、放射能・放射線等を総括する概念として原子力を捉えている。したがって、原子力をエネルギー源としてだけでなくて、あるいは核爆弾というようなものだけでなくて、もう少し多様な側面があるということを最初に強調することが大切であると考えている。表１に挙げたように、天の恵みとしての原子力、文明発展の成果としての原子力、総合的な学術研究の対象と手段としての原子力、エネルギー源としての原子力、放射線源としての原子力、そして、これらを含めて21世紀の問題への対応手段としての原子力など、原子力にはポジティブなイメージも多い。一方、これらの側面とともに当然ながら我々が考えなければいけないものとして、現代社会の懸念としての原子力というものがある。

表1　原子力の見方

（核反応によるエネルギー、放射能／放射線）

○ 天恵としての原子力
宇宙創世と進化、太陽光、地熱、生物進化

○ 文明発展の成果としての原子力
巨視的世界像と微視的世界像の統合

○ 学術研究の対象及び手段としての原子力
近代科学の開拓と新しい世界像への挑戦

○ エネルギー源としての原子力
核分裂エネルギー、核融合エネルギー

○ 21 世紀問題への対応手段としての原子力
資源（エネルギー）、環境、成長持続

○ 現代社会の懸念としての原子力
原子力大事故、放射性廃棄物、核兵器拡散

元々原子力というのは、宇宙の始まりとともに存在し、太陽の光や地熱は原子力に由来するものであり、人類を誕生させた生物の進化にも放射線の与えた影響は非常に大きいといわれている。まず、文明発展の成果としての原子力という点を考えてみよう。人類は古くからこの世界がどのように成り立っているのかを考え、既にギリシャ時代にはデモクリトスが原子という概念を持つに至った。このように考えると、これは理知的な世界像を形成するベースにもなっている。宇宙の成り立ちや進化についても原子力あるいは原子核の科学が答をだしている。例えば、人間の持っているミクロスコピィックな世界観、あるいはマクロスコピックな世界観、それを統合した総合的世界観の形成にこれらの科学的概念が寄与している。これは文明発展の成果の１つといえる。さらに、原子力・原子核には学術研究の対象としての側面があり、より深遠な潜在的可能性の開拓に向けて多様な研究開発が進められ、その成果の反映として、20世紀はそもそも原子力によって開かれてきたともいえる。

実用的には当然のことながら、先ずエネルギー源としては核分裂エネルギー、核融合エネルギーがあり、放射線は医療・農業・工業などの多くの分野で使われている。さらには、現在の重大な関心事となっている21世紀の資源の問題、環境保全の問題を解決するとともに、資源・エネルギー供給及び環境保全に適切な調和を保ちつつ、さらに成長を持続させようとする場合に、原子力は有力な手段になると考える。このためにも、原子力科学技術はその多様な可能性を発揮して、原子力に関するネガティブな側面、例えば事故、放射性廃棄物、核兵器の拡散といった懸念を解決するとともに、原子力の知的・技術的な貢献というポジティブな側面をさらに開拓することが重要と考える。

2.エネルギー源としての特徴

原子力のエネルギー源としての特徴は、エネルギーの発生密度が極めて高く、利用が可能な温度が非常に高く、かつ資源量が膨大であるということにある。これらの特徴は、関連する技術を発展させることにより、その可能性が引き出されてくる。普通のエネルギー源、例えば、化石燃料である石炭・石油は、エネルギーを取り出すプロセスの効率は時代とともに向上しているが、最も単純には、空気で燃やすことでエネルギーが得られる。一方、原子力の場合は技術を駆使してその可能性を引き出さなければならないというのが一つの特徴である。

資源量の大きさについていえば、核分裂や核融合にしても、必要な天然の資源（核分裂：ウラン、トリウム資源、核融合：トリチウム、リチウム、重水の資源）は殆ど無限に近いくらいあると言える。ウランに関しては、陸上の資源を上手に利用してプルトニウムまで効率的に燃焼させると、非常に長期間にわたって十分に使える。また海水中のウラン資源は陸上の資源に比べて桁外れに多く、陸上の利用可能と考えられているウラン量が300～400万トンであるのに対し、海水中には40～45億トンが存在すると見積もられている。リチウムや重水も同様である。このように原子力には優れた特徴があるが、石炭や石油の燃焼と異なり、これは日常的な感性では認識しにくいエネルギーであり、認識するためには測定器が不可欠であるという特徴がある。

3.社会的受容への課題

一般に、社会がある技術、あるいはある製品を受容する際には、それらの利用に伴うリス

クと利益の比較を定性的ではあるが判断基準として用いてきた。これは、ある技術を利用することによりそれに固有なリスクが生じ、また利用しないことによって利用した場合に比べて、ある不利益を受けるためである。人は一体どのくらいのリスクを社会的に許容しているのか。このことにいて、英国の国立放射線防護庁が調査を行い、概ね1年間に1万人に1人くらいが死亡するというリスクが受け入れられる限度であるとの結果を得ている。このリスクは、偶然ではあろうが、日本の交通事故の死亡リスクと概ね一致している。日本人はこのリスクを認識した上で車に乗っているかは分からないが、現在の交通事故による死亡リスクがさらに増加すると、大きな社会問題となろう。

一方、殆ど考慮に値しない些細なリスクとして、1年間当たり 100万人に1人以下の死亡リスク値が挙げられている。原子力をエネルギー源として利用することによるリスクは、これに比べてさらに1桁か2桁程度低いと見積もられているが、社会的受容という点では困難な状況にある。これは原子力のように感性での認識が困難な事柄に対しては、リスク・利益の比較による判断が世の中に浸透しにくいということを示唆している。このように、リスクの受容には心理的要因があり、米国科学アカデミーの研究結果の一例を表2に示す。

表2　リスクの認知と評価に影響する質的因子

要因	公衆の関心が高くなる条件	公衆の関心が低くなる条件
大災害の可能性	死傷が同時的、同一地域で起きる場合	死傷が時間的、場所的に散発している場合
周知度	なじみがない	なじみがある
理解度	理解不能なメカニズムやプロセス	理解できるメカニズムやプロセス
個人による制御の可能性	制御不能	制御可能
暴露への任意性	不本意	自発的
子供への影響	子供に特にリスクがある	子供へのリスクは特にない
影響発現	遅れて現れる影響	即時に現れる影響
後世代への影響	後世代へのリスク	後世代へのリスクはない
被害者の身元	被害者の身元は確認できる	統計上の被害者
恐怖	恐怖の大きい影響	恐怖の少ない影響
公共機関への信頼度	責任ある公共機関への信頼の欠如	責任ある公共機関への信頼
報道機関の注目度	報道機関の注目は高い	報道機関の注目は低い
事故歴	重大な事故、時に小さい事故	重大及び小さい事故がない
公平さ	リスクと便益の不公平な分布	リスクと便益の公平な分布
便益	明らかではない便益	明らかな便益
可逆性	影響は不可逆的	影響は可逆的
原因	人間の行為や過失による	自然現象や不可抗力による

注）比較対照するリスクの選択に当たり、上記の区別に留意することは有益である。これらの区別（例えば、自発的リスクと不本意なリスクの比較）を無視した比較は、適切な条件を付さなければ失敗する可能性がある。

出典：「リスクコミュニケーション」Covello et al 1988.

この表は、左欄に示す要因について公衆の関心が高くなる条件が重なると、公衆はリスクの原因となる事柄を受け入れにくくなるということを示している。例えば、大災害の可能性があるか、よく分かっているか、分かりやすいか、自分自身がそのことを制御できるか、子供に影響があるか、後の世代に影響があるか、被害者がどのような障害を受けるのか、何となく恐ろしいか、それから報道機関が注目しているか、等の要因がある。このようないくつかの要因について条件を比べると、リスクの認知という点で原子力は極めて不利であり、公衆が受け入れたくないという要因が多い。

4. 原子力の理解に向けての課題

原子力は一般の人が共感を持ちにくいという特性を内在している。今まで科学や技術は人間の夢を実現してきた。例えば人間が空を飛びたいという夢が飛行機になって実現し、速く走りたいとか速く動きたいという願望から馬や馬車が、さらに、オートバイ・自動車が生まれた。また、魚のように泳ぎたい、水の上や水の中を自由自在に行動したいという夢が船や潜水艦として実現した。これらの技術は、概ね人間の夢・想像力と結果とがある意味で直接的に結合しているといえる。しかし、原子力や放射線は、それらを認識するためには測定器の助けが必要であると既に述べたように、夢あるいは直感とかなり乖離している。原子力は知性を総合的に結合して実現したものであり、感覚的・直感的イメージを与え難いところがある。さらに、初期に原子力研究開発が推進されたのは、学術の部分は別としても、巨大なエネルギー利用の部分については、市民からの直接的な期待やニーズに必ずしも基づくものではなく、戦争の早期終結という国家の政治的目的に基づくものであった。このことが原子力に関する国民の共感のなさを作っている原因の一つとも考えられる。これらのことを認識した上で、原子力についての市民の感性との乖離を解消する努力が必要である。

近代文明社会においては、近代科学によって世界像が変革され、技術によって人間活動領域が拡大してきた。したがって、近代文明社会の恩恵を享受するためには、人々が物事を認知するとともに、認知したことへ適切に対応するためには、単に感性のみに依存するのでは不十分であり、知性と測定器による認知を基礎とした対応が求められる。この点では原子力や放射線はその典型的な事例であり、認知と対応において、いかに感性と知性の調和を達成するかは教育上の重要な問題であろう。

一方、21世紀の社会では、廃棄物の問題、地球温暖化の問題、核兵器の問題などが大きな懸念の例として挙げられている。これは、人間活動による正の価値の生産・利用に伴い負の価値が出てきていることを意味している。これまでの人間活動ではこの負の価値はコストの中に入れてこなかった。しかし、人間の活動がより活発になり、負の価値を内部経済化する必要が認識されつつある。負の価値、例えば廃棄物についていえば、発生量が天然の処理能力を充分下回っていた時代では大きな問題とはならなかったが、これが現在では成立しなくなりつつある。炭酸ガスの問題とか、その他の温暖化ガスの問題はまさにその例である。したがって、今後は負の価値を管理するという概念を人間活動の中に取り込んでいく必要がある。廃棄物の問題、地球温暖化の問題、核兵器拡散の防止の問題はいずれも全地球的課題であり、これらの懸念あるいは問題の解決に原子力科学技術を役立てていく努力を積み重ねることが、原子力の社会的な貢献の一つの重要なポイントである同時に、原子力への社会的共感の醸成に有益と考えている。

5. 日本原子力研究所の研究開発の方向

現代の社会的課題の解決に向けて、原子力科学技術を役立てようとする原研の挑戦を以下に紹介する。原研は、図1に示すように、

- 原子力をエネルギーとして利用するための研究開発
- 原子力の多様な特性を利用するための総合原子力科学研究

の2つの分野を中心に研究開発を実施している。これらの研究開発はそれぞれ独立しているものではなく、総合原子力科学研究の成果が原子力エネルギー研究開発の芽を提供し、また原子力エネルギー研究開発の成果が総合原子力科学研究にフィードバックされている。原子力エネルギー研究開発としては、21世紀を見越した先端的なエネルギーシステムの開発を通して、エネルギーの安定確保や環境保全に貢献することを目指している。一方、総合原子力科学研究では、原子力の立場から新産業の創成や国民生活の向上に役立つ科学技術の総合的な発展に貢献することを目指している。これらの研究開発を支えるため、原研は非常に多くの分野の研究者集団を擁するとともに、他の研究機関にはないような最先端の大型研究施設を整備・運用している。これらのポテンシャルを活用して協力研究や施設の共同利用を積極的に行い、原研はCOE、COFとしての役割を果たしていきたいと考えている。

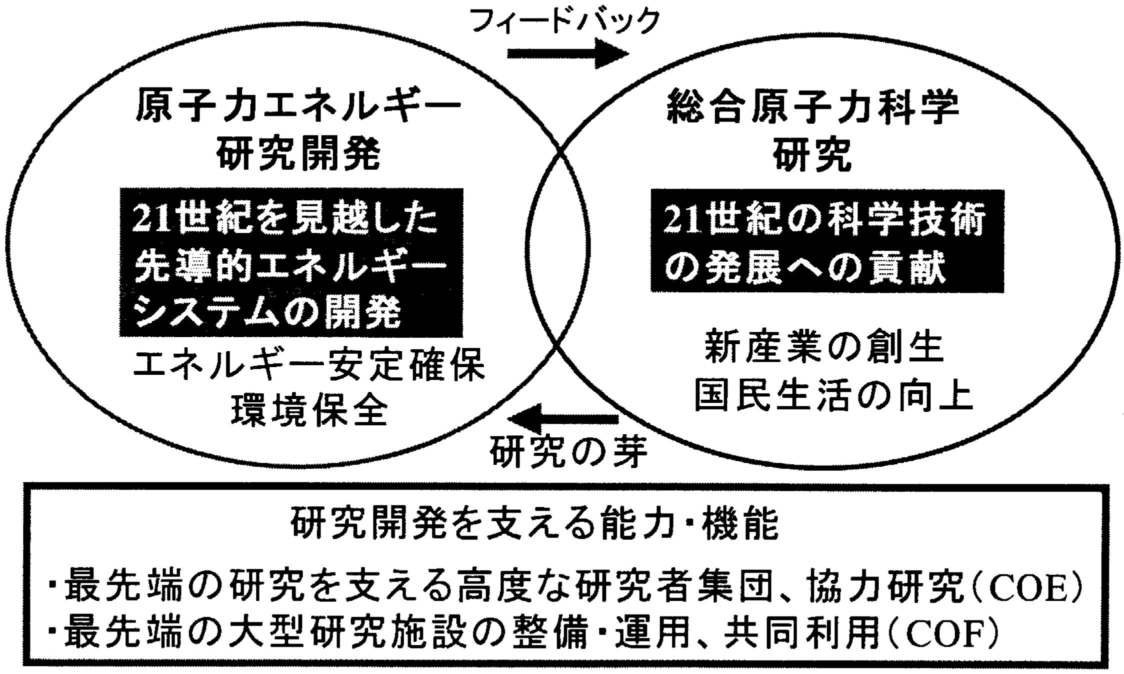


図1　原研の研究開発の方向

原子力エネルギーの研究開発については図2に示す課題に取り組んでいる。現在原子力発電の主役である軽水炉は、今のタイプで殆ど成熟した技術である。ただし、経済性やエネルギー源の有効利用という点からは改良すべき余地があり、原子炉の安定的長期的利用や発電効率を高める高度化技術開発、燃料経済性を向上するための高燃焼度技術開発、さらには資源有効利用やウランの転換効率を高めるような新型炉の研究開発を行っている。将来型のエネルギーシステムとしては、最近ようやく原子炉としてスタートした高温ガス炉を用いてエネルギーを軽水炉よりはるかに高い温度から、広い範囲にわたって利用するための技術開発

と、さらに究極のエネルギー源といわれている核融合の研究開発を行っている。その他に核分裂炉の利用を支えるものとして、燃料サイクルに関する新しい技術があり、廃棄物をなくすための技術である消滅処理、プルトニウムを効率よく燃やすための技術、さらに前に触れた海水からのウランの捕集などの研究開発を行っている。また、これらの研究開発を支えるものとして、技術やシステムのを安全にするための安全研究を行っている。

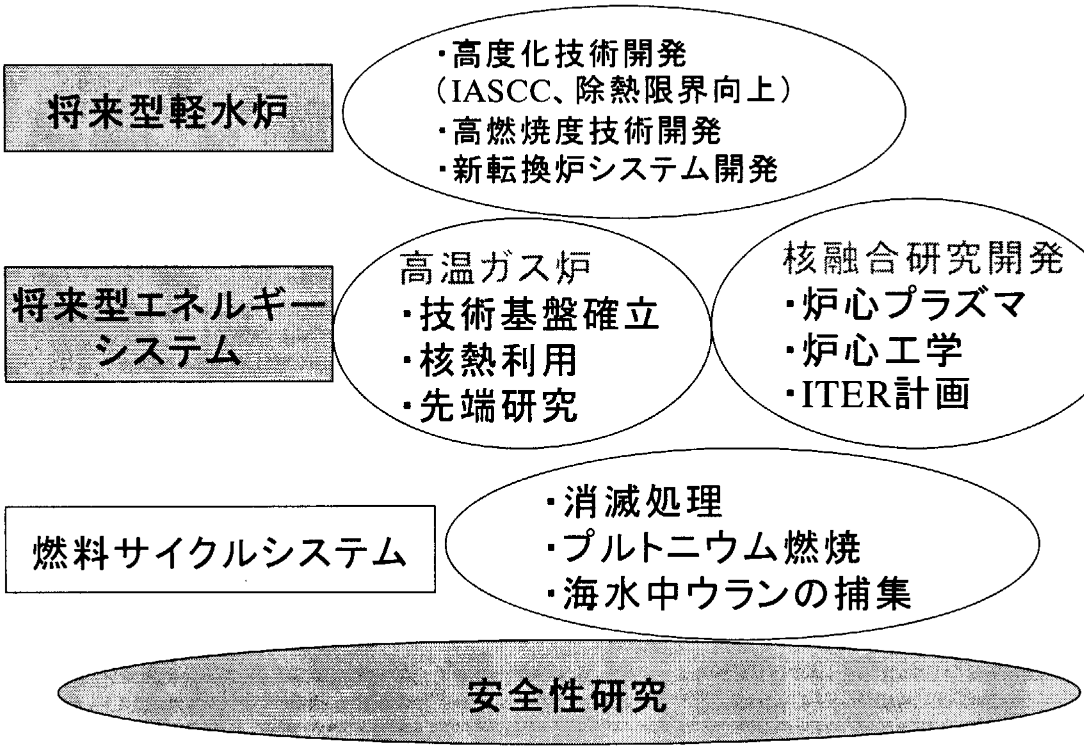


図2 原子力エネルギー研究開発

一方の総合原子力科学研究の分野では図３に示すように、ビームサイエンスが研究の柱の１つであり、観測手段あるいは加工手段として重要であるとともに原研の特徴を活かせるイオンビーム、中性子、光量子、放射光について、線源開発と利用研究を進めている。あらゆる近代的な科学技術においては、いかに短い時間（時間に関する分解能）、あるいは細かい所（空間に関する分解能）を観測できるか、それがどういう形で達成できるかということがキーポイントである。イオンビームは電荷した粒子、中性子は電荷のない粒子、光量子・放射光は電磁波というように観測手段・加工手段としてそれぞれ特徴があり、これらは極めて広い分野の科学技術にとっての観測の共通基盤であるので、これらの線源を原研の中で整備して使えるようにしてきている。さらに、それを支えるための先端基礎研究や計算科学を進め、それを基盤としての環境科学研究への踏み出しを始めた。この様な研究を通して、総合科学技術の発展に貢献すべきであると考えている。放射線は特に観測の道具であると同時に加工の手段でもあり、これを使って地球の環境保全、食糧問題の克服、あるいは医療・産業技術の創成、さらには以上の全体を含んでの知的資産の蓄積に貢献したいと考えている。

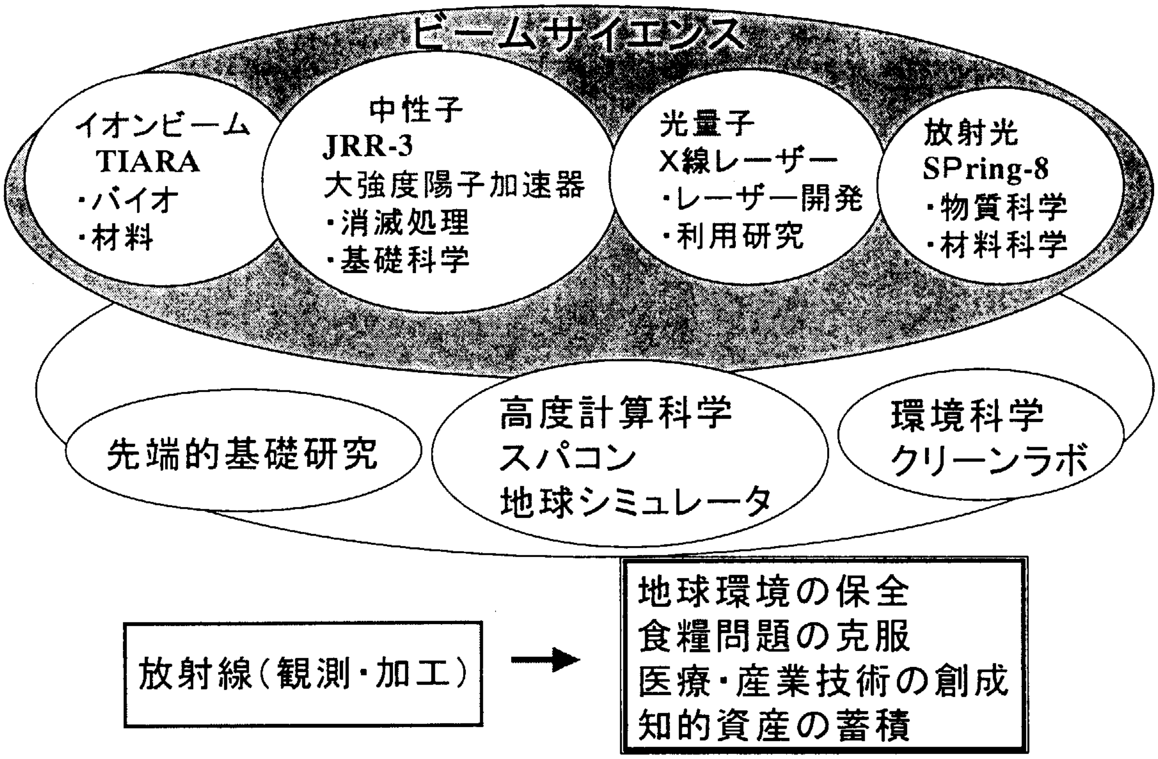


図3 総合的原子力科学研究

6. 研究開発のトッピクス

以上に述べた観点から原研で実施している研究開発のいくつかの例を以下に紹介する。原研では研究用原子炉から発生する中性子を使って種々の研究を行ってきたが、多量の中性子を利用する新たな研究を進めるため、中性子源開発を中心とした中性子科学研究の計画を立案した。

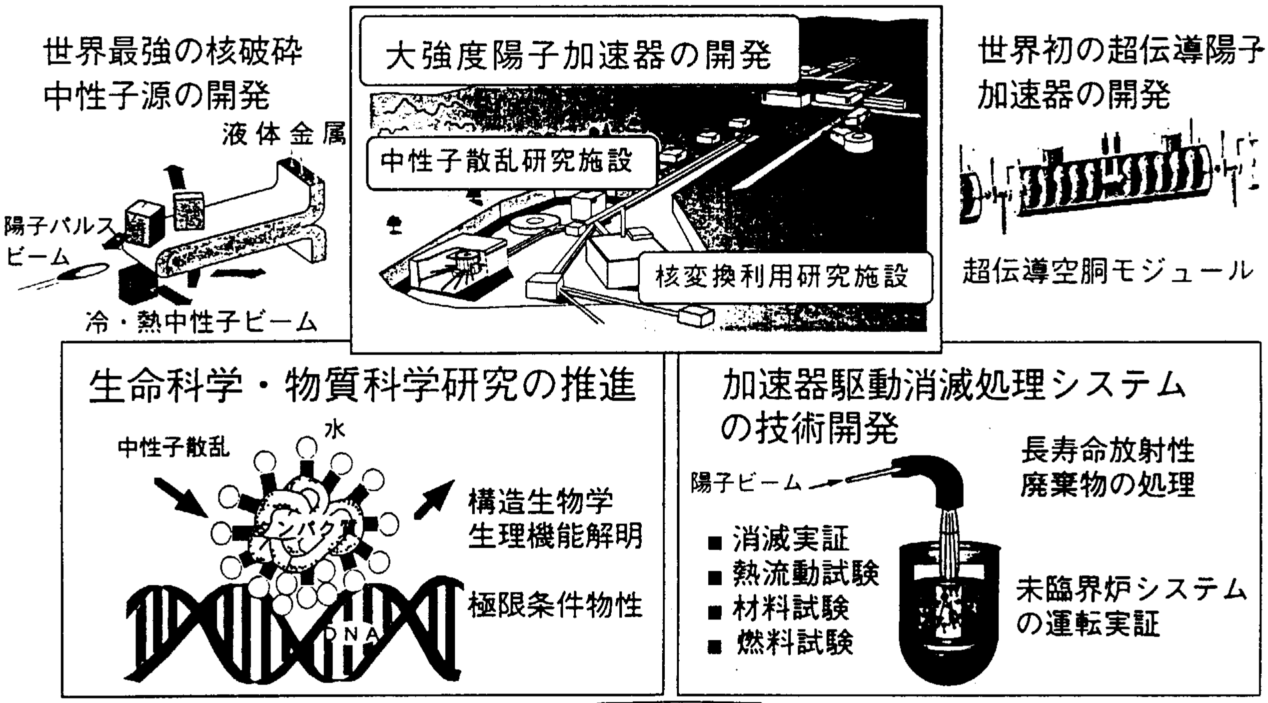


図4 中性子科学研究計画

加速器で陽子を加速して重金属のターゲットに当てると、ターゲットの原子核に破砕反応が起こり、中性子が発生する。原研では効率的に多量の中性子を発生させるために大強度超伝導陽子加速器と核破砕中性子源の開発を進めている。このような多量の中性子を利用して基礎的な研究、例えば生命科学や物質科学の研究の推進に役立てることができる。他方、現在大きな問題となっている高レベル廃棄物についても、特にそれに含まれる長寿命の放射性核種の処理（短寿命化）に利用することができる。廃棄物を処分するには大きく三つの考え方がある。すなわち、

- 廃棄物が世の中にリスクをもたらさないくらい薄くしてしまう、
- 廃棄物を特定の場所に閉じ込めてそれが外へ出ないようにする、
- 廃棄物中の有害成分を消滅する、

というオプションである。薄めるというオプションは今の世の中では恐らく採用しえないと考えられるので、閉じ込めるか無くしてしまうかのいずれかのオプションが残る。閉じこめや消滅といった処理技術について、今後開発される技術のコストがどの程度となるか、技術として成熟するかどうかということは、今後の研究開発によるが、原研では廃棄物問題の根元である有害成分を消滅するというオプションの研究を進めたいと考えている。

消滅処理の概念を図５示す。陽子をターゲットに照射すると多量の中性子が発生し、これを高レベル廃棄物に照射すると、廃棄物中の長寿命成分（例えば、アメリシウム、ネプツニウムなど）に核分裂が起こり短寿命成分に変換することができる。このような消滅処理を行うことにより、そのまま高レベル廃棄物を処分するより 500年程度の時間帯でみると、放射能の影響が100分の１ないし 200分の１に少なくなる。しかも高レベル廃棄物をそのまま処分すると、放射能が数万年以上も残るものがあるが、消滅処理を施すことにより数百年で環境への影響が殆どなくなるという利点がある。

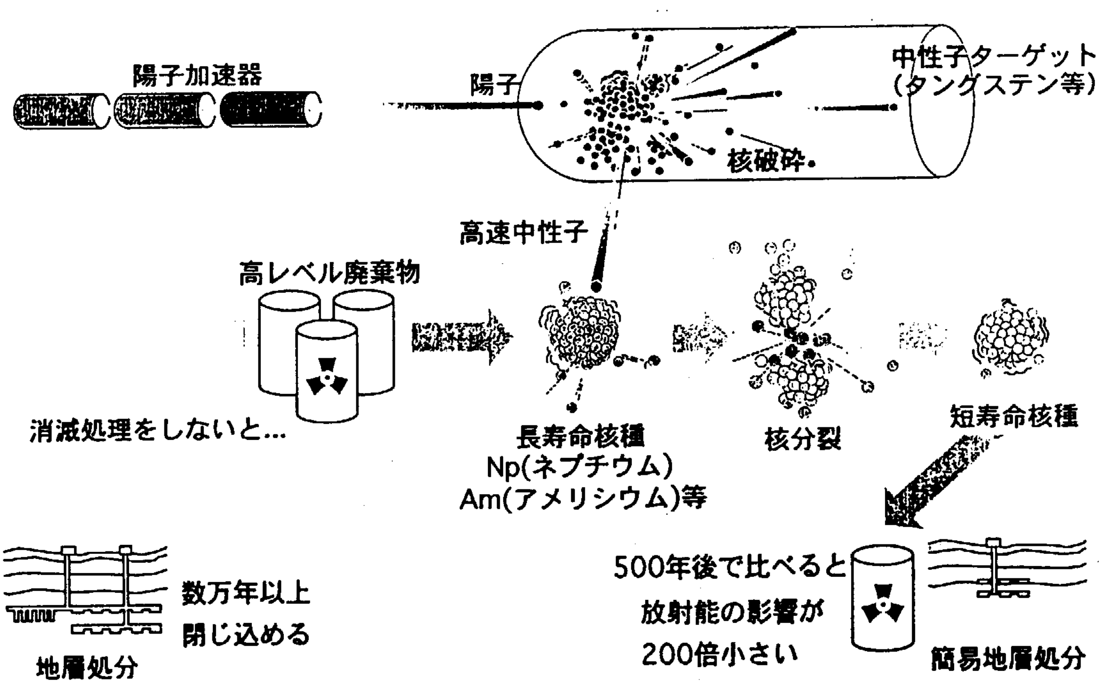


図５　消滅処理の概念

次に放射線の利用研究について紹介する。原研における放射線利用研究は以前はγ線及び電子線が中心であったが、現在ではイオンビームの利用研究が活発に行われている。イオンビームのエネルギーもMeV（ミリオンエレクトロンボルト）からGeV（ギガエレクトロンボルト）領域に移りつつあり、広範囲なエネルギー領域の放射線利用が可能となってきた。以下に放射線利用の例を示す。

生活に役立つ放射線利用の例

○高分子機能材料
　－橋掛け重合：耐熱・難燃材料、改良天然ゴムラテックス
　　　　　　　　ハイドロゲル創傷被覆材
　－グラフト重合：電池用隔膜、空気清浄フィルター
　　　　　　　　海水中有用金属捕集材
○無機機能材料：半導体素子
○環境保全・資源利用技術
　－環境保全：排煙処理、汚泥処理
　－資源利用：オイルパーム廃棄物の飼料化
○照射：医療器具の滅菌、食品照射（海外で実用化）
○バイオ技術：品種改良、育種
○医療：診断、ガン治療

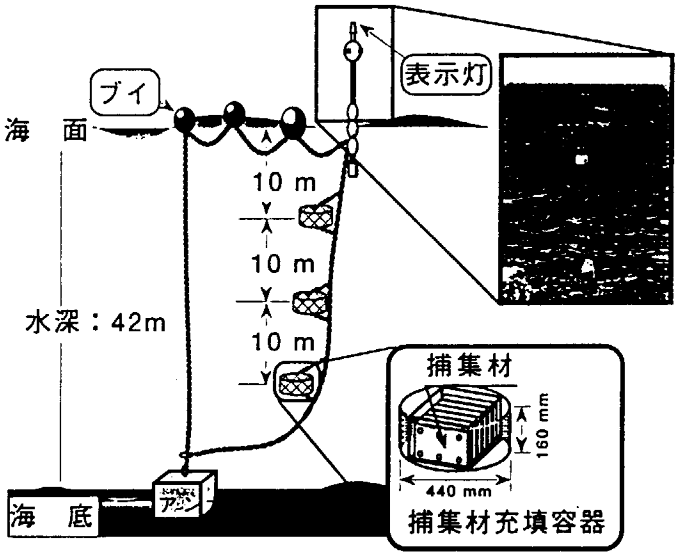
高分子の機能材料については、放射線を利用した橋かけ重合（直鎖状の高分子の間に橋を架けて安定な高分子材料を製造するプロセス）を用いて、耐熱性、難燃性の材料の合成、天然ゴムラテックスの改良、ハイドロゲル状の絆創膏材料の合成などの技術を開発してきた。放射線を利用したグラフト重合（ある種の高分子に異なる高分子等を結合させるプロセスで、接ぎ木の概念に類似している）を用いて、電池用の隔膜、空気清浄用のフィルター、海水中金属イオンの捕集材等の合成技術を開発してきた。電池用の隔膜を例にすると、広く使われているボタン型電池の隔膜は殆どが放射線重合で作られた材料で作られている。さらに、将来の宇宙利用に役立つと考えられる放射線に強い半導体の開発、環境保全・資源利用技術の分野では排煙処理、汚泥処理、オイルパーム（ヤシ油の搾り滓）の飼料化などにも取り組んでいる。この他、バイオ技術、医療などのかなり広い分野で放射線が利用されてきている。以下に、原研で開発した技術の数例を示す。

図6に海水中ウランの捕集材の開発の現状を示す。捕集材はポリエチレンにアミドキシム基（ウランなどの金属を吸着する機能有する）を放射線の重合反応で接合したものである。この捕集材を容器（タコを取ったり帆立貝を養殖したりするカゴと似たもの）に入れて海水中に浸すと、捕集材にはウランをはじめバナジウム等の貴重な金属が吸着される。

環境保全を目的に開発した発電所用の排煙処理プロセスの概要を図7に示す。発電所の排煙を冷却後、アンモニアを付加して放射線（電子線）を照射すると、放射線化学反応が起こり窒素酸化物（NOX）や硫黄酸化物（SOX）が排煙から除去され、硫安とか硝安の肥料に変化する。このプロセスでは、SOXが94％、がとれ、NOXが80％除去されるという実績をあげた。このプロセスは国内外で実用化に向けた試験が実施され、中部電力の名古屋火力発電所ではこの技術が実証されている。

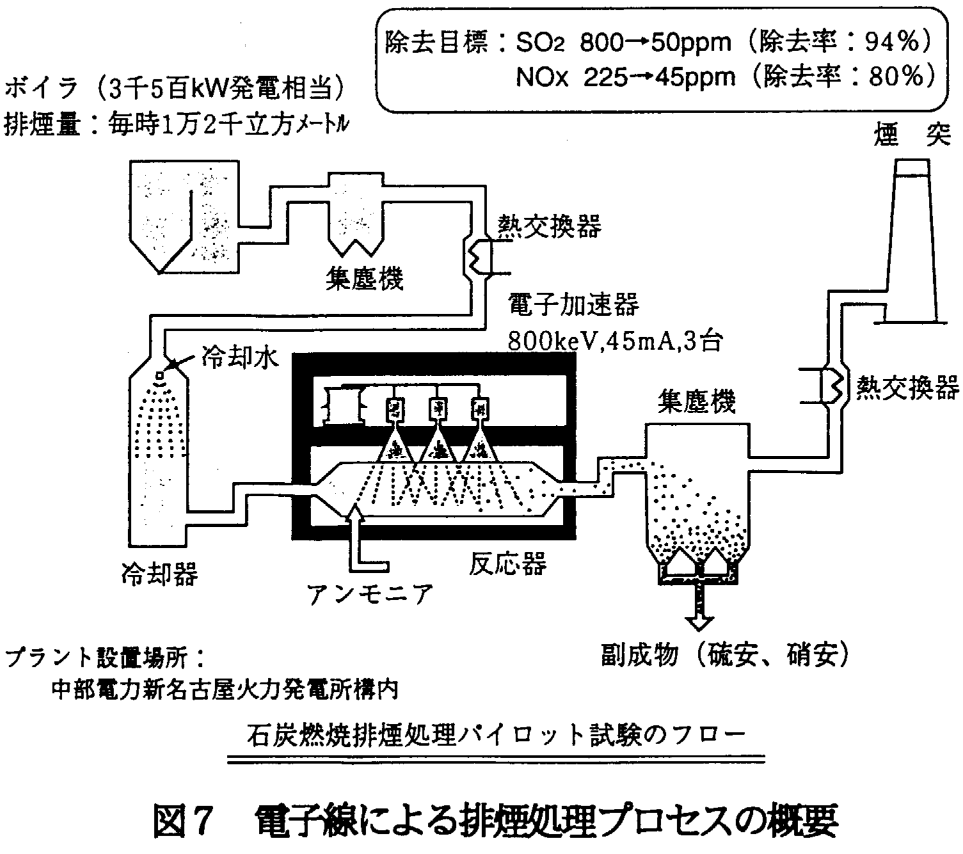
放射線グラフト重合法を用いて合成した捕集材を用いて、海水中に極微量溶解しているウラン、バナジウムなどの希少金属を選択捕集するシステムを開発

- 従来技術の１０倍以上に捕集性能を向上
- アミドキシム基をつけたポリエチレンの不織布（捕集材）
- 海流や波力で海水を動かす（ポンプ不要）



実海域予備試験装置

図6　海水中ウラン捕集材の開発の現状



石炭燃焼排煙処理パイロット試験のフロー

図7　電子線による排煙処理プロセスの概要

最後に、環境科学に対して原子力の高度な技術を役立てていこうとする取り組みを紹介する（図8）。原子力の分野では種々の研究目的から、非常に詳細・微細に分析する技術や高度な計算を行う技術が開発・利用されている。原研ではこれらの技術を基礎にしながら、大気中・地中・海洋中の極微量な物質を測定すると同時に、これを計算機の技術とも合わせて、環境中で物質がどのように移動しているかを追跡し、地球環境における物質循環の機構を解明する研究を開始している。これは地球環境保全に直結する今後の重要なテーマであり、原子力科学技術が貢献できる重要な分野と考えている。

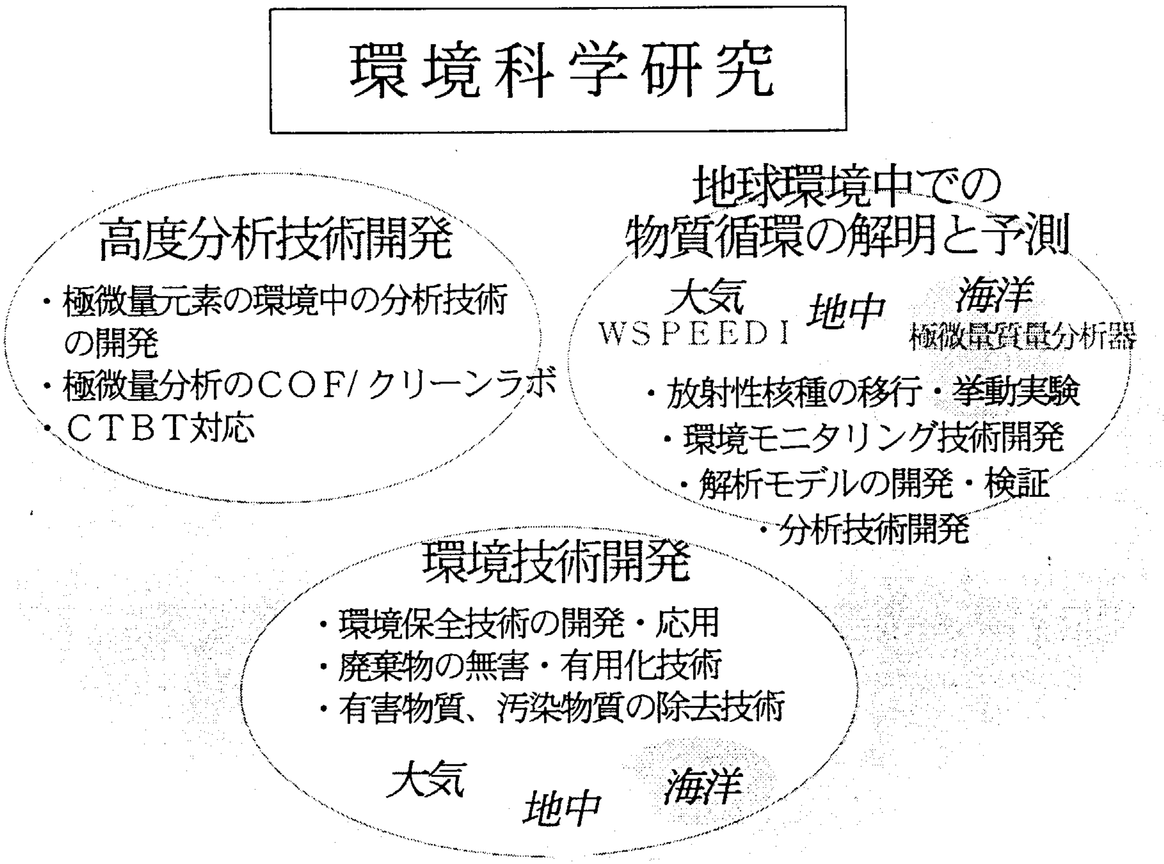


図8　環境科学研究計画

今までに原研の研究開発の例をいくつか示してきたように、原子力科学技術は見方によっては非常に広いものであり、生活の中に既に取り込まれているものも多い。しかし、明確な社会的受容のためには克服すべきいくつかの問題がある。原子力科学技術者は、それらを乗り越えて、21世紀の社会のために最善の努力をすべきであると考えている。

1.8 GLOBAL WARMING AND NUCLEAR POWER

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ABSTRACT

The concentration of carbon dioxide in the atmosphere is steadily increasing and it is widely believed that this will lead to global warming that will have serious consequences for life on earth. The Intergovernmental Panel on Climate Change has estimated that the temperature of the earth will increase by between 1 and 3.5 degrees in the next century. This will melt some of the Antarctic ice cap, raise the sea level and flood many low-lying countries, and also produce unpredictable changes in the earth's climate. The possible ways of reducing carbon dioxide emission are discussed. It is essential to reduce the burning of fossil fuels, but then how are we to obtain the energy we need? We can try to reduce energy use, but we will still need to generate large amounts energy. Some possible ways of doing this are by using wind and solar generators, by hydroelectric and tidal plants, and also by nuclear power. These possibilities will be critically examined.

1.INTRODUCTION

In December 1997 a large international Conference took place in Kyoto on the subject of global warming and the means to combat it. This follows the Rio Earth Summit in 1992 when Governments of the more developed countries were urged to reduce emissions of greenhouse gases such as carbon dioxide to 1990 levels by the year 2000. It is often expensive or politically unpopular to do this, and many Governments have shown a marked disinclination to take effective action. At the Kyoto meeting Governments reviewed the situation and agreed on targets to reduce carbon dioxide emissions to avert an impending global catastrophe. These agreements have still to be ratified, and even if they are ratified, there remains to problem of how to achieve these reductions.

It has long been known that due to extensive burning of the fossil fuels wood, coal, and oil the concentration of carbon dioxide in the atmosphere is steadily increasing. This gas acts like the glass in a greenhouse: it lets the sun's rays through but blocks the secondary radiation. As a result, the earth warms up, the Antarctic ice cap melts and the level of the sea rises, inundating coastal regions. While many of us would welcome a warmer climate, there may be other unpredictable climate changes.

There are other gases that contribute to the greenhouse effect, in particular methane, nitrous oxide and the chlorofluorocarbons (CFS). The last two of these are far more damaging per molecule than carbon dioxide. The concentrations of these gases are increasing annually by 0.4% for carbon dioxide, 1.2% for methane, 0.3% for nitrous oxide and 6% for CFS.

There has been much argument about the reality of global warming, and the weight of scientific opinion, as given in the Report of the Intergovernmental Panel on Climate Change, is that the earth will warm by 1 to 3.5 degrees Centigrade in the next century, causing a rise in sea level of about 50 cm. These arguments will not be discussed here; instead, attention will be concentrated on what we can do about it. Anyone unconvinced by the arguments can consider the other products of burning fossil fuels which include sulphur dioxide, nitrous oxide and whole range of noxious substances. These fall as acid rain and pollute the lakes and forests so heavily that the fishes and the trees die. They pollute the air we breathe, increase respiratory diseases and shorten our lives.

Apart from these immediate consequences, a rise in the global temperature may produce far-reaching changes in the earth's climate. We may already be seeing some of these effects in the warmer weather in some countries and the floods and droughts in others. On the longer term, a rise in sea level will practically eliminate many low-lying countries such as Bangladesh and many islands in the Pacific and Indian oceans, and severely reduce the areas of many others, including Holland and England, with devastating consequences for the people living there. We have a serious moral obligation to tackle these questions before it is too late.

2.POLLUTION

Coal power stations are particularly polluting, and a typical one will emit each year eleven million tons of carbon dioxide, a million tons of ash, five hundred thousand tons of gypsum, sixteen thousand tons of sulphur dioxide, twenty-nine thousand tons of nitrous oxide, twenty-one thousand tons of sludge, a thousand tons of dust and smaller amounts of a whole range of other chemicals such as calcium, potassium, titanium and arsenic. To produce one gigawatt-year of electricity about 3.5 million tons of coal are burnt, and this contains about 5.25 tons of uranium. Most of this is caught by the filters, but a few thousand tons of ash will escape carrying with it a corresponding fraction of the uranium. This accounts for the radioactivity emitted by coal power stations. All the gaseous waste is poured forth into the air we breathe, and inevitably damages our health.

This problem is so serious that it must be studied objectively, by assessing as far as we can the consequences of various proposed solutions. There is no place for emotion or rhetoric, prejudice or politics.

3. WAYS TO REDUCE CARBON DIOXIDE EMISSIONS

It is essential to reduce the burning of fossil fuels. The only practicable ways are to increase the price or to replace them by some cleaner source. Just raising the price is a counsel of despair that bears most heavily on the poor. Unless some system of differential tariffs is devised, they will no longer be able to heat their homes or cook their food.

It is far better to find another solution. One possibility is to use energy more efficiently. We could moderate our lifestyle by adjusting our thermostats, avoiding unnecessary journeys, walking instead of driving, and using public transport wherever possible. We can insulate our homes, lag pipes and install double glazing. Industrial processes can be re-designed to improve the efficiency of energy use. Any resulting reduction in price can have the unwanted effect of increasing energy use. In spite of all efforts to reduce energy use in these ways, it still continues to rise rapidly. Any attempt to limit it further would seriously damage living standards, particularly those of the poorer people.

Thus increased efficiency is valuable, but the net effect is limited, and so we have to see if there is another energy source that is non-polluting. The renewable energy sources are particularly attractive, as apart from the emissions due to manufacture they are completely non-polluting. Hydroelectric power has long been a major energy source, but in most developed countries has already been exploited to the maximum possible extent. There are just not enough suitable rivers; while it is excellent for Norway and Switzerland, it is useless for Denmark and Bangladesh.

The next most promising renewable source is the wind. In the last few years wind turbines have increased in efficiency and the costs have come down. The amount of energy in the winds is enormous, but it is so thinly spread that many hundreds of wind turbines are needed to equal the output of a coal power station. Wind speeds vary erratically, and the turbines operate over a limited range: if the wind speed is small the power output is small and if it is very large the blades have to be feathered to avoid damage. The result is that wind power is unreliable and somewhat more expensive than other sources. The present contribution of wind power to Britain's energy needs is 0.16%, and it will be a long time before it makes a significant contribution.

The other renewable energy sources, solar, tidal, wave and geothermal are all either of limited capacity, or too expensive to provide useful amounts of power. This is shown by the recently published plans of the European Union to spend £110 billion to double the contribution of renewables to 12% by 2010. Nearly all of this (96%) is hydropower and the burning of wood and farm wastes. In 1995 the contribution of wind power was 4 TWh (terawatt hours),0.2% of the EU total, and by 2010 it is proposed that this be increased to 80 TWh, or 2.8% of the total. Solar power is to be increased to 0.35%, and geothermal to 0.2% of the total. Overall, it is proposed to spend £43 billion on wind, solar and geothermal to obtain an extra 82.5 TWh, just 3% of the EU total. It is difficult to avoid the conclusion that a totally disproportionate expenditure is being proposed for a very meagre return.

4. NUCLEAR POWER

There is another energy source, the nucleus of the atom. For the same investment it would be possible to build a hundred nuclear power stations that would reliably generate at least a thousand TWh. This is a well-tried technology that already generates about 20% of the world's electricity, and this can easily be increased. France is already about 80% nuclear and as a result has the cheapest electricity in Western Europe, and is able to export it to Britain, Switzerland and Italy. Western Europe as a whole is about 50%. nuclear. In 1988, for example, 1866 billion kilowatt hours of electricity was generated by nuclear power stations. The same amount would be produced by burning 900 million tons of coal or 600 million tons of oil. Thus the emission of 3000 million tons of carbon dioxide is saved by using nuclear instead of coal or oil. As countries go nuclear, so their rate of carbon dioxide emissions fall. Since 1970, France has halved its emissions, Japan (32% nuclear) has achieved a reduction of 20%, while the USA (20% nuclear) has reduced it by only 6%. The emission of noxious gases like sulphur dioxide is also dramatically reduced by going nuclear.

The British Government has set a target of a 10% cut in the period from 1990 to 2010. By 1995, a reduction of 6% had been achieved, and this is due to the increase in nuclear output by 39% from 1990 to 1994. However, if no more nuclear power stations are built, this is set to rise steeply in subsequent years as the older nuclear power stations retire, and the Government will find it impossible to reach its target. Many new gas power stations are now being built, and these emit only half the amount of carbon dioxide as coal power stations. However this is offset by the leakage of methane, which has a global warming potential about sixty times that of carbon dioxide. These two effects are about the same, and so if this is true then no reduction in global warming is to be expected from the switch to gas power stations. Even if this effect is neglected, then if gas increases to 43.5% while coal declines to 2.5% we can expect a 10% reduction is carbon dioxide emissions, while if nuclear rises to 43.5% at the expense of coal there will be a reduction by 20%. Some recent estimates of the emission of carbon dioxide (in tonnes per gigawatt hour) from various power sources are: coal 870, oil 750, gas 500, nuclear 8, wind 7 and hydro 4.

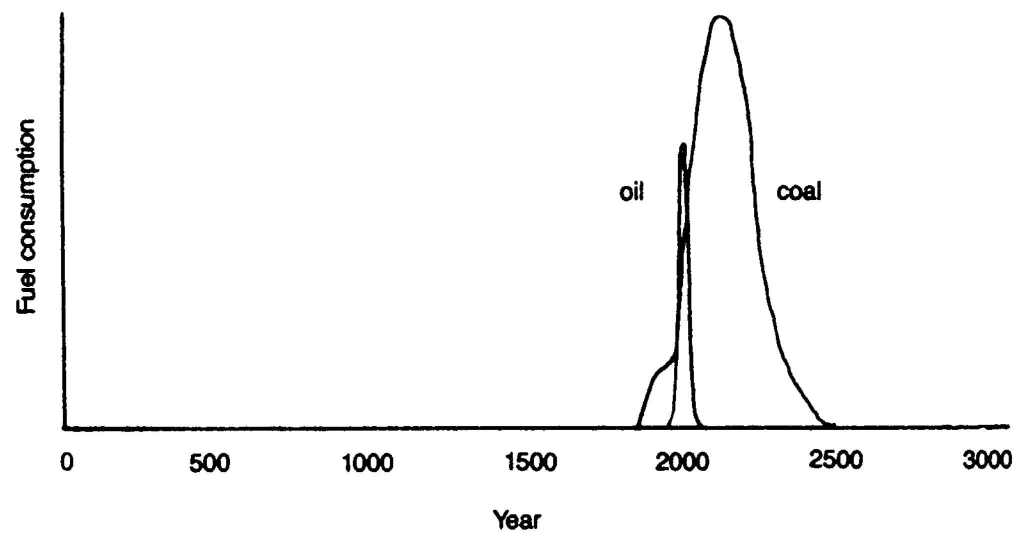
The importance of nuclear power in reducing carbon dioxide emissions has been admitted by a recent report of the parliamentary Select Committee on Trade and Industry which says that "without a significant component of nuclear power generation the plant mix achievement - or maintenance - of the Government commitment to a 20% carbon dioxide reduction on the 1990 level in the period after 2010 appears doubtful". If no more nuclear power stations are built in the UK, there will be only three in operation by 2015.

It is thus difficult to see how global warming can be averted without more nuclear power stations. Statistical analyses show that they are demonstrably safer than other energy sources. Surprisingly to many people, they emit less radioactivity than coal power stations, and the costs of decommissioning are relatively small. The problem of waste disposal has been solved: the radioactive fission fragments can be sealed in insoluble ceramic, put in stainless steel containers and buried deep in a stable geological formation. Long before any radioactivity can escape, it will have decayed naturally to a level similar to that in the surrounding rocks. The onus of demonstrating a better way to combat global warming lies on the opponents of nuclear power.

In order to stabilise the emission of carbon dioxide by the middle of the next century we need to replace 2000 fossil fuel power stations in the next forty years, equivalent to a rate of about one per week. Can we find 500 sq.km. each week to install 4000 windmills? Or perhaps we could cover 10 sq.km. of desert each week with solar panels and keep them always clean. Tidal power can produce large amounts of energy, but can we find a new Severn estuary and build a barrage costing £9 billion every five weeks? The same sort of question could be asked about nuclear power. The answer is that in the peak period of nuclear reactor construction in the 1980's the average rate of construction was 23 per year, with a peak of 43 in 1983. A construction rate of one per week is thus quite practicable. It is a well-tried and reliable source whereas the alternatives are mainly wishful thinking.

5. THE LONG-TERM OUTLOOK

We may also reflect that if we do not solve the problem now, then it will soon be solved for us. We are living in a very special period in human history when oil, gas and coal are readily available. At present rates of consumption oil production will peak in the first half of the next century and will thereafter fall rapidly, as shown in the Figure. The world average duration of oil supplies is about 45 years, and of gas about sixty years. The world average duration of coal reserves is about two hundred years. After this time, fossil fuel burning



The expected duration of fossil fuels, AD 0-3000.

Oil and natural gas will last only for a moment in man's history.

(Sir George Porter, President of the Royal Society. From "Is Science Necessary?" by Max Perutz, Oxford University Press, 1991).

will cease and alternatives will have to be found. The only practicable large-scale energy source will then be nuclear power and so inevitably it will have to be developed on a large scale. If we continue to burn the fossil fuels we not only pollute our earth and bring on global warming, we also deprive future generations of these valuable materials, the bases of the petrochemical industries. Would it not be better to solve these problems now by further developing nuclear power, instead of waiting until it is too late?

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1.9 低線量影響研究最近の話題

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1. はじめに

放射線防護基準は、1925年最初に論議された当時、耐容線量tolerance doseという考えを元に設定された。耐容線量とはそれを超える被曝がなければ目に見える障害は発生しない、つまり、しきい値線量があるという概念であった。ところが、第二次世界大戦後、大気圏内核実験の多発によるヒトの遺伝的影響への危惧から、許容線量permisible doseという考えに基づく防護基準へと変化した。このしきい値を認めない概念は、1927年のMullerによるショウジョウバエを用いたエックス線人工突然変異実験により、科学的根拠を得て、現在放射線防護の規範として広く受け入れられている。すなわち、実際のデータのない低線量域の障害を、高線量域での線量効果関係を直線でしきい値なしとして外挿して推測する、直線しきい値なし仮説Linear Non-Threshold Hypothesis---LNT仮説が放射線防護の規範となっている。

しかし、最近このLNT仮説の普遍妥当性に対して疑問が出始めている。いわゆる放射線ホルミシスの実験データが広く見られるようになったからである。本稿ではこのようなデータを中心に最近の低線量影響研究の話題を紹介する。

2. ホルミシスとは

生物系では、通常、用量-反応関係が直線でないのは例外と言うより、普通に見られる。高用量域の反応からは予期できない逆の反応も見られることもある。ホルミシス現象と呼ばれる。放射線は高線量域では確かに生物に障害を与える。直線仮説によればどんな低線量でも、それなりの障害を生物に与えることになるが、この予測に反し、しばしば免疫系を刺激したり細胞増殖を促進したりすることがある。つまり、生物に「益になる」作用をもたらす場合がある。狭い意味でこれを放射線ホルミシスと呼んでいた。

現在、放射線ホルミシス研究は、

1. 適応応答
2. 低線量放射線による生物活性刺激効果
3. 直線仮説からは予測できない低線量での効果
4. LNT(Linear Non-Threshold)仮説の否定？

の4つの観点から研究されている。

2は本来のホルミシスという語の意味する現象であり、Luckeyの2つの著書以来多数紹介されている。3とも関連することだが、数cGyというこれまでほとんど生物影響の研究のなされていなかった低線量域で、高線量域の結果の直線外挿からは、全く予測もできなかった、きわめて興味ある生物作用が発見されつつある。

これらは、個々の現象の面白さもさることながら、生物が放射線をどのように受け止めているかという生物の持つ基本的応答の面からも興味深い知見も多い。いまやこれらの知見は、直線(LNT)仮説がその前提としている、DNA分子を直接標的とするヒット理論のみでは説明できず、機能的統一体としての細胞さらには個体が示す応答制御の機構やゲノム安定性の維持機構など複雑な生体制御の問題として捉えなければならないことを示唆している。

しかし、LNT仮説が、ヒット理論を基礎としてその基盤となる機構もっていることに対

して、現在、4の立場の最大の弱点はホルミシス現象を説明できる機構についての確固たる考えがないことである。ただ、個々の一例報告的事例の羅列だけでは、何の説得力もない。筆者は、細胞あるいは動物個体の低線量放射線への反応が、単にDNAの損傷の機械的帰結ではなく、低線量を細胞全体、あるいは個体全体は細胞全体・動物個体全体として捉え、そこから、複雑な制御を経てある種の応答を示すのではないか？と考えている。このような、仮説を証明し、単純なLNT仮説に基づかない現象を見いだしていくことが、これからのホルミシス研究の課題と考えている。

2.1. 適応応答

生物はある環境(刺激)因子に暴露される以前に同じあるいは同類の刺激に少し曝されるとその因子に対する抵抗性が生じる。これを適応応答adaptive responseといい、放射線を含め広く認められている。1980年代、アメリカのWolffが細胞の放射線障害の一つである姉妹染色分体交換の頻度が、数cGyという低線量の前照射により有意に減少することを報告したのが最初で、その他の細胞障害のみならず、マウス個体の骨髄死を指標した場合にも明確に認められる。すなわち、cGyオーダーの低線量の前照射により、6-7 Gyという骨髄死を引き起こす放射線に対する抵抗性が誘導される。その一部は骨髄幹細胞の低線量放射線による刺激として説明されているが、その機構の多くは不明である。現在は数多くの追試実験によっても確認され、国連科学委員会の報告書でも放射線適応応答は確かな現象として引用されている。

2.1.1. 動物個体レベルの適応応答

放射線に限らずDNAを傷つける物理的あるいは化学的因子に曝されると、哺乳類細胞は一般に“ストレス応答”と総称される、一連の一過性の反応を示す。同種の因子による致死作用に対する抵抗性の誘導、DNA複製の上昇、細胞の成長や増殖に関係する遺伝子の発現の上昇、また、細胞内シグナル伝達系関連のタンパク質の合成上昇などがその典型である。このうち、最初に挙げた例が放射線では特によく知られており、“低線量放射線の適応応答”と通称されている。したがって、放射線ホルミシスはストレス応答のひとつである、といえる。

動物個体レベルでの適応応答は、低線量前照射より、引き続く致死線量照射に対する抵抗性の誘導現象として活発に研究されている。マウスの場合conditioning doseと称される低線量前照射の線量は通常5-50cGyが用いられる。この線量に応じて適切な間隔をおいてchallenging doseと呼ばれる致死線量を照射すると、低線量前照射を受けた実験動物群は、受けなかった対照群に比較して明瞭に生存率が高いことが観察される。すなわち、低線量の前照射により致死線量放射線に対する抵抗性が誘導されるのである。

この実験で大変興味あることは、前照射の線量に依存して、抵抗性の誘導される時期が全く異なることである。前照射線量が5-15 cGyの時には、その2ヶ月後に行われた致死線量照射に対してのみ抵抗性が誘導される。これに対し、30-50 cGyというより高線量の前照射の場合には、その2週間後の致死線量照射に対してのみ有効である。すなわち、前照射の線量が比較的低い場合と、高いときとでは、明らかに放射線抵抗性誘導の機構が異なると推定される。

より高線量域前照射(50 cGy)の場合、骨髄における造血幹細胞の増殖が前照射により刺激促進され、2週間後の骨髄死誘発線量に対する抵抗性が誘導される。しかしながら、低線量(5-15 cGy)前照射の場合の抵抗性誘導機構は全く不明である。大阪府立大学先端研の米沢先生たちは、この場合、前照射として全身照射が必須で、頭部のみの照射でも胴部のみ照射でも有効でないというデータを示している。すなわち、単に造血系への照射効果だ

けではなく、中枢神経系あるいは何らかの全身機能の関与が、この抵抗性誘導には必要らしい。なにしろ、2ヶ月後にやっと抵抗性が誘導されるのであるから、単に免疫系のみの関与とは考えられず、より複雑で、いくつもの系を介する結果であるに違いない。

このような実験事実は、これまでの放射線生物学の範囲では、なかなか発見できなかった。低線量の特異的効果を求めて行われた実験の一つの成果である。

2.1.2. 細胞レベルの放射線適応応答

京大放射線生物センターの佐々木らは、マウスm5S細胞を用い、低線量放射線に対する反応を検討するために、先ず細胞に2cGyのＸ線を照射し、続いて3GyのX線を照射した。そして3Gy照射によるＸ線の影響が2cGyの前照射によってどのように修飾されるかということで反応特性を解析した。2cGyの前照射は後照射による染色体異常を出来に難くする。すなわち細胞は適応応答を示す。2cGyの前照射と3Gyの後照射の間の時間間隔を変えた実験から適応応答はすでに照射後l時間で有意に認められた。

2cGyのX線前照射をしたのち5時間後にいろいろな線量で照射し、照射した組胞を再び培養することによって染色体異常、細胞の生存卒、6-thioguanine耐性突然変異、フォーカスアッセイによるトランスフオーメーションを調べた。低線量前照射によって組胞は染色体異常の誘発、致死効果、突然変異の誘発に対して耐性となるがトランスフオーメーションに対してはむしろ感受性となる。

ここで面白いことはこの適応応答を誘発する線量は、2-10cGy付近の特定の線量域であることである。佐々木らは、cGyオーダーで適応応答を起こすことは、γ線が細胞に与える素線量(荷電粒子1個が細胞を通過した場合に細胞に与えるエネルギー)が0.2cGyであることから考えて、DNA損傷が引き金になっているとは考えがにくいとしている。細胞全体あるいは細胞膜が標的となっている可能性がきわめて高いと考えてる。

また、細胞内シグナル伝達系の中心であるPKC(プロテインキナーゼC)の阻害剤を用いるとこの適応応答が見られなくなることから、この放射線適応応答の発現に細胞内シグナル伝達系か必須であることを示している。これらの結果は、低線量域の放射線に対して細胞が、全体として、決してDNAを標的としてではなく、細胞全体が統一した系として応答するすることを明らかに示している。

2.2. 生物活性の低線量放射線による刺激

古典的なホルミシスの定義を生んだ現象である。1970年代フランスのPlanelが鉛シールド箱の中でゾウリムシを培養し、自然放射線がない条件ではゾウリムシの成長が抑制されることから、自然放射線がこの生物の成長に必須であることを主張したのが最初である。アメリカのLuckeyはこのような無脊椎動物や植物における低線量放射線の活性刺激の例を庞大な数を集め上記の「放射線ホルミシス」として1980年代の初頭刊行した。

2.3. 直線仮説からは予測できない低線量での効果

低線量放射線の実験のさなかに偶然見つかった面白い現象がここに紹介する中枢神経系への作用である。雄マウスを同一ケージに長期間飼育しているときに、しばしば問題となるのは、マウス同士の喧嘩である。多くは尻尾の付け根の尻部分を噛み付かれ出血する。ひどい場合には死に至る。低線量照射したマウスでは、この傷が少ないことに偶然気付いた。私たちのグループの宮地さんは、そこで、大変独創的な実験を計画し、低線量放射線の特異的抗ストレス作用を発見した。

雄マウスを一匹飼い状態で長くおくと(resident)、いわゆるストレス状態となり、攻撃性が増大する。ここに、別なマウスを侵入させると(intruder)、侵入マウスに対して激しい攻

撃をおこす。これを、resident-intruder testといい、社会的隔離によるストレスのモデル動物実験系として用いられている。宮地さんはこの系を用いてマウスのストレス誘発攻撃性に対する低線量照射の影響を定量的に測定した。すなわち、侵入マウスを入れてから直ちにマウスの反応をビデオカメラに一定時間記録し、噛み付く回数と最初の攻撃までの経過時間を測定して攻撃性を定量化して解析したのである。その結果、このマウスの攻撃性が、5-15 cGyという低線量放射線によって7-10日後明瞭に抑制されることがわかった。この攻撃性の抑制は、隔離ストレスによって誘導された攻撃性にのみ発揮される。一匹飼いでなくグループ飼いの雄マウスでは、この効果が見られないからである。つまり、低線量放射線はストレスによってマウスに見られる効果を軽減する作用があるということになる。

さらに、興味あることは、この放射線効果が、25-35 cGyに線量を上げたときには、見られないことである。すなわち、より低線量域の5 -15 cGyの線量域にのみに特異的にみられるのである。直線仮説に従えば、放射線の生物作用の線量-効果関係は、単純な比例関係とみなされており、線量が低いほど、その効果は小さくなるとされている。ところが、この場合、高線量域の方が効果がないのである。逆にいえば高線量域の作用からは全く推定できない効果が、より低線量域で見られるのである。

放射線ホルミシス論者の一人のSaganは、高線量の作用からは予測できない低線量域独特放射線作用を、放射線ホルミシスの定義の一つに上げているが、この定義に従うとすれば、上記の低線量の作用は放射線ホルミシスの一つといえる。

哺乳類の性行動の中枢は攻撃行動の中枢と同じ部位にあるとされている。そこで、上記実験のintruderに発情雌マウスを用いることによって、性行動に対する低線量放射線照射の効果を解析できる。結果は予測した通り、攻撃行動に対する上記の効果と全く同じであった。すなわち、低線量域にのみ性行動の抑制がみられ、より高線量域では、この効果は見られなかった。

さて、このような動物の行動に対する低線量放射線の効果はこれまで全く報告されておらず、新しい発見である。放射線生物学の面からも、動物行動学の面からも大変面白い発見であるが、当然次に問題になるのは、その機構である。放射線がどこに効いているのだろうか？

これまでは、全身照射であったから、放射線生物学の解析の常道として部分照射によって関与する器官組織を調べた。予想の通り、頭部照射のみで全く同様な効果があることがわかり、中枢神経系の関与が明確となった。そこで、中枢神経系への効果をより明確にするために、マウス頭部に電極を埋め込み、脳波を直接調べることにした。睡眠波を示している睡眠中のマウスに、4 cGyという低線量X線を照射すると、直後に覚醒を意味する波形に変化することがわかった。マウスはなんと4 cGyという低線量放射線を“感ずる”ことができるのである！

この4 cGy照射を繰り返し行うと、しだいに覚醒波を示すマウスの数が減少してくることもわかった。すなわち、マウスは4 cGyを感ずることができるだけではなく、一般の刺激に対してと同様、反復されると次第に感じなくなるのである。言い換えれば、適応反応をも示すのである。

さらに、同じ実験を、嗅球を手術で除去したマウスに行うと、上記の脳波の変化は全くなくなることがわかった。嗅球がないと、マウスはX線を感じないのである。このことから、中枢神経系のなかでも、嗅球系がX線の“感知”に働いていると考えた。嗅球に働く神経伝達物質である一酸化窒素(NO)の阻害剤を注射すると、反復照射に対する適応が消失することがわかった。これも嗅覚系の関与を示す一つの証拠である。

部分照射の実験をさらに細かくして、頭部を嗅球を含む前部と、含まない後部を別々に照射する実験を行うと、攻撃行動も性行動も嗅球を含む前頭部に照射したときのみ、抑制

がみられることがわかった。いよいよ嗅覚系の関与は確かである。
　これまで、放射線抵抗性であるとして、ほとんど省みられなかった神経系が、以上のような新しい視点にたつと、きわめて放射線感受性であることが明らかになってきた。これらの実験は、単に放射線ホルミシスの分野に止まらず、神経生理学と放射線生物学を結ぶ全く新しい分野を開拓するものであると、私たちは確信している。

2.4. LNT(Linear Non-Threshold)仮説の否定？

　広島・長崎の原爆被爆生存者における発がんのデータがLNT仮説を裏付けるヒトのデータとしてしばしば引用されている。しかしながらこのデータでも実際に問題となる低線量域でのデータはなく0点に向かって外挿した直線を用いているのが現状である。さらに、大きな問題は原爆被爆という瞬間大線量被曝のデータであるという事である。すなわち、線量率が極めて大きな被曝のデータであり、私たちが日常実際に問題になるのはこれとは異なり、低線量率、低線量被曝である。一般にとくに低LET放射線では、低線量率被曝では大線量率被曝の場合に比較して、生物影響が大きく低減する。
　最近、マウスを用いた実験で線量率を低下させていくと、ある線量率以下では発がんがみられなくなるデータが得られ始めている。すなわち、マウスの放射線発がんでは線量率にしきい値が存在する場合が実際にあるのである。がんセンターの田の岡先生らは、β線によるマウスの皮膚がんで(図1)、広島の山本修先生らはトリチウムによる胸腺腫で(図2)この事実を見事に示した。

3. おわりに

　1997年11月17日より21日まで、南スペインのセビリアでIAEAの主催により、“Low doses of ionizing radiation: biological effects and regulatory control”と題するシンポジウムが開催された。これは、上記のような放射線ホルミシスのデータが報告されるにつけ、ICRPなどいわばLNT派と放射線ホルミシス研究者が一堂に集まって会議をしよう、ということであったので、筆者も参加させて頂いた。ところが実際はホルミシス研究のデータはほとんどポスター発表であるのに対し、LNT仮説を支持する話はlectureして、十分な時間が与えられており、全体としての印象は、ホルミシスの動物実験のデータはいくらあったとしても、ヒト(広島・長崎の原爆被爆生存者)のデータは、このとおりLNT仮説を支持しており、現在のICRPの立場は揺るぎもしない！ということを強調する会議といってもいいものであった。
　確かに、現在のホルミシス研究は、未だ未熟であり、実証データとそれを説明する理論のない、単なる主張は、宗教であると非難されてもしかたがない。このような主張のみの発表がなかったとは言えないことは残念である。
　繰り返しとなるが、いまや上記のホルミシス研究の知見は、直線仮説がその前提としている、DNA分子を直接標的とするヒット理論のみでは説明できず、機能的統一体としての細胞さらには個体が示す応答制御の機構やゲノム安定性の維持機構など複雑な生体制御の問題として捉えなければならないことを示唆している。
　私たちは、このような新しい観点にたって、すべての放射線の生物影響研究を見直したいと考えている。もちろんまだ、未熟な分野であり、これからなすべきことは山積しているが、いつの日か放射線防護の基準にこれらの研究成果が反映できる日がくることを夢見ている。

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Threshold dose response of mouse tumor induction by β irradiation *(Tanooka)*

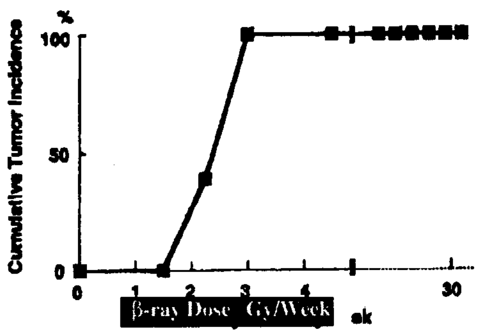

図1

Dose rate dependency of mouse thymic lymphomas induced by ^{3}H *(Yamamoto, O)*

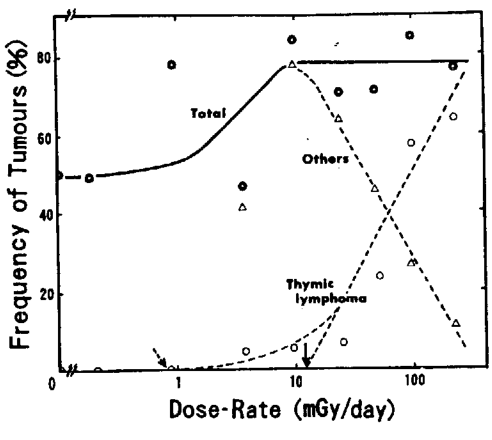

図2

1.10 MORTALITY OF ATOMIC BOMB SURVIVORS IN NAGASAKI

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ABSTRACT

We analyzed the risk in 2,743 atomic bomb survivors by using a new dosimetry system. From the database, we selected 2,743 exposed persons and a total of three times 2,743 age-matched controls who were living far from the center of the A-bomb radiation in Nagasaki at the time of the explosion and who were still alive in 1971. The mortalities from all causes for male subjects exposed were slightly lower than, or almost equal to, those of unexposed persons. Death from cancer, however, increased in both sexes after all levels of irradiation except in males exposed to 0.01-0.49 Gy. In males, the risk was showed significant reduction in death from all diseases other than cancer classified according to 0.31-0.40 Gy.

1. INTRODUCTION

In 1945, two atomic bombs were dropped on Hiroshima and Nagasaki for the first time in human history. Since 1945, many studies [1,2,3] have been performed on the effects of the atomic bombing, for example, the physical damage, estimation of radiation dose and medical studies of the effects of the atomic bomb survivors and so on.

In 1972, the Scientific Data Center for the Atomic Bomb Disaster (renamed as the Division of Scientific Data Registry, Atomic Bomb Disease Institute in 1997) was founded in Nagasaki University to analyze the radiation effects on atomic bomb survivors. Information about A-bomb survivors are generated in many organizations. We have collected information from the City Office, Health Management center and other organizations. We have constructed an A-bomb survivor's Database in 1968[4], and we have collected medical data of survivors into the database there after.

2. METHODOLOGY

Atomic bomb survivors are the persons who have been issued the Atomic Bomb Health Handbook from Nagasaki City Government. There were 83,050 persons registered as atomic bomb survivors living in Nagasaki as of 1968. The Health Management Center of Nagasaki City offers a free health examination to atomic bomb survivors twice a year. Since 1968, data of about two and half million health examination items have been stored in a database of a computer in Atomic Bomb Disease Instutute in Nagasaki University.

We analyzed the risk in 2,743 atomic bomb survivors by using a new dosimetry system. From the database, we selected 2,743 exposed persons and a total of three times 2,743 age-matched controls who were living far from the center of the A-bomb radiation in Nagasaki at the time of the explosion and who were still alive in 1971. Number of subjects show in Table 1.

3. CONCLUSION

In our first analysis, we did was to compare the death rate between A-bomb survivors and controls. The figure 1 shows the mortality from all causes. The abscissa is age, and the ordinate is the death rate per one hundred thousand persons. The solid lines are for atomic bomb survivors, the dotted lines are for the control group. The circular symbols are for males, the triangular symbols are for females. Above sixty years old , the mortality of the exposed group is actually lower than that of the control group. Strangely, this result was unexpected. We think that this was due to early detection of disease and the advice about health care in the periodical health examination. A-bomb survivors have two free health exams per year.

The figure 2 shows the risk of cancer. We have analyzed the risk of atomic bomb survivors. The number of exposed group with radiation dose above 0.006 Gy were two thousand seven hundred and forty three persons. The number of zero dose group are eight thousand two hundred twenty nine persons. The abcissa is radiation dose, and the ordinate is the risk. Unity of the risk means the mortality rate of unexposed people. The risk of cancer increased with increasing dose for both sexes.

The figure 3 shows the risk of non-cancerous diseases. The risk of non-cancerous diseases did not increased with exposed radiation dose for male and female. However, in males exposed to 0.31 to 0.40 Gy, the risk was lower than unity.

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Table 1. Number of subjects

Radiation Dose(Gy)	Male	Female	Total
0	3,159	5,070	8,229
0.006-0.30	540	922	1,462
0.31-0.40	111	139	250
0.41-0.50	69	126	195
0.51-1.00	126	214	340
1.01-5.99	207	289	496
Total	4,212	6,760	10,972

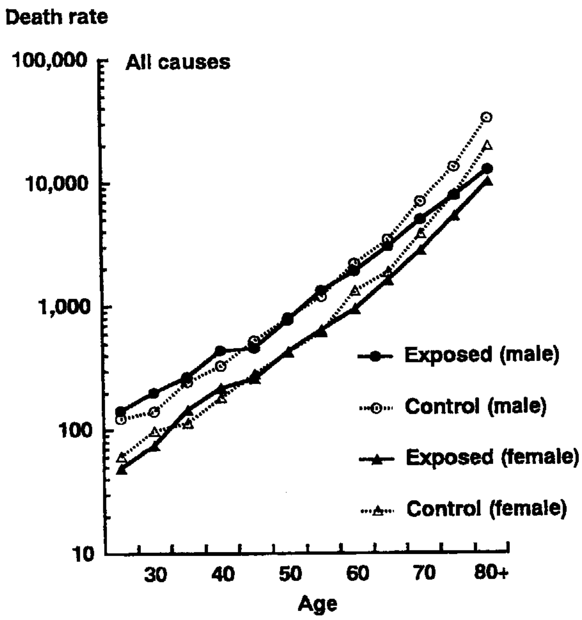

Fig. 1 Compare the mortality of exposed and control

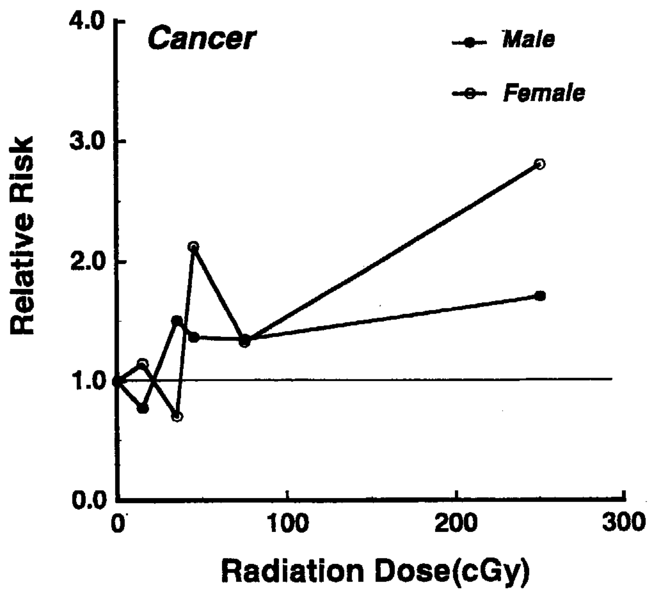

Fig.2 Relative Risk by radiation dose and sex (Cancer)

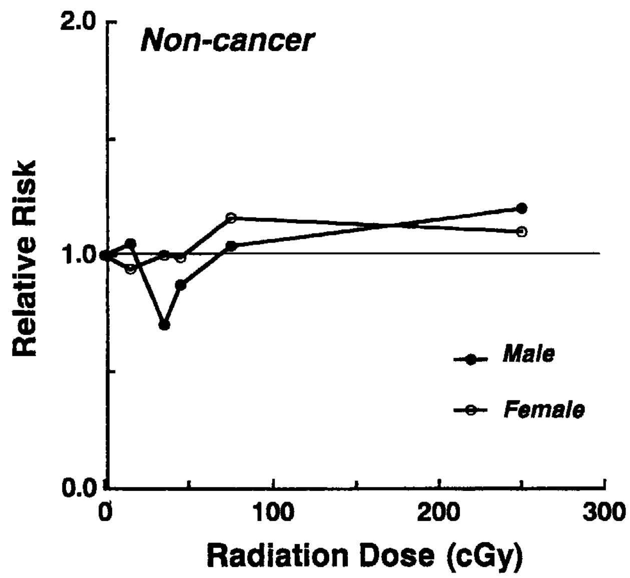

Fig.3 Relative Risk by radiation dose and sex (Non-Cancerous disease)

1.11 UNDERSTANDING NUCLEAR ISSUES

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ABSTRACT

In our days technological progress for the benefit of society is slowed down by the fact that common citizens (opinion-forming media reporters, journalists, furthermore elected decision-makers) are underinformed about basic numerical facts concerning harms and benefits of high technology. Here a comparative risk study is presented about smoking, ozone hole, global warming, and ionizing radiation. This approach has turned out to be successful in educating the youth in Hungary; because school-going teenagers do understand numbers.

1. ACCELERATING HISTORY

In early centuries, the societal and technological progress was slow, unnoticed within one generation. Orientation and skills were learned by imitating the parents. This resulted in a high respect of fathers and grandfathers. The industrial revolution accelerated the speed of progress. The time between the invention of steam engine (Watt 1765) and locomotive (Stephenson 1825), between the discovery of electromagnetic induction (Faraday 1831) and utilization of alternating current for energy supply (Zipernowsky 1885), between the telegraph (Morse 1821) and the public telephone centrale (Puskas 1879) took about two generations. This allowed schooling time enough to introduce the new scientific ideas to the mind of fresh generation. This is why compulsory schooling was introduced in the 19th century, in order to prepare the incoming generations for productive work and democratic citizenry. The teacher became high authority in the eyes of young people. Dennis Gabor, Hungarian-British Nobel-laureate inventor of holography, wrote in his book entitled *Inventing the Future*:

-- *Moses showed the promised land to his people but then he led them around for forty years in the wilderness until a new generation worthy of it had grown up. Now forty years is not an unreasonable estimate for educating a new generation, which can live in leisure created by high technology, but we must find a better equivalent of wilderness. At present stage of information technology the time ought to be shorter -- merely the time to train teachers and for the teachers to train the first generation of modern workers. It is not so much the education of the people, which is slow, but the education of their leaders.*

In the 20th century the revolution of modern science accelerated the pace of history from generations to short decades. Theodore von Kármân discovered the Kármân vortex train behind moving bodies (1910s) and created the streamlined jet aircraft (1940s) within one generation. The neutron was discovered (Chadwick 1932); then the idea of utilization of neutron chain reaction was patented within two years (Szilard 1934). A nuclear pile started working within a decade (Chicago 1942, Obninsk 1947), and soon atomic bombs exploded (Hiroshima and Nagasaki 1945).

Quantum mechanics (Heisenberg 1925) was applied to explain the structure of solids (Wigner 1940s) and Bardeen, student of Wigner, invented the transistor in 1947). Then the portable transistor radio inflamed the Islam consciousness even among illiterate Bedouins, leading to revolutions, wars, and a world wide oil crisis. Even the Cold War was fought and won rather more by telecommunication than by armies. The electronic computer (von Neumann, 1945) led soon to e-mail (Kemeny 1964). The youth of the world (much more the students than their teachers and professors) switched to Internet. Kasparov lost against Deep Blue (1997). The fast pace has made schoolbooks outdated, the youngsters use TV for orientation in our Brave New World. But the media and politicians were shocked by the unexpected invasion of private life by nonlinear physics, quantum mechanics and nuclear technology. The citizens (even worse: politicians and generals) were supposed to make (democratic or totalitarian) decisions about issues what they has not fully understood. This resulted in highly emotional but irrational controversies. (Malaria--DDT, fossil fuel--climatic change, nuclear bomb test--nuclear power plant, DNA--genetic manipulation). The outcome was grassroots anti-science movement, even in the media, because the journalists -- supposed to shape public opinion – were irritated by their own scientific illiteracy. This symptom resulted also in risky military situations, and in millions of victims (from malaria epidemy, air pollution, and nuclear bomb test fallout), in numbers far exceeding the number of victims in Hiroshima or Chernobyl. A characteristic symptom is to overemphasize less important issues and to overlook the important ones. E.g. the worldwide impact of the Chernobyl accident was blown up out of proportions compared to the consequences of atmospheric bomb tests enjoyed by the "patriotic" military leaders of the superpowers.

The approaching turn of the century offers the most appropriate occasion to discuss this issue of public understanding, to turn to the public by presenting them the actually relevant nuclear issues.

The present high responsibility of scientists and teachers implies educating the democratic citizens of the 21st century in schools and in the media for understanding basic science and technological trends, together with their (actual or potential) social impacts. Teachers had to offer knowledge in schools what they had not learned at the university. Scientist had to explain ideas to the public, which are not yet in the textbooks. This duty may seem to be hard, perhaps impossible to fulfill but our experiences in Hungary have shown that it's not the case. As our teachers experienced, even the students interested in humanities pay much more attention to nuclear classes than e.g. to lessons on geometrical optics. The problem left is that journalists and members of the cabinet cannot be called back to these lessons. But we used to tell the teachers that the to-be-ministers and generals of the 21st century are now sitting in the school banks; they are today students of present teachers. Cornelius Lanczos encouraged us to save the world by education saying: -- *Nearest to the genius is the child.*

2. SMOKING

According to the World Health Organization, 27 billion cigarettes are sold in Hungary in a year. Every year about 29 thousand people die due to smoking-related causes. By assuming linear proportionality, *smoking one cigarette results in 1/million probability of fatal disease. If out of 1 million exposed persons one will die due to this exposition, we shall speak about 1 microrisk.* In Hungary, with a population of 10 millions, one third of people smoke, that is an average smoker consumes 9000 cigarettes per year, exposing himself/herself to 9000 microrisk=0.9 % risk each year. (The number of victims for other types of suicide amounts 5000/year, equivalent to 500 microrisk/year.) Passive smokers (children of smoking parents) may take about 30 microrisk/year (equivalent of 30 cigarettes): from among one million children of smoking parents about 30 may die due to the parents' habit.

The cigarette consumption decreases in the U.S. and in Scandinavia. The multinational tobacco companies look for compensation of losses in Eastern Europe and in the Third World. Since 1990 (since the liberalization of tobacco advertising) the cigarette consumption is increasing by about 1% per year. The World Health Organization estimates the total number of victims of smoking to 3 millions/year world wide, being about equal to the number of victims at traffic accidents. Taking the rate of increasing consumption into account, the number of tobacco victims may reach 10 million per year in the decades to come.

3. PUBLIC RISKS

The mathematical definition of risk is $R=P \cdot C$, where P is the probability of occurrence and C is the seriousness of the consequence. (In case of certainty, $P=1$. In case of death, $C=1$.) According to the definition of probability, if N people are exposed to the same risk R, the *collective risk* (i.e. the expected number of lethal casualties due to this exposure) is $N \cdot R$. According to international assessment, one microrisk is incurred while

traveling	2500 km *by train,*
flying	2000 km *by plane,*
traveling	80 km *by bus,*
driving a car for	65 km,
bicycling for	12 km,
riding a motorcycle for	3 km,
smoking a cigarette,	
living 2 weeks with a smoker,	
drinking half a liter of wine,	
living in a brick house for ten days,	
breathing in a polluted city like Budapest for three days.	

Looking at these numbers, one may conclude that people consider a few microrisks acceptable: one microrisk means about smoking a cigarette, or consuming a bottle of light wine, or making a weekend by car, or riding motorcycle to pick up a girlfriend. In legal terms the U.S. Congress considers *one microrisk to be acceptable.* The *"Right of Knowledge"* act, accepted by the State of California with a majority of two-thirds in 1987, states that *"nobody may be exposed – consciously or unconsciously – to a chemical effect that may cause cancer or genetic harm, without calling the attention of the person to be exposed to this danger".* But in court one must know what a punishable *non-zero risk* means. A physicist may be inclined to say: *What I can measure.* (But you may elaborate more accurate tests!) According to the legal praxis in California, an exposure above 10 microrisks must not be caused without advanced warning. This is why warnings must be printed on every packet of cigarettes: *"Smoking may be harmful for your health."*

One *microrisk* may look small in itself. But let us consider a state of N=100 million inhabitants. If each person is exposed to the 'affordable' 1 microrisk, this means a *collective risk* $N{\cdot}R$=100. Hundred innocent causalities in a country do not look such a low price any longer! This example shows that *the presentation of risk* offers a chance to manipulate the public. For example, after the Three Mile Island nuclear accident a local newspaper wrote: *"The release of radioactive noble gases increased the risk of a person living in that environment by the equivalent of smoking half a cigarette."* (It is reassuring, isn't it?) The four million people living in the affected environment were informed by another local newspaper: *"The irresponsibility of technocrats kills two innocent victims!"* (It is terrible, isn't it?) Simple multiplication may show that the two statements are equivalent! Society can be educated for democratic decision-making (e.g. about the route of progress) by obtaining relevant information and by being schooled in rational thinking.

Different professions are risky in different ways. In trade the risk is about 10 microrisk per year. In factories it is 10-100 microrisk per year. In transportation it is about 400 microrisk per year. In coal mining it is 800 microrisk per year. At the construction of high electric transmission lines it makes 1200 microrisk per year. At deep-sea oil wells it is 1500 microrisk per year. At deep sea fishing it may reach 1800 microrisk per year. To be the president of the U.S. means several thousand microrisks per year.

4. OZONE HOLE

"If you don't go out in the sunshine, you may get rickets (rachitis)"-- we were told by grandpa. It's true: the near ultraviolet radiation contributes to our production of vitamin D.

The first humans emerged in Africa; they were evidently dark-skinned. When some of them were driven by overpopulation to cloudy Europe, a mutation decreasing the pigment production was an advantage: the body collected more sunshine, therefore their organism could produce more vitamin D. This is why medical doctors recommend a sun-lamp for the long dark winter afternoons in Northern Europe.

The hard ultraviolet photons of sunshine break up the molecules of air, which is how the ionosphere has been produced. Deeper atmospheric layers are reached only by soft ultraviolet photons (0.5--0.7 aJ) and by visible photons (0.25--0.5 aJ). In the first billion years of Earth's history the bombardment of soft ultraviolet photons made the survival of complex organic molecules impossible, life could not evolve on land. The green plankton in the sea, however, began to pump oxygen into the atmosphere by photosynthesis ($h\nu + CO_2 \longrightarrow C + O_2$), and the energetic ultraviolet photons broke the oxygen molecules in the stratosphere, producing ozone ($h\nu + O_2 \longrightarrow O + O$, $O_2 + O \longrightarrow O_3$). The ozone ($O_3$) is able to absorb also the soft ultraviolet photons ($h\nu$=0.6 aJ), that the electrons in the short O_2 and N_2 molecules cannot do. Under the protection of this ozone shield, life dared to occupy the continents.

In 1984 at springtime the thickness of the ozone shield dropped to one-sixth of its usual value above the Antarctica. The ozone *hole* reached record size in the 1990es. The suspects were found on the spot: they were freon-type (CFCl, chloro-fluoro-carbon) molecules, used in sprays, in refrigerators and in air conditioners. These man-made molecules are durable enough to diffuse up to the stratosphere, there the hard ultraviolet rays of the Sun brake them up, and the liberated Cl and F atoms catalyze the decay of ozone. Ultraviolet photons cross through the ozone hole; they harm green leaves and may cause skin cancer in human beings.

Populations of pale skinned people, who like to enjoy sunshine, are especially sensitive. (Remember the sun-tanned blond movie stars in bikinis!) In the U.S. skin cancers make about 40 % of all cancer cases, more than 100 000 are registered every year. Skin cancer is three times more common in the sunny Texas than in the rainy Iowa. The number of skin cancer cases has doubled in 20 years and quadrupled in 40 years even in Europe.

According to the U.S. Environmental Protection Agency 1% thinning of the ozone layer may increase the ultraviolet radiation by 2 %. This could cause a 4 % increase in skin cancer and 0.5 % increase in eye cataracts for pale-skinned, blue-eyed population, meaning e.g. 6000 extra deadly megamelanoma cases in the U.S. and several tens of thousands worldwide. The number of lethal skin cancer cases grew from 200 in 1980 to 500 in 1990, indicating an increase from 20 to 50 microrisks/year in Hungary! This is why a suntan is already out of fashion in California and on the Riviera. This is why blinded sheep has been observed in South-Chile. This is why the Montreal Protocol urges the elimination of freon-type compounds.

The climbing of the skin cancer frequency is the steepest among twen-agers in Hungary. Due to the latency period of skin cancer this may be due of their sunbathing when they were teenagers in the 1970s. The diffusion of the freon to the stratosphere, to reach the ozone layers takes about 10 years. Unfortunately, freon molecules survive humans. If we stop releasing these kinds of molecules today, the ozone layer will start recovering only after one or two generations from now. The sins of fathers will be met at their children and grandchildren.

Ultraviolet radiation is harmful because it excites and destroys organic molecules. In the coming pages, we shall focus our attention to ionizing radiation, not only because radioactivity is the most feared, but because it can be measured, checked, researched and controlled the most easily.

5. IONIZING RADIATION

Radioactive decay liberates energy: it produces ionizing radiation. The unit of *activity* of a sample is 1 Bq (Becquerel) =1decay/second. The radiation may destroy molecules. The ions disturb the delicate network of the biochemical metabolism in the human body. The overall number of ions may be considered to be the measure of the impact of this radiation. The *dose* is the ratio of the absorbed ionization energy E to body mass M, that is E/M.

(The corresponding unit is 1 Gy = 1 gray = 1 joule/kg = 1 J/kg. – The cell is able to neutralize a few ions, to repair smaller damages by fabricating special repair enzymes. The differences in the biological effects of different particles can be taken into account by a quality factor Q which is 1 for X-rays, γ- and β-radiation, is 2--10 for slow--fast neutrons, is 20 for α-particles and fission fragments. The *dose-equivalent* is defined as $D=QE/M$. Heavier charged particles are absorbed easily by cloth and skin; therefore the public is exposed mostly to X-rays, γ- and β-rays. Thus for the understanding of *everyday risks* this distinction is not so relevant.)

The unit of dose equivalent D is 1 Sv = 1 sievert = 1 joule/kg (for X-rays, â- and ã-radiation). We know from the bitter experiences of Hiroshima and Nagasaki that D>10 Sv is lethal. D=4 Sv results in death with a probability of 50 %. A few Sv causes acute symptoms (loss of hair, bleeding in the gut) within days. In everyday life much smaller doses occur. We shall use 1000 times smaller units: 1 mSv (millisievert) = 1 Sv/1000.

There was a zone in Hiroshima and Nagasaki (in belt at a distance of 1.5--2.5 km around the epicenter) where people survived but they have received radiation doses of about 100 mSv. Their medical history and the causes of their death were tracked carefully. These statistics have been compared with those of the Japanese population living elsewhere. The estimation obtained by subtracting the normal mortality and by extrapolation, *assuming a linear proportionality between risk and dose*, has shown that a dose equivalent of 1 mSv increases the risk of lethal leukemia and cancer by about 50 microrisk. The *International Committee on Radiation Protection* recommends this *risk/dose* factor in official calculations. (At much higher dose the factor is taken twice as large, but such high doses do not affect the public.) So what is the risk of 1 mSv dose equivalent? *50 lethal cancer cases by million people exposed.* Equally risky are

to smoke 2 and a half packets of cigarettes,
to bicycle for 600 km,
to drive for 3250 km,
to cross a busy road twice a day for a year,
to drink one glass of wine per day for a year,
to be X-rayed for kidney metabolism.

The law says that the artificial radiation burden on the population must not exceed 5 mSv/year (corresponding essentially to 5 microrisk/week) and the International Committee on Radiation Protection recommends to decrease this limit to 1 mSv/year (1 microrisk/week). This value may be over-prohibitive: it corresponds to the risk of smoking one cigarette per week. (Medical interventions to save life may and do surpass this value.) For those who are working professionally with radiation the maximum dose tolerated in a year is 50 mSv, but in average the radiation load must not exceed 20 mSv/year. (The largest exposure within the Hungarian Nuclear Power Station was 33 mSv in one case.)

A gentleman of 75 kg mass contains $750 \cdot 10^{25}$ atoms. Biochemistry tells us: what kinds of atoms they are. The percentage by weight and the number of atoms in units of 10^{25} are given for the important chemical elements in a body of 75 kg.

H	(10 %)	450	P	(1.3 %)	1
O	(60 %)	185	Ca	(1.3 %)	1
C	(20 %)	75	S	(0.5 %)	0.7
N	(5.4 %)	19	K	(0.3 %)	0.3
Na	(2.7 %)	1.6	Rb	(0.02 %)	0.01

H, O, C, N occur in the essential organic compounds (food, protein). P plays a role in DNA, S is essential for some enzymes, and Ca is present in bones. Na^+ and K^+ ions play role in ion transport.

The atmosphere is under steady bombardment by the energetic protons of cosmic rays. They produce nuclear reactions in the upper atmosphere, liberating neutrons among others. The neutrons may transmute nitrogen into radiocarbon: $n+^{14}N$ $^{14}C+H$.

The ^{14}C nucleus is radioactive, it is produced and it decays, its equilibrium concentration amounts $^{14}C/^{12}C=10^{-12}$. The gentleman of 75 kg contains $75\cdot10^{25}$ carbon atoms, including $75\cdot10^{13}$ radiocarbon atoms. Of these radiocarbon atoms 3000 decay every second.

Solar energy is liberated by the nuclear fusion of hydrogen: H+H $^2H+e^+$, $H+^2H$ ^3He, 2^3He $^4He+2H$, but reactions like $^2H+^4He$ $^3H+^3He$ also occur. The solar wind blows ^3H (tritium) to the Earth. Tritium is radioactive with a half life of 12 years (emitting electrons with maximum energy of 0.002 pJ). The equilibrium concentration of tritium in rain water is $^3H/^1H=10^{-17}$. The gentleman of 75 kg is made mostly of hydrogen atoms, among them he contains 4.5 billions of tritium atoms, from which about 100 decay in every second.

In this region of the Galaxy a supernova exploded 4.6 billion years ago. At the very high temperature of the explosion, neutrons *evaporated* from the nuclei. Some of these produced new nuclei: $n+^{87}Sr$ $^{87}Rb+H$, $n+^{40}Ca$ $^{40}K+H$. Accumulation of the ejected materials made the Solar System. The Sun and planets were born 4.59 billion years ago. ^{87}Rb, having a half-life of 500 billion years, is still present, constituting 28 % of natural rubidium. ($25\cdot10^{20}$ ^{87}Rb atoms are present in the body of the gentleman.) 100 of them decay in each second. The half-life of ^{40}K is only 1.28 billion years, most of it has already decayed during the long life of Earth, and today it makes only $4^0K/K=0.0118$ % of natural potassium. The body of the gentleman contains $30\cdot10^{20}$ of them. Due to their shorter half life, many ^{40}K atoms decay per second. Between two heart beats, about 8700 radioactive atoms decay in our body; our own activity is 8700 Bq.

Fortunately, most of these nuclei emit electrons of low energy. Therefore the dose deposited by ^3H, ^{14}C, ^{87}Rb is small. The ^{40}K decays are the most abundant and most energetic. About one-third of the decay energy of 0.2 pJ is deposited in the body (two-third of the ã-photons and all the neutrinos escape.) This means that the ionization energy deposited in 1 kg of the body is (5500/75)·(0.2 pJ/3)=5 pJ/kg s, meaning a dose-equivalent of 0.15 mSv/year. By adding the ^{14}C dose, one may conclude that *our own body gives us a dose equivalent to* 0.18 mSv/year. In reaching the age of 55 years the gentleman collected a total dose of 10 mSv. This means a 0.05 % risk of dying from cancer produced by the radioactivity of one's own body. One person out of two thousands is going to be killed by the radioactivity of his own body. You can escape this only by jumping out of your skin. (The total risk of dying from cancer is about 20 %, and that of dying anyway is exactly 100 %.)

We should be aware that the gentleman irradiates not only himself but his girlfriend as well during their close encounters. He is a radioactive source of 8700 Bq! In his body 5500 ^{40}K nuclei decay every second. 10 % of these decays produce ã-photons of 0.23 pJ each, so he is a ã-source with the power 126 pW. If she absorbs only 8 % of that energy while sharing a bed with him, then her body is irradiated by $2\cdot10^{-13}$ Sv/s. In an eight-hour night this gives a total dose-equivalent of 5 nanonsievert. A thousand and one nights can give her 0.005 mSv. In this happy way she takes total 1/4 microrisk (i.e. 1/4 000 000), equivalent to the risk of 5 pulls from a cigarette! Is it worth of taking? (Let us not forget that a pull of cigarette would shorten her life expectancy by 25 seconds, but virgin life style would shorten her life expectancy by about 6 years according to statistics.) For a man the corresponding risk is lower: just from this point of view she is less active, due to her smaller body weight. (Furthermore, a strict bachelor lifestyle may shorten his life expectancy by 10 years. Medical X-rays shorten our life in average by 2-3 weeks.)

6. RADON IN HOMES

The half life of ^{232}Th is 14 billion years, that of ^{238}U is 4.5 billion years, that of ^{235}U is 1.2 billion years, and that of ^{40}K is 0.7 billion years. These decays supply the internal heat of Earth. (We enjoy it in thermal spas.) But not only heat emanates from the Earth. The gaseous decay product of ^{40}K makes now 1 % of the atmosphere as innocent ^{40}A. The gaseous decay products of ^{238}U (namely ^{222}Rn) and that of ^{232}Th (namely ^{220}Rn) are not so harmless: they are radioactive themselves. ^{220}Rn decays within one minute, therefore it usually does not have time to diffuse into our living room. But ^{222}Rn's half life is 3.8 days, long enough to reach us. The radon activity of indoor air depends upon the soil, building bricks, house structure, and room ventilation. Rough values are:

outdoor air near the ground	10 Bq/m^3
ventilated room	40 Bq/m^3
closed room	80 Bq/m^3
highly contaminated room	4000 Bq/m^3
cave of very high activity	40000 Bq/m^3

In uranium mines, before the era of forced ventilation, the miners inhaled contaminated air. According to statistics, a year spent in an air with radon concentration of 5000 Bq/m^3 increased the risk of lung cancer by 1 %. This means that (taking a life span of 50 years) the risks of radon induced cancer can be calculated by assuming linear *risk/dose* relationship:

living in the wild:	A=12 Bq/m^3	D=0.3 mSv/y	R=0.15 microrisk/year
ventilated house:	A=40 Bq/m^3	D=1 mSv/y	R=50 microrisk/year
well insulated room:	A=80 Bq/m^3	D=2 mSv/y	R=100 & microrisk/year
contaminated flat:	A=800Bq/ m^3	D=20 mSv/y	R=1000 & microrisk/year

Sweden has been built upon a granite block, relatively rich in uranium. Rolf Sievert and Bengt Hultqvist measured the ã-activity in 1000 apartments already in the 1950s. There was a wide scale survey of radon activity concentration in the early 1980s. By comparing the two surveys one finds that the average of the later measurements is *four times larger* than the average of the earlier survey. The explanation may be the "energy-saving" insulation of the doors and windows, due to the oil crisis of the 1970s.

In Hungary, the abundance of lung cancer tripled in 30 years, but this can be accounted more to chemicals (smoking and air pollution produced by cars) than to radon inhalation. But if the population of Hungary would listen to the advertisements recommending efficient door and window insulation (in order to "conserve energy"), irradiation may increase by 1 mSv/year. The population of Hungary is 10 million people, so by assuming a strict proportionality an additional 1 mSv/year dose for everyone would result in $N{\cdot}R=(50{\cdot}10^{-6}){\cdot}\,(10{\cdot}10^{6})=500$ additional lethal lung cancer cases per year (added to the present number of 6400 cases)!

7. LOW DOSES

The *risk/dose* relation has been measured empirically in the 100 mSv region (in Hiroshima and Nagasaki). From that point an extrapolation has been used (with steepness of 50 microrisks/mSv) to reach the low-dose region at 1 mSv. The linear extrapolation down to very low doses relies on the argument, that the attack of ionizing radiation is a probabilistic phenomenon: a ã-quantum *either hits* a DNA molecule at one of its sensitive sites (initiating cancer by the uncontrolled replication of the damaged pattern) *or does not.*

A suspicion against linearity was raised recently. Bernard Cohen (University of Pittsburgh) intended to decipher the risks of low doses empirically. He compared the lung cancer statistics of the different counties in the U.S. with the average radon activity concentrations in these counties. The observed data don't follow the theoretical *rise* but show a definite *decrease* in the region of 100 Bq/m^3. The discrepancy between "theory" and "facts" amounts about 20 standard deviations! Originally Cohen did not believe in the reality of this conclusion, therefore he extended his investigations to the regions of Sweden, Finland, China, where the uranium rich granite rocks produced enhanced radon emission. The outcome has confirmed the empirical conclusion that *a low level radiation load of a few mSv/year seems to suppress cancer risk.* A similar significant minimum was reported by Esther Tóth in Hungary.

A direct indication has come from the recent study of the survivors of the Nagasaki atomic bomb. Those people who survived and received a modest dose in Hiroshima and Nagasaki lived in average 4 years longer than the control population. Sohei Kondo (Osaka) has published curves showing that the probability of getting leukemia, lung cancer, colon cancer as a function of dose *drops* at first, it has a *minimum* at about 20-50 mSv, it follows the *linear rise* only above 100 mSv.

At vaccination, a controlled tiny amount of toxin is injected into the blood of humans, in order to activate the biological defense against expected greater attacks. It may be that small doses (or a given dose extended to longer period) may have similar effect: it may activate the defense (repair enzyme and antibody production) against oxidative attacks. It may increase the immunity against carcinogens. This indicates that *the human organism may have a sensitivity threshold at a few mSv.* It can defend itself biologically against doses below the threshold, but it is unable to do so against stronger or multiple attacks. A human cell seems to be able to repair a slight damage in a few hours, may ready itself for expected new attacks, but it is irreversibly damaged by the simultaneous attacks of several ionizing particles. In this case the best defense is that the damaged cell commits suicide, instead of multiplying itself in an uncontrolled way. This explains why *no genetic harms of ionizing radiation were observed among humans* in Hiroshima and Nagasaki.

8. PUBLIC DOSE

We can calculate now our own dose received in the last year. Let us consider the natural radiation load first. (The numbers have been rounded off.)

ionizing cosmic radiation at sea level	0.30 mSv/year
cosmic neutron flux at sea level	0.05 mSv/year
100 m height excess	0.02 mSv/year

(The atmosphere offers a shield against cosmic radiation. Its flux doubles at each 1800 m of altitude.) Radioactive isotopes of cosmic origin contribute as well:

^{40}K in the body and environment	0.18+0.15 mSv/year
^{14}C and ^{3}H in the body	0.015 mSv/year
^{87}Rb in the body	0.06 mSv/year
U-family in the environment	0.10 mSv/year
Th-family in the environment	0.16 mSv/year
Rn inhaled	0.3 mSv/year
Natural sources (rounded off)	1.5 mSv/year

This would be the dose received by a prehistoric human living in the wood, sleeping in the nest at the top of a tree. But civilization (especially the industrial revolution) changed our lifestyle. Wolves and smallpox were eradicated, but other risks were created. If you live and work in house, add

living on the ground floor*	0.5 mSv/year
in a light concrete house (9 mg U/kg)	1.8 mSv/year
in a brick house (3.5 mg U/kg)	0.7 mSv/year
in a light panel house (1.5 mg U/kg)	0.3 mSv/year
in a wooden house (0 mg U/kg)	0.2 mSv/year
Radon excess in the house (rounded off)	1 mSv/year

(* 1 mSv/year for 40 Bq/m^3 radon activity concentration in bedroom.) "Move to a wooden house resting on piles! By doing so you can suppress your radiation load by 1 mSv!" Are you going to do it? -- Further artificial doses:

air flight for each 2500 km	0.01 mSv/year
wristwatch with luminous numbers	0.02 mSv/year
watching black-white TV, 1 hour/day	0.01 mSv/year
watching color TV, 1 hour/day	0.02 mSv/year
medical X-rays, in average	0.5 mSv/exposure
Technological load (Hungarian average)	0.5 mSv/year

The average load on the Hungarian citizen is about 3 mSv/year, reaching a risk of 1 % during lifetime. (In Sweden, due to the dominating granite surface and single-level housing, this value was about 7 mSv/year before the radon mitigation campaign. In Kerala it may reach 13 mSv/year due to the thorium-rich soil.)

The nuclear plants of the world supply about 200 GW of electrical power. The related industry (radon release at uranium mining, active Kr and Xe emission at fuel reprocessing) brings an extra load upon the population of the Northern hemisphere: *World's nuclear industry:* 0.00015 mSv/year/capita.

The anxiety over nuclear power plants stems from the consequences of the tragic accident that happened at the nuclear power station in Chernobyl (Ukraine). The author of the present paper paid a personal visit to Chernobyl in the late 1991, with a dose-ratemeter in hand. The number of direct causalities was 30, and might have approached 100 within the first year. The amount of ejected radioactivity could be measured, it is known worldwide. The radiation dose, received in the first year was in Hungary measured to be 0.2 mSv. The overall dose from Chernobyl in the years to come is estimated to be cca 0.4 mSv -- equivalent of smoking a pack of cigarettes by each Hungarian. Is it terrible, isn't it?

The International Atomic Energy Agency estimates the collective risk due to Chernobyl to be 600 000 Sv, corresponding to 30 000 collective risk, as the most pessimistic estimation, using the proportionality hypothesis. (20 % of the Europeans, i.e. 120 millions will die anyway of cancer. We shall never know who of those died because of the accident.)

In the era of anxiety people are afraid of risks. In the months following the Chernobyl accident the number of surgical abortions jumped by 50 000 in Western Europe (as we have seen, without good reason). The team of the International Atomic Energy Agency found in Ukraine that there are more psychic problems than radiation-induced medical cases. *Ignorance and unjustified anxiety may kill as well.*

9. SINGLE INCIDENTS

Thousands of victims from an industrial accident are certainly an unacceptable price for comfort. Such unstable graphite moderated and water cooled nuclear reactors (operating only within the former Soviet Union) must be eliminated. (The U.S. eliminated them 40 years ago, following the intervention of Edward Teller.)

Hiroshima, Nagasaki, Windscale, Harrisburg, Chernobyl focused the public anxiety on nuclear risks. Nuclear fission produces radioactive fragments necessarily. If they get into the atmosphere, they create risks that Cross borders. The largest recorded radioactive releases were (in units of 10^{18} Bq):

Hiroshima bomb	0.01
Present H-bomb	1
100 megaton bomb	10
All atmospheric tests	100
Windscale reactor accident	0.04
Harrisburg reactor accident	0.0001
Chernobyl reactor accident	4
Coal industry, yearly release	0.6

Present dose from previous atmospheric tests is 0.01 mSv/year, the collective dose for humankind amounts 50 000 Sv/year, corresponding to a collective risk of 2500 in 1990. According to the report of the United Nations (1988) the collective dose commitment due to all the previous atmospheric nuclear explosions is estimated to be 30 million Sv. By using the *linear risk/dose formula*, one obtains a collective risk exceeding one million!

The largest tests were performed in Novaja Zemlja in the 1960s, since them a large fraction of the radioactive fallout decayed. The memoirs of Andrei Sacharov (published in 1990) describe, how he became irritated by the plans to test the 60 megaton H bombs developed in the 1960s. He made some rough estimations: all the previous nuclear explosions had not emitted as much radioactivity till then as the explosion of one single 60 megaton bomb would do. He estimated the number of indirect causalities to be in six figures. (You may repeat his calculations using the data given in this paper.) We know the final outcome of the story. Mr. Khrushchev rejected Sacharov's protest, two big bombs were exploded. The physicists made their measurements and performed their calculations worldwide. A global protest wave -- lead by scientists -- forced the superpowers to agree a ban on atmospheric tests. But smaller powers wanted to develop their bombs as well: they continued low-scale testing for a while, but the global protest wave forced also them to stop atmospheric explosions.

Nuclear fallout can be measured exactly, as the Hungarian schools did after Chernobyl, and they monitor radon in the environment since. High technology can be controlled. Humans, too, have to learn controlling themselves, to prevent war games and technological catastrophes. (The number of the causalities of car accidents in Europe approaches a million per year.) We share the hope that in the coming century the main issue will be cleaning up the environment: acid rain, ozone depletion, carbon-dioxide induced warming. These are more complex chemical issues. DDT accumulates is the body of fish, its use has been prohibited worldwide. Since that the suppressed enemy, malaria, spreads again, killing 2 millions in 1994. We have to learn to measure, understand and control the chemicals, as we have done with the risks of ionizing radiation.

10. GLOBAL WARMING

- *Global warming is possibly the single greatest threat ever to the future of life on the planet. Its ultimate consequences have been compared by eminent scientists as "second only to a global nuclear war".* -- This is a statement of Greenpeace International. In this respect the official experts of the Intergovernmental Panel on Climatic Change agree with the opinion of grassroots environmentalists: -- *There is increasing empirical evidence that human activity makes a noticeable impact upon the climate.* -- NASA goes even further: -- *Humankind performs such a global experiment with the atmosphere of our planet, which may have unforeseeable consequences.* -- There is a scientific, political and ethical consensus that the climatic instability and global warming may become a central issue of humankind for the 21st century.

For scientists, facts and numbers tell more than emotional and eloquent declarations. In past centuries (1400--1800) the CO_2 concentration of the atmosphere was steady 0.028 %. Then due to the industrial revolution it began climbing at an accelerated rate: 0.030 % in 1900, 0.031 % in 1950, 0.032 % in 1960, 0,033 % in 1975, 0.035 % in 1990, 0.036 % for 2000. The industrial revolution raised the average global temperature by 0.6ºC. The hottest year of meteorological history was 1998, but the spring of 1999 was warmer by 0.6ºC than the average of the 1960--1990 period. In the last summer, the temperature did not sink below 100ºF in Dallas on 19 consecutive days. (This was higher than body temperature. In this case the human organism cannot get rid of the surplus entropy.) The increased evaporation resulted in enhanced water circulation, drought and famine in the tropical regions, and torrent floods at cooler regions. In 1998 thousands of humans died due to floods. The Intergovernmental Panel on Climatic Change stated:

The fast climatic changes of the future imply surprises for us, due to the nonlinear character of the climate. The behavior of such nonlinear systems will become especially unpredictable when the system is affected by quick impacts. As example we may mention the change in the system of oceanic currents due to human interventions. – Since then, El Nino made headlines.

The most sophisticated climatic predictions of the Lawrence Livermore Radiation Laboratory supercomputer, taking into account also the reflectivity of the SO_2 produced smog, reproduces the past trends and fluctuations successfully, therefore its predictions are accepted. Humankind releases 30 billion (10^9) tons of CO_2 year by year, which makes 2 % of the total CO_2 content of the atmosphere. A part of this released CO_2 is absorbed by the green vegetation and the oceans, but it is rather certain that the atmospheric CO_2 content will double well within the 21st century. This will result in a temperature rise of 2--5ºC, and a rise of see level well above 1 meter.

One must not forget where this CO_2 surplus originates from. The U.S. releases 23% (i.e. 5.26 tons per capita per year), Germany 5% (2.89 tons/capita/year), the developed countries altogether (the golden 1 billion) 70% of CO_2. China releases 12% (0.71 tons/capita/year), India releases 5% (0.24 tons/capita/year), the developing world altogether (the poor 5 billion people) releases 30% of the CO_2. The population of our planet doubled in the second half of the 20th century. It is expected that the First World (with an average income of $10 000/year) will keep its population steady and may double its standard of living. The Third World (with a present average income of $1000) will triple its population and may quadruple its income. Anyway, it is hard to avoid the conclusion that *human industrial activity will increase tenfold in the next century.*

At the United Nations and in the European Union the coastal countries make a majority. Due to the thermal expansion of water, the rise of the sea level was 25 cm in the 20th century. (In the Ice Age the sea level was 100 m lower. The thickness of ice on the Arctic Sea reduced from 6 m to 4 m in the past 20 years. Melting the ice on Greenland would result in a rise of 5m. Melting the ice of the Antarctica would make a rise of 60 m.) Thus there is a strong diplomatic pressure to stop the greenhouse warming. The representatives of the world's nations assembled in Kyoto in the last December. In their luggage, they took the following offers for the reduction of the CO_2 release till 2010 with respect to their level of 1990:

The European Union has a long coastline, they offered 15 % reduction. Switzerland (producing electricity mainly from nuclear and hydropower) offered 10 % reduction. England offered 8 % reduction with respect to 1990 (they are now above the 1990 level by 12 %). Hungary intended to offer 8 % reduction. The American delegation was in a difficult position: at present the U.S. is already by 10 % above the 1990 CO_2 release, and the Senate instructed the delegation to accept a return to the 1990 level if and only if also the Third World accepts considerable reductions. The demand of the oceanic island countries was the overall reduction of 20 %. The same 20 % - reduction with respect to the 1990 global CO_2 release - was demanded by the Greenpeace International. Experts say that, for stopping the rise of the global atmospheric CO_2 concentration, a reduction of the yearly release by 60 % would be necessary. The finally reached agreement was the following:

European Union	--8 %	U.S.A.	--7 %
Bulgaria, Romania	--8 %	Japan, Canada	--6 %
Czech Republic	--8 %	Poland, Hungary	--6 %
Estonia, Latvia, Lithuania	--8 %	Croatia	--5 %
Switzerland	--8 %	Russia, Ukraine	0 %
Slovakia, Slovenia	--8 %	Australia	+ 8 %

Seeing the U.S. policy, the E.U. also went back with its obligation. Russia would not mind a bit warming in Siberia. The Third World has not committed itself, they argued that the present high CO_2 level has been caused by the First World. Thus the outcome was very modest, it will not solve the problem of global warming and sea rising.

My personal opinion is that we cannot hope very much from politics. Politicians look ahead only to the next election. Industrialists look ahead to the financial gain at the end of the year. The CO_2 and freon molecules, however, stay in the atmosphere for 100 years. The thermodynamical reaction time of the atmosphere may be even longer, due to the huge heat capacity and CO_2 absorbing capability of the oceans. For the same reasons, the changes are irreversible -- at least on human time scale. The fate of the global climate is not interesting for politicians or businessmen. It is relevant only for parents who have children, and for teachers who have students. Our students, children and grandchildren will we citizens of the 21st century.

11. CONCLUSION

In a democratic society, decisions have to be made by the society. The citizens have to understand the issues, they should evaluate them with ethical responsibility, and they should force their decisions on the politicians. This means that the incoming generations should understand and shape their future. I am convinced that problems like the coal/nuclear power alternative can be solved only by education.

The memory of Hiroshima and Nagasaki, the memory of Three Mile Island and Chernobyl are a heavy burden upon nuclear power. But the ethnic conflicts and irresponsible diplomatic behavior killed more people in former Yugoslavia than the Hiroshima and Nagasaki bombs did. Gas accidents kill more than nuclear accidents. Air pollution caused by coal industry (or smoking) kills hundred times more each year than Chernobyl might kill in toto. But for a TV reporter it is difficult to understand that a graphite moderated, water cooled reactor shows positive feedback at thermal fluctuation, but a water moderated, water cooled reactor shows a negative feedback: it stops working when water boils away. The difference is similar to the difference in the responses of a barrel of gasoline or a barrel of beer if we throw a flaming match into them.

If we ask the anti-nuclear activists, should we use the dirty coal power, which is far more dangerous for the public, than nuclear power, they react: -- *Conserve energy! Insulate your windows!* --But it is a wide experience in Northern and Central Europe that after the oil crisis the increased insulation of dwellings raised the indoor radon level by a factor of 2 to 4. And at moderate climate radon and its progenies produce the main radiation load upon the population. (In Hungary, the average radon dose per year is ten times higher than the radiation load from Chernobyl was in 1996; in spite of the fact that Chernobyl is only 600 km away from Budapest.)

We think that air pollution and global warming are ethical problems in the same way as nuclear armament is. We try to discuss these problems with Hungarian teachers. They have noticed: if they discuss the issue of global responsibility towards the future in physics, chemistry, geography and biology classes, each student (even to-be-poets, businessmen and politicians) pay attention. This convinces the teachers that nuclear disarmament, energy options, CO_2 greenhouse are interesting *scientific problems*, which are made even more interesting due to their *societal relevance* and the associated *ethical responsibility*. In a highly successful teacher initiative, over 15 000 Hungarian high school student have measured the radon activity concentrations year long in their own bedrooms. When an Israeli educator raised the question to them: -- *How would you react in case of a nearby nuclear accident of Chernobyl dimension?* -- students answered: --*We would measure the fallout!* -- The winter of 1996/97 was especially cold, frosty and snow-rich in Hungary. During that winter, the radon surplus dose exceeded the 1986 surplus dose that Hungary received from Chernobyl. This was what high school students measured and understood! They have also to understand, that our using high consumption cars now in Europe may kill babies one generation from now 10 000 km away at the river delta in Bangladesh.

This is a concrete way how we may educate to global citizenry. Let me repeat my thesis: *in a democratic society people must understand the future.*

Integrated collective doses from specific events (UN SCEAR 1993)

Hiroshima bomb explosion	1.5 thousand man-Sv
Windscale reactor accident	6 thousand man-Sv
Harrisburg reactor accident	0.05 thousand man-Sv
Chernobyl reactor accident	600 thousand man-Sv
El Chicon volcanic eruption	10 thousand man-Sv
All underground bomb tests	0.2 thousand man-Sv
Largest atmospheric hydrogen bomb test	1000 thousand man-Sv
All atmospheric bomb tests	30 000 thousand man-Sv

Collective global doses pro year

Watches with luminous dials	2 thousand man-Sv
Flying by airplanes	10 thousand man-Sv
Medical (X-ray) diagnosis	1800 thousand man-Sv
Medical radiotherapy	1500 thousand man-Sv
Phosphate fertilizer industry	300 thousand man-Sv
Geothermal power	0.005 thousand man-Sv
Natural gas production	0.003 thousand man-Sv
Oil industry	0.1 thousand man-Sv
Coal fired industry	110 thousand man-Sv
Public dose from nuclear industry	1 thousand man-Sv
Occupational dose from nuclear industry	2 thousand man-Sv
Living in houses (radon indoor)	6000 thousand man-Sv
Natural radioactivity	7000 thousand man-Sv

Collective dose from producing 1000 GW-year electricity

Coal	20 thousand man-Sv
Oil	0.5 thousand man-Sv
Peat	2 thousand man-Sv
Natural gas	0.03 thousand man-Sv
Geothermal power	2 thousand man-Sv
Nuclear power	6 thousand man-Sv

Students may calculate the number of victims by the (official) linear model (50 victims/thousand man-Sv) or by the threshold model (negligible at low doses). As we have mentioned above, according to WHO estimate, smoking demands 3 million victims per year, and this habit is wildly advertised on giant posters by multinational firms in Eastern Europe and the Third World. Mining coal, feeding coal ovens, and cutting trees may result in accidents. The number of (occupational + public) victims associated with the production of 1 GW-year electricity is, according to official data of the International Atomic Energy Agency.

	COAL		OIL		GAS		PEAT		WOOD		NUKE	
mine-silicosis	0.3										0.1	
mine-accident	1.1		0.9			0.4	1		1.2		0.04	
mine-radiation	0.02	0.3									0.04	
transport	0.1	0.5	0.5	0.05	0.02	0.03			0.8		0.01	0.05
processing	0.06		0.5		0.05						0.06	
construction	0.15		0.05	6	0.06						0.1	
maintanence	0.16	20				0.02		0.9			0.1	
production-rad		0.7			0.25		0.002	0.1	1	1		0.02
reprocess.accid.											0.01	
reprocess.rad											0.05	0.12
disposal rad											0.47	0.25
victims	total **23**		total **8.1**		total **0.5**		total **2**		total **2**		total **0.7**	

2. Panel Discussion

（パネル討論）

The Status and Problems of Radiation Education in Various Countries

（海外諸国における 放射線教育の現状と課題）

2.1 RADIOLOGY EDUCATION IN HUNGARIAN SCHOOLS

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ABSTRACT

Basic concepts of nuclear physics are not more abstract and more difficult than those of electricity. For the orientation of the citizens of the 21st century, the Hungarian school curriculum has made them compulsory for all teenagers. According to the teachers' experience, the students find nuclear issues more relevant and more interesting than the topics inherited from the schoolbooks of earlier centuries.

1. AIM

School education -- relying on the pedagogical praxis of earlier teacher generations -- presents the mathematics of the Antiquity, the physics of the early Industrial Revolution (17/18th century) to the youth living in the 20/21st century. And the science teachers are surprised that the teenagers pay less and less attention to solve close-ended numerical problems about rigid bodies, direct currents, and geometrical optics, while living in an environment of semiconductor chips, mobile phones, and nuclear weapons. This conservative teaching habit excludes modern science and high tech from the human culture. Honest grassroots movements among the youth advocate a world free of 'alien' nuclear power and computer network, and advocate returning to the 'understandable' world of their ancestors.

The cleanest form of energy is offered by electricity, therefore it is the most comfortable and most popular option for people. In the last two decades Hungary utilized nuclear power to cover almost half of its electric consumption. This has made our country more independent from outside economical and political pressure. This is one of the main reasons, why statistical physics, atomic physics, nuclear physics, and astrophysics have become parts of the Hungarian high school curriculum. (The Japanese translations of the corresponding schoolbooks, written by Esther Toth, have been printed recently by the Maruzen Publishing Co. in Tokyo.) The actual official state curriculum has made the orientation in nuclear science compulsory already in the middle school, i.e. for all teenagers. Our experiences have been very positive: present teenagers -- even to-be poets, politicians, businessmen -- show much more interest towards radioactivity and nuclear power plants than towards forces acting on rigid bodies and direct current networks. Nuclear physics can be treated with much simpler mathematics than e.g. the resistance in case of alternating current.

2. NUCLEAR DROPLETS

Nuclei are much simpler structures than atoms, molecules, or solids. According to experiences (electric scattering on nuclei in the Rutherford experiment) nuclei are of *constant density*. Nuclei are made of (positive) *protons* and (neutral) *neutrons*. These constituents have almost equal masses. The protons repel each other electrically, but nuclei are still stable formations due to the intensive *nuclear attraction*, which acts among these nuclear particles. The nuclear attraction is about hundred times *stronger* than the electric repulsion, but it has a *short range*: much shorter than the size of the nucleus. These empirical properties of the nuclear force have the consequence that inside the nucleus each particle has the same number of neighbors, thus its binding energy is independent of the size of the nucleus, of the total number A of particles (constant heat of boiling). A particle on the surface, however, has fewer neighbors, thus its binding is weaker (surface tension). These characteristics of nuclear forces explain the constant density, the surface tension, and the spherical shape. Nuclei remind us on water droplets. The *fusion* of small droplets to a larger one would release energy, because fusion decreases the overall surface. But...

3. NUCLEAR VALLEY

Protons and neutrons -- like electrons in the atomic shell – are subject to the *Pauli principle*: on the energy ladder only two protons and two neutrons can stay on the same grade. This is why about half of particles are protons and half of them are neutrons in a stable nucleus. Thus the nuclear droplets are positively charged and repel each other by long-range electric force. The *intensity* of the short-ranged nuclear attraction and the *long range* of the electric repulsion make the nuclei to long-lasting structures. This explains the stability of chemical elements, which is the basic axiom of school chemistry.

The chemical properties of elements depend on their electron shells. The size of the electron shell depends upon the positive electric charge of the nucleus, i.e. on the number Z of protons in the nucleus. The Periodic Table of chemical elements terminates, however, at $Z<100$. The explanation is very simple: electric repulsion between two protons is about 100 times weaker than nuclear attraction. But the electric repulsion has a long range: the joint repulsion of all the other protons may become comparable to the nuclear attraction of the immediate neighbors in case of $Z \sim 100$, which destabilizes the very heavy (high Z) nuclei.

A nucleus is made of Z protons and N neutrons, altogether $A=Z+N$ particles. The average binding energy per particle is weakened if

a) A is small (large fraction of particles is on the surface),
b) Z is large (intensive electric repulsion acts among protons),
c) $Z>N$ (protons are forced to high energy levels by the Pauli principle,)
d) $N>Z$ (neutrons are forced to high energy levels by the Pauli principle).

Nuclear particles feel themselves most comfortable (possessing the deepest average binding energy per particle) at medium-sized nuclei ($A \sim 50$), with about 50 % protons and 50 % neutrons in them. This can be visualized by a map, indicating the *average binding energy per particle* versus Z and N. A narrow valley runs through the Z--N} plane, more or less following the $Z=N$ line. Two sides of the valley ($Z>>N$ and $Z<<N$) are steep due to the Pauli principle. Starting from small $A=N+Z$ values, we walk downhill in the Nuclear Valley, due to the short range of nuclear attraction and decreasing relevance of surface energy; this is the *Yukawa slope*. For large Z values, however, we begin climbing uphill along Nuclear Valley, due to the electric repulsion between the many protons present in the nucleus, this is the *Coulomb slope*. At the deepest point we find the iron nucleus ($A=56$).

It is a remarkable fact of Nature, that the chemical elements populate the whole Nuclear Valley, but the most common metals are to be found at its deepest part: at the *Iron Sea*. We don't pick up a rusted iron nail, but we take a golden ring with.

	large Z Coulomb slope	
{$Z<<N$} Pauli slope	$Z \sim N, A \sim 50$ **IRON SEA**	$Z>>N$ Pauli slope
	small A Yukawa slope	

4. RADIOACTIVITY

If one puts an arbitrary Z number of protons and N number of neutrons together, the system goes quickly to its energy ground state by emitting electromagnetic radiation within a tiny fraction of a second, in the same way as atoms do. But at nuclear transitions the emitted photons have much higher energy (*ã-radiation*).

If $N>>Z$, then the nucleus can transform itself to another nucleus of deeper energy by a *neutron proton* transmutation, releasing also a negative electron (and an antineutrino). But the transmutation of a nuclear particle is a *weak transition*, it takes much more time: minutes, days, even years. (*â-decay*).

If $Z>>N$, the *proton neutron* transmutation may lower the energy content of the nucleus. The proton can get rid of its positive charge by capturing an electron from the atomic shell. (By electron capture or by emitting a positive positron. In both cases a neutrino, too, is emitted. In order to decrease the lexical knowledge to be memorized by the students, we do not speak about positrons and neutrinos in the school. We speak only about electron emission to increase Z, electron capture do decrease Z. These â-transitions enable the nuclei to slide down the Pauli slope to reach the Nuclear Valley.) If we replace a neutron (standing high up on the energy ladder) by a proton, the new particle may find empty proton grades downstairs, therefore it jumps down, â-decays are usually followed by ã-decays.

If the electric charge of the nucleus is too large, by splitting into two parts it could decrease its energy: the two fragments would repel each other vehemently. But the first step of splitting would be the deformation of the spherical droplet, i.e. an increase of its surface, which means increasing surface energy. The energy will drop only after the formation of two spherical droplets out of a larger sphere: sliding down on the Coulomb slope may begin. Thus splitting of a large nucleus could liberate electric energy, but an energy barrier prevents it. A He nucleus may leak through this barrier by quantum tunneling, but that may take thousands, millions, even billions of years. (á-*decay*). For larger fragments the tunneling time would be even longer.

We experience that the nuclei, occurring in Nature, are to be found down, in the Nuclear Valley. This is the result of sliding down on the slopes. Radioactivity -- as *nuclear cooling* -- is a natural phenomenon in the same way as the cooling of hot water in a cup is -- but the released energies are larger, even million times larger.

5. OUR NUCLEAR HISTORY

In the Universe the most common chemical element is hydrogen, making about 75 % of the cosmic stuff. This hydrogen the leftover from the Early Hot Universe. In the first second of the cosmic history the temperature was so high, random thermal motion was so intensive, that composite nuclei could not survive. Cosmic history started with H. As if a shower had poured a lot of water at the Zero End of the Nuclear Valley. But positive protons repel each other therefore they cannot merge...

In the gradually cooling Universe gravitational attraction formed gas clouds. The work of gravity heated these contracting hydrogen clouds up to several million degrees. At such a high temperature there is a certain chance for the single-charged H nuclei (Z=1) to collide, to touch each other and to make He (Z=2) by nuclear fusion. The released nuclear energy feeds the starlight.

In the stellar interior the temperature is originally not high enough to make also the fusion of He nuclei (with charge +2e) possible. But when the H fuel of the star becomes exhausted, the gravitational pull heats the center to 100 million degree, and the fusion of He begins, three He make C, one more He makes O, these life essential elements. Such hot He burning stars are known as *red giants*.

When the He content of the star becomes exhausted, the star is very hot and it shines intensively. The energy loss is covered by further gravitational collapse. The central part of the star collapses to nuclear density, a *neutron star* is formed. The outer layers keep falling in and upon impact they are heated up to billion degree. At such a high temperature the collisions are so energetic, that nuclear droplets start boiling away. All nuclear reaction channels open up; the whole Periodic Table becomes populated. Nuclear matter is dispersed along the whole Nuclear Valley.

But this total nuclear freedom does not last long. Within minutes the heat of the layers falling in produces a thermal explosion: the giant star strips its outer layers off. Gas shells, rich in heavy metals, are ejected to the outer space. Faraway astronomers can register the brilliance of the quickly expanding hot gas sphere as *supernova explosion*. In the heat of this explosion even the heaviest elements (Z>90) were formed. Such an explosion occurred in this region of the Galaxy 4.6 billion years ago. (Its time can be read from radioactive clocks: by measuring the ratio of radioactive elements and their decay products in the most ancient meteorites.)

From the collision of the ejected dirty supernova-material and the pure interstellar hydrogen gas the Solar System has been formed. Thus the Sun is made of the lightest elements, with some metallic concentration. As the work of gravitational attraction warmed the Sun above 10 million centigrade, the nuclear fusion H Sunshine is fed by the liberated binding energy of helium nuclei. (*Helios* is the Greek name of the Sun.)

The innermost planets were formed from dust grains, covered by the ice of H_2O and CO_2. The sunshine made these planet lukewarm, thus the volatile H_2, He, CH_4, Ne escaped. The radioactive elements, inherited from the supernova, melted the Earth in the first half billion years of her existence. Heavy metals (Fe, Co, Ni) sunk to the core of the planet. Lighter metallic oxides and silicates made the crust. As the radioactivity decreased, the crust solidified. Volcanism released CO_2 and H_2O, to make atmosphere and ocean. The sunshine, produced by *nuclear fusion* in the Sun, keeps the oceans liquid, warms the atmosphere, drives the winds and rivers, and feeds life by photosynthesis. Geothermal heat, produced by *radioactive nuclei* inside the Earth, manifests itself in hot springs and volcanism. These two phenomena, *the two flows in the Nuclear Valley towards the Iron Sea*, keep the Universe changing and they shape the face of our home planet.

Deeply inside the Earth the melted rock material expands, becomes lighter, and rises to the surface. Here the magma cools, solidifies, shrinks, becomes heavier and sinks down. This geothermal circulation drives the plate tectonic motion: continents collide, mountain chains are formed, between the continents oceanic rifts open up. India hits Asia at a speed of 4 cm/year, producing the Himalayas. Such plate tectonic drift has made the chain of islands, which is Japan today.

The composition of the Sun is changing due to nuclear fusion. Its temperature rises slowly; its luminosity increases by 5 % per billion years. The water was liquid on Venus 3-4 billion years ago, and then it evaporated to the atmosphere. The icy moons of the Jupiter will melt in 2-3 billion years from now. But liquid ocean is present on the Earth since 4 billion years, offering time long enough for biological evolution. What sort of air conditioning preserves the steady temperature of our blue-green planet?

The sunshine warms the soil. The lukewarm soil emits infrared radiation. Terrestrial temperature depends on the balance of heat input and output. The actual temperature depends sensitively on the CO_2 concentration of the atmosphere, because CO_2 molecules absorb this infrared radiation. Without the atmospheric CO_2 the Earth would be as frozen as the Moon is.

CO_2 is released by volcanism and is dissolved in rainwater, to make carbonic acid: CO_2+H_2O H_2CO_3. Carbonic acid attacks volcanic silicates and dissolves them into seawater in the form of limestone: $CaSiO_3 + H_2CO_3$ $CaCO_3 + H_2O + SiO_2$. The sedimentary limestone and sand sinks deeper and deeper. Down the limestone dissociates due to geothermal heat: $CaCO_3$ $CaO+CO_2$. The CO_2 rises into the atmosphere in carbonated springs. The calcium oxide and sand make $CaSiO_3$ again, and the molten silicate -- due to thermal expansion -- flows to the surface at volcanic eruption. This steady circulation of CO_2 is driven by the weathering of rocks (sunshine) downwards and volcanism (radioactivity) upwards.

If the climate warms up, e.g. due to increased solar luminosity or to increased CO_2 concentration in the atmosphere, the stronger thermal motion accelerates the chemical reactions. Faster weathering means extraction of more CO_2 from the atmosphere, thinning greenhouse, and lower temperature. (The speed of the geochemical reactions in the deep is not influenced by temperature changes outside) If the climate cools, weathering slows down, less CO_2 is extracted, and the increasing atmospheric CO_2 warms up the atmosphere. This *negative feedback* keeps the temperature of the biosphere at constant level. Our special planetary air conditioning is driven by sunshine (nuclear fusion) and geothermal heat (nuclear radioactivity). This air conditioning does not work on Venus (the planet is too hot, it does not have rainwater to make carbonic acid). It does not work on Mars either (the planet is too small, it cannot preserve radioactive heat to drive plate tectonics and volcanism). On the Earth, we are fortunate. The only problem is that the reaction time of the terrestrial air conditioning -- offered by Nature -- is rather long, several thousand years. It cannot offer defense against such a sudden attack like converting all fossil fuels into CO_2 during the few hundred years of the Industrial Revolution.

Thermonuclear fusion in the Sun and natural radioactivity in the Earth are both delayed cooling of supernova materials. They are natural phenomena, as the cooling of hot water in the pot and flow of rivers into the ocean. Well, the phenomena of Nature can be controlled and utilized, as the water mill does with the energy of the rainwater running down the valley. The efficiency can be enhanced; the level difference can be increased by constructing dam. Why don't we utilize the natural flow of nuclear matter along the Nuclear Valley towards the Iron Sea? The discovery of *nuclear fission* made the artificial transmutation of very heavy uranium into medium-heavy nuclei possible in nuclear reactors. A nuclear power plant is a straightforward utilization of a natural phenomenon in the same way as the water mill or windmill is. The advantage of nuclear power plant with respect to chemical power plants is that it does not affect the carbon-dioxide greenhouse.

It is a psychological fact, however, that nuclear power was discovered in the 20th century, in our lifetime. Humans have not got used to it through generation, like they learned to use firewood or riverflow or coal. It is now the duty of radiology education, to express in simple terms, what nuclear energy is. In conclusion, let us quote James Lovelock, the British atmospheric chemist, who has elaborated the Gaia model of the terrestrial biosphere, which has become the guiding principle of environmentalists:

-- The natural energy of Universe is nuclear energy, this feeds the starlight on the sky. From the point of view of the Director of the Universe chemical energy, wind energy, and water mill are insignificant phenomena, as a coal fired star would be. And if it is so, if the Universe of God is driven by nuclear power even today, then why do people demonstrate against making electricity out of nuclear power?

APPENDIX

For those teachers, who like formulas: The volume of the spherical nucleus is proportional to the number A of its constituents, thus its radius is $R=R_0A^{1/3}$ ($R_0=1.2\cdot10^{-15}$m). The binding energy contains the main (negative) term proportional to A. The binding is decreased by the (positive) surface energy proportional to $4\pi R^2$ and by the Coulomb energy $0.6(Ze)^2/4\pi\varepsilon_0R$. Due to the Pauli principle, a positive n^2 term appears in E/A (binding energy per particle) if the relative neutron excess $n=(N-Z)/A$ is different from zero. These altogether give the following formula:

$$E(A,Z)/A=-\mathring{a}_B+\mathring{a}_S A^{-1/3}+\mathring{a}_C Z^2/A^{4/3}+\mathring{a}_P(A-2Z)^2/A^2.$$

This is the equation for the Nuclear Valley, the positive terms describe the Yukawa slope (decreasing with increasing A), the Coulomb slope (rising with increasing Z) and the Pauli slopes (rising with increasing n^2). Comparison with the measured binding energies gives: $\mathring{a}_B$=2.52pJ, $\mathring{a}_S$=2.85pJ, $\mathring{a}_C$=0.11pJ, $\mathring{a}_P$=3.80pJ. For a fixed A particle number, E is a quadratic function of Z, its minimum $Z_{min}\}=0.5A/(1+0.0075A^{2/3})$ gives the most favorable proton content of the nucleus.

JP0050073

2.2 NUCLEAR PHYSICS TEACHING FOR JAPANESE TEACHERS FROM A HUNGARIAN PHYSICS TEACHER

with Love and Respect

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ABSTRACT

I intend to give belief to science teachers living in an efficient society where entrance examinations and evening schools, making money and art of advertisement seems to be the emperor of the children's mind. If a nation does not want to import creative people from abroad, it will change the education any way. The changes should come from genuine teachers who work on the field, who meet the young people day by day. Nuclear literacy is only an example to show how we can catch the attention of the open minded young people. The teachers who love their students will find further possibilities.

1. LECTURES AND READING

At about 1980 the Hungarian physics teachers noticed that their students are not so interested in physics lessons as before. If the students were in a good term with their physics teachers they questioned them about semi-conductors or super-conductors, about molecular biology or nuclear power in break-time. And their questions were on *how these work, how they can be used* and not about the names of old and wise physicists having lived at the beginning of this century. That time the Hungarian Academy of Sciences initiated a movement to create a new science curriculum for schools. Then new school books were born. And new teaching methods begun to form.

One of the new chapters is nuclear physics. (The Japanese version of the Nuclear Physics text book was published by the Maruzen Co., Ltd., Tokyo in 1998 December in the excellent translation of Jumpei Ryu and Tae Ryu.) In this book nuclear physics is based on the binding energy of nuclei, or better: *on the changes of energy of nuclei.* In this structure nuclear physics consists of three main parts in the text book:

1. Experimental discovery of nuclei and neutron (Rutherford's, Chadwick's and other experiments, shown by computer simulation)
2. Droplet model for heavy nuclei (mapping the energy valley in the plot of energy per nucleon versus the number of neutrons and the number of protons)
3. Applications of the droplet model (radioactivity as "cooling" of nuclei, fusion, fission; natural and artificial radiation, health effects, reactors, power plants, bombs)

In Hungary this book is used in the last year of the high school which means about the 25% of the whole population. According to the last national curriculum (1996) a very simple version of nuclear physics and radiation protection have to be introduced to the whole population in the middle school before the age 16.

Problems (*in italics*, a possible solution in roman characters):

A good percentage of the older high school teachers, and all the middle school teachers missed the nuclear chapter of physics in their education. In the last 10-15 years many of the physics teachers went to voluntary postgraduate teacher training in nuclear physics courses because of the pressure of their students.

At the entrance examinations there are no questions about nuclear physics. In Hungary there are a few physics competitions where the first 10 students are accepted in universities without entrance exams. In the last year the Leo Szilard Competition on radiology was accepted also as one of these competitions.

Nuclear physics in the last year of the high school was too late, the students arrive with many ugly misconcepts about radioactivity learnt from newspapers and television. This is why the newest national curriculum brings nuclear physics earlier: to the age less than 16 years old and for the whole population.

2. SIMULATION AND EXPERIMENT

Nuclei don't age: their decay occurs as randomly as traffic accidents. Let ask the students of the whole class to stand up, then to throw a 10 Y coin every time when you clap! Those whose coin fall with the value facing upwards have to sit down. Let count the students standing after each clap! With this simple game you simulate the randomness of radioactive decays, in order to introduce the idea of half life time.

The computer offers many other possibilities for simulations, and not only for half life time but for the Rutherford's and the Chadwick's experiment, for the nuclear chain reactions, reactor or power plant simulations as computer games. These simulations can help to understand the non-visible phenomena, the experiments with expensive equipment.

But to understand something in a deep way means not only to be able to follow the logical steps of a proof leading to a conclusion. If you introduce everything via computers then your students will forget about the real world, nuclear physics may become a "virtual reality" (where everybody has at least three lives). In science one can understand something if one has one's own experiences. The teacher needs to offer experiments (not only computer simulation or video) for their students in the classroom. Here there are a few of the classroom experiments what is used in Hungary:

^{137}Cs is an artificial element on Earth, born in nuclear fission. It has a half life of 30 years, and by β decay it becomes ^{137}Ba. The ^{137}Ba is born usually in excited state, so it has to make a γ decay, with a half life time of 2.5 minutes. The Cs and

Ba can be separated by chemical solution. Many years ago East Germany produced a so called "school isotope generator": a porous ceramic pill absorbed ^{137}Cs on its inner surface was taken into a syringe. Thus the chemical solvent was able to wash out the Ba from the pill easily. The radioactivity of the solution containing ^{137}Ba can be measured by the simplest Geiger counter. Because of the short half life time, this experiment fits to lesson time.

From educational point of view it is important to show the students that radioactivity is a natural phenomenon. Putting six layers of ordinary medical gauze at the end of the tube of a vacuum cleaner one can collect the very small dust particles and small water droplets from the air in about 30 minutes. If there are any radioactive ions in the air they will stick to the dust. In this way, again with the simplest type of a Geiger counter, one can show the radioactivity of air in the school..

Even more simpler way to collect the radioactive ions from the air is by using a balloon. Blow a big balloon, rub it with hair to make it negatively charged, and hang the balloon not too far from the floor. (For better result use the ground level of the house.) Measure the clicks per minute by a Geiger counter before you blow up the balloon, this will be the background radiation. About a half an hour is enough to wait for the collection of radioactive ions from the air. Then let the air out of the balloon, and measure the clicks per minute again on the original sized surface of the balloon. (The surface was large when it collected the ions. Now, on the smaller surface there is higher density of radioactive material.)

In the last two cases one can also make a *measurement* and not only an observation of the presence of natural radioactivity. The radioactive ions in the air are coming from the decay of radon, the radioactive inert gas. Radon is everywhere on the Earth. After the decay of radon (^{222}Rn) radioactive polonium (^{218}Po), then radioactive lead (^{214}Pb), then radioactive bismuth (^{214}Bi), etc. are coming. The lead and the bismuth makes β and γ decays. This is why the simplest Geiger counter is able to detect them. The half life of the radioactivity of the dusty medical gauze or that of the balloon is about 40 minutes. (This comes from the 20 minutes half life of the ^{214}Pb and the 27 minutes half life of the ^{214}Bi.)

Problems:

Some teachers who were amazed by the computer possibilities tried to introduce "everything" by computer codes. - The only solution is to WAIT! Wait till the teacher realizes again that science is interesting because it can not leave away the real world. Most Hungarian teachers have already been cured from the disease of virtual reality.

*East Germany does not exist any more to create such an inexpensive school isotope generator (*60 *US Dollar that time). Thus only those schools are happy to use it which bought this* ^{137}Cs *source before* 1985 (*the half life of* ^{137}Cs *is* 30 years). B*ut other schools are poor to buy the expensive American or Japanese version of the same isotope generator.* - The radon is present everywhere, collecting the daughter elements by vacuum cleaner or charged balloon can solve this problem.

In the early 80-ies the Soviet Army was still present in Hungary. It was easy to buy from the soldiers (on the very black market) military Geiger tubes Bright young boys built up the electronics for these tubes creating very good Geiger counters. But the Soviet troops went out from Hungary ... These days some Ukrainian people bring relatively cheap Geiger counters from the Chernobyl region, selling them on the (not so) black market. In Japan the Geiger counter is not a problem, you can lend it from the State, each student could use them in the school or even at home.

3. EXPERIENCE AS EARLY AS POSSIBLE

When you teach your son to count, you use his fingers: "one, two, three, ..." You use his fingers although you do not explain at first to him that fingers are consisted of living cells, in those cells there are water molecules and DNA, and proteins... You use these fingers because they are at hand. When you teach your son to count, you do not stop at 2 and 3 and 5 explaining that they are primary numbers, even the concept of odd and even number is coming later when he is able to count routinely. The students know a lot of things about numbers before they learn number theory. We should not forget this practice when we want to make our pupils and students to be familiar with radioactivity.

With the help of a Geiger counter every pupil at the ages 10 to 14 can map the radioactivity in his or her environment. Where the Geiger counter is clicking faster, there is more radioactivity. They can observe the radiation of furniture, the swimming pool, the wall of the school, the soil in the garden, flowers, mushrooms or even their own body. If they find a granite wall they become excited and happy. (See also the experiments in the Fourth Elementary School in Nerima-ku, Tokyo).

In Hungary all the researchers thought there was no radon in homes at an unhealthy high level due to the geology of Hungary. Then in 1992 it turned out surprisingly that there was a small village in North Hungary where because of special geological reasons the indoor radon levels were high. The Hungarian School Network of Radon Survey started in that year. In that nice village, Mátraderecske, people did not understand why the white collar researchers were entering their homes and murmured not understandable words; the local people questioned them whether they were in danger or not, but it was in vain: there was no answer. Newspapers cried about the hell of radioactive homes in their village, about catastrophic situation but at the same time people did not sense anything special in their homes. Then I arrived to the village together with my students.

We went to the village school and we played together with the local students to make them experienced with Geiger counters. We talked about radioactivity, and about its health effect. The elementary school pupils became literate in radiation protection. They went home and they explained their parents what happened in the school. They asked their parents, grandparents, and other relatives, whether they could bring home small detectors (CR39) to know how high was the radon level in their bed rooms. In this way we were able to measure the radon in all the homes of the village. When the results came, together again with the local pupils we gave the results to the house owners. The pupils had to explain what was the meaning of 500 Bq/m^3, they had to speak about the meaning of yearly average, about the possible health effects. In the homes where the radon level was higher then 800 Bq/m^3, with the students we found out very cheap and effective mitigation methods after having consulted with the house owners.

In Mátraderecske our school laboratory (named RAD Lauder Lab) had learnt:

1. To make measurement at home (not only in physics lab) is a huge attraction for pupils.
2. It has became natural for pupils: radioactivity is everywhere, even in their bed rooms.
3. It is very important to let the house owners know the results in their home, with explanation at a mental level what they can follow.
4. The students were excited to learn as much as possible about the topics because they wanted to be well informed in front of their parents and relatives.
5. The pupils had to learn also how to communicate with people at different literacy levels and different attitudes towards the radioactivity.
6. We also learnt in Mátraderecske how to reduce the radon level where it is too high.

After the first two years of these lessons in Mátraderecske we have invited any other villages to take part in the radon survey. Up to now the RAD Lauder Lab - in co-operation with the local physics teachers and pupils - measured the radon level in more than 15 000 homes in Hungarian villages. This means also that about 15 000 Hungarian pupils learnt about natural radioactivity in the above mentioned direct way together with their parents. (Hungary is a small country, 10 million inhabitants, so 15 000 pupils are many.)

Problems:

Money for the detectors. If you want to make similar radon measurement in Japan one (only one!) detector costs (together with the evaluation done in USA) 60 US $. In Hungary it is much cheaper. I buy the CR39 track detectors from United Kingdom for 0.5 US$ each. We use a very simple box (0.07 US$) for container. We have learnt how to etch the detectors. My old students built up a tracks counter machine. They also wrote an excellent image analyzing program for IBM PC. One result costs less than 1 US$, including mailing, but not including the work made by the teachers and many pupils of the RAD Lauder Lab without any extra payment. To take part in the survey would costs about 2-300 US$ for each school, but up to now I were able to create money by finding sponsors, so to take part in the survey is free for any Hungarian school.

One could think that this is *only childish work*, but in each year we take part at the International Intercomparision of Radon Measurement organized by the National Radiation Protection Board, England, and our data turn out to be good. The students and pupils are generally much much reliable than the adults ...

4. RESEARCH

"One can not make fire if one does not bear the temperature of fire." If a teacher has never felt the smell of scientific research at least on a small scale, he/she would not be able to educate for scientific thinking.

When a village school gets the results of the radon levels of homes, the teacher and the pupils try to explain themselves the differences. Why there is higher radon level in one room than in the neighboring room? Why was the result larger in Autumn than in Spring? Last year Winter the radon level was lower than this year, WHY? And so on, there are many more questions for discovery because the indoor radon level depends on many parameters: geology, house structure, meteorology, the way of living, etc. Discussing these questions - even only in the short breaks - a good teacher can teach deeper scientific thinking than during the official lessons by slopes and pulleys, AC and DC. For pupils and students the unknown is the real challenge. Taking part in the radon survey they feel that there are no written answers to choose one of them, but *they are* themselves who have to make hypothesis what should be checked by their own experiments.

In the last seven years the RAD Lauder Lab measured the radon level in many homes, enough to ask the question whether there is any health effect of high radon level. We collected the cancer cases with the help of the local doctors, and identified the bed rooms of the patients 15-20 years before the cancer turned up. In the case of women (younger than 60 years, no smokers) we can state with a probability not less than 98% that between 100 Bq/m^3 and 170 Bq/m^3 the cancer incidence is less than at lower or at higher radon activity concentrations. (For your orientation: the Japanese radon average in homes is only 39 Bq/m^3!) It means that a few times higher radioactivity from indoor radon than the average would result lower cancer risk! This was published in the medical journal Pathology Oncology Research, London (the editors did not say it would be a childish work).

From time to time in human history teachers should think it over whether what they teach is important for the next generation or it is not. One thing is sure: if the students hate to take part in physics lessons then those lessons are not worth at all. As teachers we have to *respect* the way of thinking of our students, because they will create the *future*. When the students refuse our pedagogical tricks which we wish them to lead the conclusions what was discovered many years ago by scientists, and when the students say that the evening schools are better than our morning schools because those tell them The Good Answer for the entrance examinations, I am afraid, they are right. They want to survive the entrance exams! If you are not able to fight against those creativity killer exams, you should find something else which is more interesting for your students. As a physics teacher I think the reality is the most interesting for my students. The Hungarian experience in the School Network of Radon Survey shows us a way how to activate again the curiosity and the responsibility in our students.

Problems:

There are many problems left! But these are interesting challenges. And **the love for your students may help you every time to solve these problems.**

JP0050074

2.3 PRESENT STATUS OF RADIATION EDUCATION IN BANGLADESH

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ABSTRACT

Radioisotopes and Radiation are being widely used in the fields of agriculture, medicine, industry for the benefit of people throughout the world. At the same time the use of radiation sources can do harm to man and environment. In order to ensure the safety against radiation hazards and safe use of radiation, proper education, training, knowledge and awareness are essential. Like other countries Bangladesh is trying to achieve economic development through application of isotopes and radiation technology in agriculture, food, industry, power, health or medicine. Basic education about radiation is incorporated in the school curriculum. Courses on radiation are also given in college and university education. Research organizations, universities carry out research and development works on different disciplines using radiation and radioisotopes. Seminars, workshops, conferences, trainings on isotopes and radiation are also being organized. In 1993 Government of Bangladesh passed the Nuclear Safety and Radiation Control Act-1993 for safe use of radiation. The present paper will cover the radiation education, research & development works on radiation, applications of radiation in agriculture, medicine and industry, personal safety and radiation protection against radiation hazard and rules & regulations of the nuclear safety and radiation control act practised in Bangladesh.

1. INTRODUCTION

Basic Radiation Education is started in high school level. Then more detailed radiation education is given in college and university levels. The course curriculum contains the topics like types, natures and sources of radiation, its properties and characteristics, its uses and benefits, its dangers and safety. Universities and research organizations carry out research and development works for peaceful uses of atomic energy in the fields of agriculture, medicine and industry for socio-economic development of the country. Personal safety and radiation protection is effectively ensured through the practice of Nuclear Safety and Radiation Control Act now in force in the country. Regularly organized seminars, symposium, workshops, conferences and training courses help to give proper education for the radiation workers to protect man and environment against the danger of ionizing radiation. The present paper will highlight the radiation education in Bangladesh.

2. RADIATION EDUCATION IN EDUCATION INSTITUTES

2.1 Educational curriculum concerning radiation in High Schools

The school students spend ten years to have Secondary School Certificate (SSC). In the last two years of their high school education in science group they are taught very basic radiation education e.g., X-rays, production of X-rays, uses and properties of X-rays, radioactivity, nature of radioactive rays, characteristics of radioactivity, properties of alpha, beta and gamma-rays, half life of radioactive elements, units of radioactivity, danger of radioactivity, nuclear energy, merits and demerits of nuclear energy. Students do not have any practical demonstration to handle the radioactive sources and X-rays at this level.

2.2. Educational curriculum concerning radiation in Colleges

After successful completion of SSC examination the students get admitted in two years education in the college level to have Higher Secondary Certificates (HSC). The course curriculum of the radiation education in science group covers cathode rays and its properties, X-rays, production of X-rays, its properties and different uses in the laboratory, medicine, industry, commerce, agriculture, detective departments, kinds of X-rays, unit of X-rays, radioactivity, characteristics of radioactivity, radioactive rays - alpha, beta and gamma rays, properties of radioactive rays, kinds of radioactivity - natural radioactivity and artificial radioactivity, units of radioactivity, radioactive decay laws, half life, mean life or average life, uses of radioactivity - medicine, agriculture, industry, some important terms - Isotopes, isobars, isotones, radioisotopes, uses of radioisotopes, cosmic rays, properties and kinds of cosmic rays, atomic models, structures of atoms and nucleus. No practical demonstration is conducted at this level also.

2.3 Education curriculum concerning radiation in University

The general universities provide four years of study - three years in undergraduate level (Honours) and one year in post-graduate level (M.Sc.) in the science faculty. The technical universities/institutes also offer four years of study to have B.Sc. (Engg.) degree but medical colleges have five years of study to have MBBS degree. The course curriculum of technical universities and institutes does not contain much about the radiation education. Some basic knowledge about radiation is given. Radiology is taught in the medical colleges for awarding degree of MBBS in radiology. But in general universities a broad range of radiation education is taught both in undergraduate and post-graduate levels in the Faculty of Physical Sciences. Major topics in the course curriculum are as follows:

Atomic physics: quantum nature of radiation, photoelectric effects, compton effects, electron diffraction, Rutherford scattering, electron spin, production of X-rays, X-ray scattering.

Nuclear physics: basic properties of nuclei, radioactivity, alpha emission, gamma radiation, beta decay, interaction of radiation with matter, nuclear models, nuclear reactions, nuclear reactors, nuclear fissions, nuclear fusions, accelerators.

Radiological physics: units and measurements, biological effects of ionizing radiations, external and internal effects, low-level radiation effects, radiation protection guide and shielding, radiation detection.

Medical physics: Imaging technique - gamma camera, CAT scanner, radiopharmaceuticals radiotherapy, radiation protection, radiation dosimetry.

Nuclear and Radiochemistry: basic concepts of nuclear and radiochemistry and radiation chemistry, the atomic nucleus and its properties, radioactivity and radioactive decay laws, nuclear reactions and fission, interaction of radiation with matter and detection of nuclear radiation, nuclear reactors, cyclotron, Van de Graaff accelerators, production and uses of radioisotopes, nuclear, nuclear related and radiochemical methods of analysis and their application, nuclear power and safety.

Students at university level carry out practical experiments and research works on some selected topics of radiation. After awarding M.Sc. degrees, students may get admitted to M.Phil and Ph.D. degrees in local universities. Courses in Health Physics, Medical Physics and Radiation Protection cover the following topics:

Nuclear physics, nuclear reactors, nuclear models, physics of radiology, health physics, radiation biophysics, physics of radiotherapy, medical physics, reactor physics, radiation protection.

Universities in close collaboration with the research organizations carry out also research works on medical physics, nuclear physics, reactor physics and other related subjects for higher studies leading to M.Phil and Ph.D.

Radiation education background from High School to University levels has so far been described. Now the research and development works and applications of radiation technology and radioisotopes carried out in different research organizations are described below:

3. RESEARCH & DEVELOPMENT WORKS AND APPLICATIONS

3.1 Bangladesh Atomic Energy Commission

Since its formation, Bangladesh Atomic Energy Commission (BAEC) is playing a pioneering role in the country's nuclear research programme. BAEC has undertaken research and development programme in the peaceful use of atomic energy in its various establishments to develop indigenous expertise and thus achieve the cherished goal of self-reliance through national efforts and international cooperation. Its primary objectives are:

- Promotion of peaceful uses of atomic energy in agriculture, medicine and industry;
- Development of related technology like electronics, computer, materials science, etc.
- Planning, Implementation and Operation of nuclear power plants.
- Services in the sterilization of medical products, food preservation, non-destructive testing, elemental analysis, hydrology, etc.

3.1.1 Its major nuclear facilities are:

- 3 MW TRIGA MARK-II Research Reactor
- 3 MeV Van de Graaff Accelerator
- 14 MeV Neutron Generator
- 50,000 Curies Co^{60} Gamma Source

3.1.2 Major areas of activities in nuclear field

3.1.2.1 Physical Sciences

- Analytical methods such as Proton Induced X-ray Emission (PIXE), Proton Induced Gamma Emission (PIGE), X-ray Fluorescence (XRF), Neutron Activation Analysis (NAA), Atomic Absorption Spectrometry, Gas Chromatography, Polarographic techniques have been developed. Some of these methods are being used in analytical services and research. Trace element analysis of various samples including water, air, human hair, nail, body tissues & fluids, pulses, tobacco, food staffs is also carried out.
- Radiation vulcanization of natural rubber - latex
- Nucleonic Control System for paper, steel industries
- Non-Destructive Testing (X-ray radiography, gamma radiography, neutron radiograph), necessary services are rendered to the industries.
- Isotopes in industry and hydrology

  Application of tracer technique has been made in studying different problems in hydrology like aquifer condition related to exploration of ground water, sand and silt movement etc.

  Tracer techniques are also being used for calibration of flow rate measurement, distillation column scanning at Petrochemical Industries, RTD measurement in different industries like fertilizer, cement, paper, chemical etc, measurement of levels and interfaces in different vessels.

3.1.2.2 Biological Sciences

- Agrochemical research.

  Analytical laboratory infrastructure based on nuclear and related conventional instrumental techniques has been developed and provides necessary analytical services for analysis of pesticide residue in food and environmental samples.
- Food preservation and medical product sterilization.

  BAEC has made laudable achievement in using nuclear radiation for food preservation, pest control and medical product sterilization. Experiments are also being carried out for genetic improvement of microbes and higher plants that are of economic importance. BAEC and BEXIMCO jointly installed a "Gamma Tech" commercial plant in 1993 with 1,30,000 Curies Co^{60} Gamma Source.
- Tissue Banking:

  Radiation sterilization of tissue grafts for use in rehabilitative surgery.
- Nuclear Medicine

  BAEC is rendering valuable services to the country's population through its nuclear medicine centres. There are at present 14 Nuclear Medicine Centres situated all over the country. Radioisotopes are used for diagnosis and curative purposes. The investigations include diagnostics and treatment of thyroid gland diseases, scanning of brain, liver, kidney, bone etc., identification of diseases of liver and skin due to malnutrition and localization of tumour in various parts of the body. With the establishment of 3MW TRIGA MARK-II research reactor, some radioisotopes like technetium-99m, iodine-131, fluorine - 18 are produced and are used in the nuclear medicine centres. Some essential radioisotopes are imported from abroad.

3.2 Bangladesh Institute of Nuclear Agriculture

Better mutant varieties of rice, jute, pulses and some other crops have been evolved using nuclear radiation at the Bangladesh Institute of Nuclear Agriculture (BINA). Optimum use of different fertilizers in different types of soil and radiation sterilization of insects have been studied. BINA is the only organization which is doing research works on agriculture using nuclear techniques.

4. NUCLEAR SAFETY AND RADIATION CONTROL

Nuclear Safety and Radiation Control (NSRC) Act 1993 was passed by the Government of Bangladesh. Bangladesh Atomic Energy Commission has been entrusted and empowered for implementation and enforcement of the Act. The NSRC Division of BAEC has been empowered with the following duties and responsibilities:

- Development and strengthening of necessary Nuclear Safety and Radiation Control Infrastructure in the country through the successful implementation and enforcement of Nuclear Safety and Radiation Control Act, 1993.
- Planning, motivation, coordination, direction and control of all R&D and routine activities pertaining to Health Physics and Radiation Protection in the country in order to save life, health, property and environment from the undue risks and deleterious effects of ionizing radiation.
- Preparation/adoption of necessary rules/regulations, standards, codes, guides etc. of various practices involving nuclear and radiation technology in the country.
- Advisory and coordination activities and identifying the problems relating to nuclear safety and radiation control particularly in BAEC and also in other establishments/organizations in the country.
- Supervision of overall activities of various Health Physics Laboratories of BAEC including Radioactivity Testing Laboratory at Chittagong.
- Issuance of NOC/Permits for import of radioactive sources/materials in the country.
- Liaison with the Ministry of Science and Technology as well as different national and international bodies on the matters of nuclear safety and radiation control.
- Research and development activities aiming at strengthening nuclear safety and radiation control activities including safe radioactive waste management.
- Organizing/conducting training courses and seminars on different aspects of nuclear safety and radiation control.

Nuclear Safety and Radiation Control Regulations and Rules have already been prepared and passed by the Government and are being practised in the country. In addition to NSRC Division there are three backup laboratories in BAEC. These are (a) Health Physics and Radiation Monitoring Laboratory, (b) Radiation Control and Waste

Management Laboratory, (c) Radiation Testing Laboratory. A salient features of the activities are summarized below:

i) For peaceful application of ionizing radiation in industry, medicine and research, the NSRC Division is being issued NOC/permit for import of radiation sources and materials to different industries & organizations.

ii) Radiation protection services are being offered.

iii) Under the general supervision and guidance of NSRC Division radioactivity level of imported and locally produced (for exports) milk, milk powder and other food materials are being tested at different laboratories of BAEC to determine the maximum acceptable level of radioactivity as per Government directions.

iv) Regulation supervision of the safety and radiation protection activities of the TRIGA MARK-II Research Reactor.

v) In collaboration with NSRC Division, the Secondary Standard Dosimetry Laboratory (SSDL) and Health Physics & Radiation Monitoring Laboratory of BAEC standardize and calibrate radiation measuring equipment/instrument and X-ray machines of different Government and private hospitals and clinics in the country and also make inventories of radioactive materials and X-ray machines.

vi) In addition to the above activities this Division also reviews and examines the radiation protection programme, area and environmental monitoring activities, emergency preparedness plan and suggests certain recommendations to the concerned authority.

vii) The NSRC Division organizes training courses on Nuclear Safety and Radiation Protection to make awareness among the radiation workers and public for safe use of the radiation sources.

ix) Measurement of radioactivity in environmental samples.

x) Personnel Radiation Monitoring services in the country.

xi) Radiation Survey and Dosimetry in Hospital.

xii) Inspection services for radiation protection.

xiii) Management and disposal of radioactive waste.

xiv) Calibration of deep therapy and teletherapy units.

xv) IAEA/RCA Personnel Dosimetry Intercomparison.

xvi) Education
BAEC conducts and offers lectures and demonstrations in Radiological Physics and Radiation Protection in Part-I Post-graduate Medical courses for DMRD, DMRT of Medical Colleges and FCPS (Radiology) and FCPS (Radiotherapy) of Bangladesh College of Physicians and Surgeons (FCPS). Post-graduate students of universities carry out their research works leading to M.Phil and Ph.D on Health Physics, Medical Physics and Radiation Protection.

5. INTERNATIONAL COLLABORATION

Bangladesh has active collaboration with

i) UNDP/IAEA/RCA Regional Project on the use of Isotopes and Radiation to Strengthen Technology and Support Environmentally Sustainable Development.

ii) IAEA Technical Cooperation Project .

Under these two international collaborations, Bangladesh receives equipment, experts and trainings.

6. CONCLUSION

Through proper radiation education and training and regularly organized seminars, conferences people are becoming more awared about the benefits of radiation and its uses in agriculture, medicine and industry for socio-economic development of the country. People specially the radiation workers are very much careful and conscious about the safe handling and use of radiation sources to protect man and environment. Nuclear Safety and Radiation Control authority is enforcing the rules & regulations in the country effectively and efficiently.

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2.4 RADIATION EDUCATION IN INDIA: CURRENT STATUS

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ABSTRACT

Like others, Indians too have fear of nuclear radiation, probably because of weaker systems of proper radiation-education to the sizable illiterates. Even in urban areas, laboratories are ill equipped and radioactivity-wise practically non-functional. Only through textbooks, some concepts are introduced and the media and Internet are yet almost non-influential. Some national institutes (DAE Labs.) and a few universities including ours are involved in research and teaching. National associations (INS, IANCAS) voluntarily organize workshops, symposia, practicals for the teachers/students and informative speeches for all. Syllabus emphasizing experiments for the age group 14-17 years is proposed and implementation-methodology is discussed.

INTRODUCTION

The pioneering efforts by Jamshedji Tata for promoting science and technology education in India resulted in establishing the Institute of Science, Bangalore. Dr. Homi J. Bhabha, a student of this Institute, lead the foundation stone of Tata Institute of Fundamental Research (TIFR) and then the Atomic Energy Establishment (1948). It was Bhabha's vision and inspiration that put India on the nuclear energy map and lead her towards peaceful uses of nuclear energy; since India possess limited amount of fossil fuels and irregular hydropower sources, promoting nuclear energy programs as an alternative had been a must. The well-planned foundation and systematic growth of nuclear technology became a trendsetter for many high technologies in India.

In order to achieve quicker technological progress after the independence (1947) certain important areas were emphasized, nuclear technology obviously remaining on priority. The nuclear power corporation is now in a position to plan setting up 17 more plants by the year 2020 to raise the total installed capacity to 20,000 MW. This has placed considerable demands on advanced material technologies and the spin-off from nuclear achievements could form the basis of the emergence of certain major industries. To support this, the DAE Training Division will have to expand its program still further producing skilled specialists. Concurrently, in order to sustain the impact of technological growth in India, radiation education system has to take firm roots in the entire nation. Besides nuclear energy, India has made significant growth in the radioisotope production. Diagnostic and therapeutic facilities utilizing isotopes have become essential all over the country to treat cancer; however, these are available only in a few specialized institutions. There are 120 cobalt-60 units in the country and it is estimated that for every one million people at least one unit is required; that means the present need is of about 1000 Cobalt-60 units. To generate and sustain such rapid growth, the requirements of the nuclear materials and correspondingly the need for solutions to the related environmental problems will increase and accordingly the burden on the education systems; producing specialists in all streams, educating the entire society.

EDUCATION- BACKGROUND

Education is the training of mind, brain and character, developing requisite abilities, attitude, knowledge, interests, skill, understanding and values in a person to enable him make worthwhile contribution to human welfare. Enthusiastic minds of the younger generation need to be well familiar with the world around and the vast strides of its scientific and technological developments. Very soon the Indian population will cross the one billion mark and at present, half the illiterates of the world live in India. A considerable fraction of the society is striving for mere survival and resides mainly in the rural areas. Because of poor attention given to education during the past 50 years of independence, benefits achieved through the technological development have not percolated to the weaker/poor sections. Besides, since the medium of instruction for science and technology courses is English and because the number of English medium schools is much smaller in comparison with the regional language-schools even in the urban areas, these courses are out of reach of the rural Indians.

In spite of the above, India has a large number of higher education institutions. There are over 225 central, state and deemed to be universities and more than 8000 affiliated and autonomous colleges. The number of teachers is 300,000 and the student strength is eight million, which is going up at a rate of 4.5% per annum. As per the government statistics, in the year 1990-91 the number of pupils in the age group 6-11 was 10 million, in the group 11-14, it was 33.3 million, in the group 14-17 it was 20.9 million and at the university stage (age: 18+ years) studying in arts, science and commerce faculties alone was 4.4 million. The complexity exists because of the population spread in urban, semi-urban, rural and remote areas, use of regional languages for teaching and a diverse socio-economic-geographical background. Even though the financial input in higher education has increased almost 10 times in the last five decades, there is a resource crunch and most of the money nowadays is going for keeping the system running rather than initiation of new programs. It is no wonder then that India has widely varying academic standards and the technology education still remains to be a negligible fraction of the traditional education.

THE 'FEAR' PROBLEM

Nuclear energy is significant since it is going to be the major source of energy to remain after the first half of the 21st century. Radiation education, therefore, must be brought into regular curriculum of high school level and its futuristic growth and benefits should be stressed with positive attitude. On the other hand the impact of 200,000 human kills at one stroke in the year 1945 is so strong that even today its effects are persistently felt and revealed in the writings by educationists, politicians and many others. Years ago the present Indian Prime Minister, Mr. A.B. Vajpayee, expressed his utter disheartening through the poem (translated by us) as :

'.....Did they feel at least for a moment
That whatever has happened
Is not at all good for the mankind?
If they feel so, then the time will not punish them;
But if they do not, history will never forgive them.'

The fear developed in the hearts of Indians is so deep-rooted that it explodes out wherever possible. A chapter from a voluminous book written by Indians on medicine is with the title, 'Nuclear Hazards'; and the benefits of radiation are also included under the same heading! Professional text book writers for the high school students emphasize:

'Pollution due to radiation is a dangerous pollution of modern times. The ultraviolet rays, x- rays beta rays and more penetrating gamma rays are more and more hazardous to the body. They show adverse effects on cell growth and interfere with the genetic constitution and metabolic activities. The harmful radioactive waste is a great problem.'

PRESENT RADIATION SYLABI

Although there has been an increasing trend of nuclear energy production and of application of nuclear radiation in our day-to-day life, the spread of its scientific / technological knowledge among the Indian masses is extremely poor. The authors fear that there is always a limit to the gap between technological development of the society and the knowledge received by the society about the development. When the gap widens further, no longer being able to sustain the pressure, the society may develop enmity with that technology, howsoever beneficial it may be! And as per the university set up the existing nuclear - radiation courses on the whole are only theoretical, students do not find opportunity to even observe demonstrated experiments. Only a handful of Indian universities in the disciplines like chemistry, biology, medicine or engineering teach and do research in the radiation field. In physics, this number is sizable; however, practically none of these disciplines offer a rigorous laboratory course. Lab-work is, as if, a part of an outcome of pure science! On the other hand, the courses conducted in BARC are vocational. An urgent need appears to diversify the 'single track' education of the pure academic type and to bring down such courses to the teenagers so that vocationalization of nuclear and radiation education spreads. Such training would be related to productivity, preparation of individuals for jobs and employment potentiality, broadening of horizon, dignity of labor and more importantly, a maximum utilization of the material and human resources in the country.

Wherever delivered lectures in the universities and colleges we always asked questions like, how does the radioactivity appear in the environment?, what is natural radioactivity?, how to generate nuclear energy?, what is its importance?, what is the role of radioactivity in human activities ?, etc. To our surprise almost none of the students and even very few teachers from the refresher courses had just partial information! On the contrary, most of them expressed their fear about the past and present nuclear bombs, Chernobyl accident, radiation hazards, and so on. This clearly indicated that availability of knowledge at all levels, school, college or even at the university is insufficient. Looking at the syllabus that is framed for the age group 14-17 years, one finds some topics on radiation education; however, these are largely unrelated to the questions arising in the minds of students of that age group. For example, the children in the age group 14-15 years, the syllabus in Maharashtra State contains alpha, beta, gamma radiation and their properties, radioactive transformations, cathode and x-rays-properties and uses, radiation-pollution, etc. While for the group 15-17 years, the prescribed topics are nuclear structure: size and properties, energy levels- magnetism and shape; radioactivity, decay kinetics, determination of age of a sample, artificial radioactivity, isotope applications, binding energy, nuclear reactions: fission and fusion, carbon-nitrogen and solar energy cycles, etc.

The science syllabi for the age group 14-17 years thus include only one or two chapters on radiation in the whole science course, particularly related to physics and chemistry. Syllabi for higher levels are mainly based on English medium books written by foreign authors. Not many eminent scientists or university professors have written textbooks for the radiation course for these children. Situation is still worse regarding practicals; no experiment is performed in the laboratories. At all levels including the post- graduate one, nuclear-radiation chemistry/ physics courses and the courses like radiation biology or applied nuclear physics remain as theory courses. Hardly one/two practicals are conducted in a few institutions at the M.Sc. or rarely at the B.Sc. level. This is the real drawback in the present education system in India. Further, very large section of even urban population is deprived of any sort of vocational training. Radiation-training courses should evolve and spread into the university system. At present there are no such vocational training systems except one, which is run very effectively at the BARC.

In the existing teaching and research programs of the universities, instead of expansion, retrogation is going on; taking and example of chemistry, the established research groups present in some 7-8 institutions are rapidly shrinking their contribution and influence on the society is correspondingly getting diminished. There is an urgent need to revert this situation giving substantial support to the development of radiation-teaching/research in the universities.

PROPOSED SYLLABUS

One must be clear in mind that energy from the nucleus has to be harnessed to sustain the modern way of living. Energy crises are at the horizon; in the later part of the 21st century these are going to be severe and as the situation stands today there does not appear to be any alternative to obtain energy from the nucleus. With further advancement in technology, more and more attention will have to be paid for minimizing the outcome of artificial radiation in the human environment. Already efforts have gone in extensively in this endeavor. It becomes imperative, therefore, to introduce radiation education that highlights such efforts, and the achievements made all over the world in an unbiased way. Education must also include radiation environment nature has created for us. Everybody must be aware that the world he lives in, since and prior to the days of Adam and Eve, is full of natural radioactivity. Not only that, all of us are bombarded by cosmic radiation from outer space but also that our bodies contain radioactive polonium and radium in our bones; our muscles contain radioactive carbon, radioactive potassium; radioactive noble gases and radioactive tritium exist in our lungs, and so on. Thus the natural and artificial substances we eat and drink each day irradiate us from within. The authors would like to stress that this aspect should be introduced and exemplified to the school going children. There is a paramount need to create consciousness of the environment, permeating all ages and all sections of the society, beginning with the childhood. Education should not be monopoly of university, school or any advanced laboratory, nor it is a time-bound learning experience. It is a way of life, a long way of life. Specifically in the Indian context, education has to compete with the 21st century problems of explosion of population, poverty and illiteracy, hurdles of language barrier, of caste, class, regional imbalance, and so on. It needs to prepare the entire society to bear and sustain the impacts of modern technology which includes the nuclear one.

Based on emphasis to natural radioactivity in the environment and considering the enormous growing energy needs, fast depletion of the conventional energy sources, innumerable applications of radioisotopes and great efforts being put in and already achieved success in the safety aspects, the following syllabus is proposed for teenagers (14-17 years), to be spread over 3 years of schooling.

A. Applied Oriented Topics

1. What is radioactivity: radioactivity in the environment, cosmic rays, and radioactivity in our bodies; uranium, thorium nuclei and their daughters in nature
2. Discovery and epoch making historical inventions
3. How the radioactivity is detected and estimated: elementary concepts of GM and scintillation counters
4. Fission of nuclei: how energy releases ($E=mc^2$), depleting conventional sources and the need of harnessing nuclear energy, conversion into electrical energy
5. Radiation generated for human prosperity against radiation in the environment
6. Radiation effects on cells: maximum permissible doses, radiation safety, radiation protection-physical and biological scavengers
7. Radioisotope production in reactors
8. Applications of radioisotopes in:
   a. Agriculture
   b. Pest control: food preservation
   c. Medical: diagnosis and treatment
   d. Industry and related problems
   e. Production of new polymers, etc.

B. Theory Topics

1. Radioactivity: decay kinetics, radioactive elements, parent-daughter decay-growth relationships, alpha decay, and nuclear de-excitation, counting errors
2. Interaction of radiation with matter, units of measuring radiation dose , dosimetry, radiolysis water: free radicals ,time scale
3. Typical reactions involved in the preparation of radioisotopes
4. Analytical methods, age determinations, etc.

(Numerical problems should be solved.)

C. Laboratory Experiments

1. Determination of background radiation using GM detector/survey meter
2. Stopping beta's by Al foil, E_{max} of beta particles
3. Half-thickness stopping gammas by Pb and Cu foils
4. Application of thin film detector
5. Liquid GM counter: daughter separation and $t_{1/2}$ determination (uranium series)
6. ^{40}K activity: ^{40}KCl, $^{40}KClO_3$ and NaCl from Lab.
7. Dosimeter: Fe^{+2} --> Fe^{+3}
8. G-value determination: ($CHCl_3$)→ HCl measurement
9. Polymerization by radiation (viscometer)
10. Measurement of activity in pitchblend
11. Photoprint-Becquerel's Expt.
12. Demonstration: high activity near volcanic springs-survey meter

Dry Experiments

13. ^{14}C disintegration per day in the body muscles
14. ^{40}K dis./day in muscles
15. ^{222}Rn inhalation, disintegration per day
16. ^{226}Ra and Po dis/day in bones
17. Counting error: concept of statistics
18. Average radioactivity dis/day in a human cell
19. Video demonstration of all the above experiments
20. Film shows projecting significance of the pioneering contributions

(Experimentation Center / Mobile Lab. / Museum, etc. may be developed as a common facility for all the schools in a city. Such centers need to be funded by the DAE and also may be donated instruments in working order.)

The above syllabus is proposed only in the form of guidelines. Further details will have to be worked out by senior radiation scientists from different disciplines at various levels. Also, they need to write standard textbooks, teachers' guides, etc. in English and the regional languages. It is to be realized that merely introducing good, balanced syllabus will not serve the purpose. Bookish knowledge on radiation would lack in providing skill and also scientific attitude. The system needs to be revolutionized and for that one has to begin with the teacher education programs. The philosophy is that once a teacher knows the goal and approach, intuitively develops the required skill to propogate and the whole society then assimilates the knowledge automatically. A sound program for teachers, therefore, is essential for the qualitative improvement and expansion of radiation education. Globalization of radiation education also must be considered in the long run. The end of the present century should mark the end of a uniform education policy by introducing a variety of programs to suit the aptitude, ability and availability of students at all levels. These challenges can be met only through the dedicated teachers. Without sacrifice by this community, nothing can be created, evolved or achieved. The preference by youngsters for moneymaking and luxury oriented education needs to be transformed and hence it has become an absolute need of the day that teachers inculcate devotion academic approach emphasizing on sacrifice, co-existence and citizenship of the world community.

EFFORTS BY VARIOUS ORGANIZATIONS

The small but concrete role being played by of various Indian associations concerning the field of radiation is worth mentioning in the context of education. These have been organizing symposia, workshops including practical courses, informative talks and discussions all over the country; also publish radiation-oriented literature and regularly bring out bulletins. Various programs are being executed by the Indian Association of Nuclear Chemists and Allied Scientists and the Indian Nuclear Society. Over 2,000 life members coming from different disciplines ranging from basic sciences to reactor engineering to biology to medicine, are the member of the INS. As we recollect, 10 years ago the first IANCAS workshop was held in our University for seven days and attended by over 50 university teachers. Total 8 instructors who came at their personal travel expenditure taking privilege leave, worked day and night to set 8-10 laboratory experiments. The overwhelming success and the wholehearted voluntary participation by the teachers gave tremendous impetus to this activity since then. During the past 2-3 years, the activity entered the high school streams as well, adopting regional language as the medium of instruction. Over thirty, 'One-day lecture-cum-demonstration' programs for school children were conducted and attended by over 3000 students and 150 schoolteachers. Authors of this article also have visited on their own and lectured several times before a large number of teacher and student audiences at various levels in different institutions across the country. During the past ten years INS conducted over 50 seminars/lectures while over the period of three years IANCAS carried out rigorous two-week workshops for university teachers at 15 different locations in the country. Nevertheless, this is certainly not enough; wholehearted support and efforts by many are required to reach the desired goal. It all needs solid foundation of personal sacrifice as well, time-wise, energy-wise, even money-wise, if necessary. Such efforts should be supported by the media. The Information Technology Center in Pune University has planned to start link up a number of institutions in and around. This project is developing in collaboration with some foreign universities and the Internet will soon link all the universities, colleges, schools and research organizations in India.

CONCLUSION

If the human race desires to enjoy the enormous source of nuclear energy all through the future centuries, then it needs to put in integrated efforts towards abandoning the existing deadly nuclear weapons. These are the major cause of keeping alive the deep-rooted fear into the minds of the innocent world-community. To eliminate fear, there is a great need of applying will, courage and efforts for the implementation of appropriate radiation-education programs all over the world. Indians are indeed in the stage of effective execution in this context one may recollect what Rabindranath Tagore (NL) had emphasized half a century ago, ' A man shall be incomplete till he has not learnt to put his hand and mind to good and efficient purpose.'

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2.5 PUBLIC INFORMATION AND EDUCATION ON RADIATION SAFETY AND PROTECTION IN INDONESIA

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ABSTRACT

This paper presents a brief overview of public information and education concerning nuclear science and technology in general and radiation safety and protection in particular in Indonesia from the perspective of promoting the development and utilization of nuclear science and technology in the country. The role of nuclear science and technology in Indonesia is first introduced, followed by an overview of the nuclear activities in the country. Basic considerations, major objectives of the public information and education program on radiation safety and protection as well as basic and operational strategies to achieve those objectives are then presented. Major programs including highlights of the past and present activities as well as the prospect on future course of actions are discussed.

1. INTRODUCTION

First of all I wish to express my sincere appreciation and thanks to the Organizing Committee, in particular to Professor Matsuura, for having kindly invited me to participate at this distinguished International Symposium on Radiation Education, held here in Tokyo 11-14 December 1998. I am sure that this important meeting will give me an ample opportunity to widen my horizon on various aspects of Radiation Education, including public information and education, which in my view should primarily be aimed at achieving public awareness, public appreciation, public acceptance and finally public support and participation in the development and utilization of nuclear science and technology.

In my country, and perhaps also in many other countries, the word **"radiation"** is generally still associated with **"nuclear radiation"**, meaning the "**Rays of Death**". This negative perception was primarily caused by the fear of the potential catastrophe that could result from nuclear technology, as has been demonstrated by the devastating effects of nuclear radiation resulting from the explosion of nuclear bombs in Hiroshima and Nagasaki in 1945, which had brought the World War II to an abrupt end. To these groups of uninformed, under-informed or misinformed people, radiation is something to be feared; one should stay away from it, as it can bring nothing but sufferings and death! In my country, this perception was further reinforced by accidents at Nuclear Power Plants, such as the Chernobyl nuclear accident in 1986.

In contrast to other modern technologies, therefore, nuclear technology is marked with such a traumatic start, which had generated such a strong emotional public resistance towards the introduction, expansion or even continuation of the utilization of nuclear energy in many countries including in the most technologically advanced countries with highly educated majority of the population. Emotion has in fact significantly outweighed rational thinking in judging the benefits and risks of nuclear technology.

In view of the above, radiation education, or more specifically education on the nature, scientific and practical aspects of various types of radiation, constitutes in my view one of the fundamental pillars for the healthy development and application of nuclear science and technology worldwide. The ultimate aim of radiation education should in my view be to pull nuclear technology down from its present seat on the "**throne of death**" in the mind of many people and put it on the similar footing and treatment as other branches modern science and technology.

In this paper I shall present a brief overview on public information and education concerning radiation safety and protection in Indonesia from the perspective of promoting the development and utilization of nuclear science and technology in the country. For that purpose, I shall first briefly introduce the role of nuclear science and technology in Indonesia, followed by an overview of the nuclear activities in the country. Having presented some basic considerations, major objectives of the public information and education program on radiation safety and protection are spelled out, followed by basic and operational strategies to achieve those objectives. Major programs including highlights of the past and present activities as well as the prospect on future course of actions are discussed and summarized in the conclusion.

2. NUCLEAR SCIENCE AND TECHNOLOGY IN INDONESIA

"Breathtakingly beautiful, looking just like a bunch of emeralds on a blue velvet scattered around the equator from east to west, ..."! I could imagine those words coming from an artist-austronaut describing the beauty of the Indonesian archipelago while looking at the earth from his space ship!

Indeed, Indonesia is not only a beautiful country, strategically located in the tropics and inhabited by over 200 million people with a great diversity of languages and cultures, but it also possesses a large variety of natural resources. In short, Indonesia has a tremendous potential to become a major world power, and the strongest nation in South-East Asia. Socio-political stability, empowerment of the people and mastery of science and technology are in my view the three basic pillars for the promotion of economic and social progress.

Considering the financial, economic and socio-cultural problems presently threatening the country, mastery and application of science and technology including nuclear science and technology by Indonesians becomes in my view even more crucial for economic recovery and progress. The conducive atmosphere for the promotion of efforts to master and apply science and technology in the country is only possible if the public and the government are aware, appreciate, accept and support the endeavour. Towards this end, information and education play a key role. In the case of nuclear science and technology, information and education on radiation safety and protection constitute an important component.

❑ Role of Nuclear Science and Technology in National Development

As a developing country, especially in view of its vast economic potential - strategic geography, natural and human resources, Indonesia has a vital interest in the development and utilization of appropriate modern sciences and technologies as a driving force in the development of the country. In this context, nuclear technology has a wide spectrum of competitive, and in many cases, unique benefits to offer to the nation. Apart from power generation, nuclear techniques play an important role in Agriculture, Livestock production, Health, Industry and Environment.

Nuclear activities in Indonesia were started in 1957 as national response to the nuclear bomb testing activities in the South Pacific. Institutional, legal, scientific-technical infrastructures and the necessary human resources were developed. Scientific-technical works were initially concentrated in the detection and analysis of effects of radioactive fallout to the environment and health of the population.

❑ National Atomic Energy Agency (BATAN)

Founded in 1964, BATAN - the National Atomic Energy Agency of the Republic of Indonesia - was given the authority and responsibility as the highest national institution to develop and utilize nuclear science and technology solely for peaceful purposes for the safety, health and welfare of the Indonesian people. Since then, nuclear science and technology were systematically developed, initially primarily focussed in the fields of Agriculture, Livestock, Health, Hydrology, Sedimentology and Environment.

Step by step and in collaboration with the International Atomic Energy Agency (IAEA) as well as through bilateral cooperation with many advanced countries including Japan, human resources and scientific-technical infrastructure were systematically developed in Bandung, Jakarta (Pasar Jum'at Complex) and in Yogyakarta to support the increasing application of nuclear techniques in the aforementioned areas. Two Triga-type research reactors were acquired for Bandung (250 kW in 1964, upgraded to 1 MW in 1971) and Yogyakarta (150 kW in 1974).

A big quantum leap was made in 1978 with the establishment of a new Nuclear Research Complex in Serpong, located about 40 km south-east of Jakarta. This research complex was equipped with a 30 MW MTR-type research reactor, fuel element fabrication installations for research as well as experimental power reactors, radioisotope production center, radio-metallurgy laboratory, radioactive waste treatment installation, neutron beam scattering facilities and several supporting facilities. This complex was envisaged as a stepping stone for the introduction of Nuclear Power Plants and nuclear based/related industries in Indonesia. Despite the current financial and economic difficulties, preparatory activities towards an intelligent and public supported decision making for the introduction of nuclear power in Indonesia are still continued.

3. PUBLIC INFORMATION AND EDUCATION

As mentioned above, public information and education, in particular on radiation safety and protection, plays a key role for the acceptance and support in the development and application of nuclear science and technology in Indonesia. The fact that the application of nuclear technology was highlighted with such a traumatic start, makes it particularly challenging to inform and educate the public, that nuclear energy does not simply mean destruction, suffering and death! Even more challenging is the task to make the public aware of and appreciate, and finally accept and support the peaceful and beneficial application of nuclear science and technology for the society. In the case of the Indonesian public, the aforementioned task is made even more difficult by the various nuclear accidents, such those that have occurred at Chernobyl, Three Miles Island and Monju nuclear power plants.

❑ Basic Considerations

There are three major factors that have been considered and taken into account in developing appropriate strategy and programs on "radiation information and education" in Indonesia. These three factors are:

1. ***Negative image of nuclear technology***
   Apart from the ghost of nuclear explosion in Hiroshima and Nagasaki, public uneasiness and fear of nuclear technology have been significantly reinforced by the unfortunate accidents at nuclear power plants, such as Chernobyl, Three Mile Islands and Monju. Some of the technical-administrative their handling of these accidents, and in particular their incorrect, incomplete or distorted reporting in the mass media, have contributed significantly to the negative image in public perception in Indonesia.
2. ***Cultural diversity and generally still low level of education***
   The fact that Indonesia is inhabited by over 200 ethnic groups (tribes) with different languages, cultures and levels of education presents a special challenge in designing the appropriate strategy and programs of public information and education. The specific socio-cultural features of the different population groups have to be considered and taken into account in order to achieve the desired impact.
3. ***Large size of the Indonesian archipelago***
   With the available financial, manpower and infrastructure support, the large size of the Indonesian archipelago poses also quite a challenge, in particular in conducting information and education programs via two-way communication method.

With those challenges in mind, the limitations on the side of the available resources and confronted also with small but very vocal and financially strong anti-nuclear groups, public information and education program in nuclear science and technology, especially in radiation safety and protection, in Indonesia is not only a science and an art but also a test of stamina at the same time.

❑ Objectives and Strategy

The major objectives of the public information and education program on radiation safety and protection in Indonesia may be stated as follows:

- To achieve and strengthen awareness and appreciation by the general public, the scientific/intellectual community and the government officials that nuclear science and technology are indeed a useful and manageable branch of science and technology.
- To win and strengthen acceptance and support by the public, intellectuals and decision makers for the development and application of nuclear science and technology in the national development.
- To obtain public participation in the national effort towards achieving a nuclear-arm free world.

The general strategy to achieve those goals may be classified into basic and operation strategies as follows.

1. ***Basic Strategy***
   - Respect and take into account the cultural diversity of the population

- Ensure a balanced view of the benefits and risks of nuclear science and technology, in particular on radiation safety and protection
- Take advantage of the national and international links and cooperation

2. *Operational strategy*
   - Classify the target population into three target groups, namely the general public, the intellectuals and the decision makers
   - Train specialized "**JUPEN**" (Public Information Specialists), who should master not only the overall perspective of the scientific-technical subject in question but also the necessary techniques in public/mass communication
   - Take advantage of the modern public/mass communication technology, such as the electronic mass media.

❑ Programs and Activities

The programs and activities are designed to suit the target groups. The programs may classified into the following categories:

1. ***One-way communication program***
   This program includes provision of various types of reading materials (literature), audio-visual materials, permanent and travelling exhibitions, plays and wayangs (Javanese shadow plays).
2. ***Two-way communication program***
   This program includes dialogs, discussions, and other types of direct two-way communication among the participants.
3. ***Mixed program***
   This program includes seminars, symposia, workshops, special courses for teachers and special interest-groups, where opportunities for exchanges of opinions, questions and answers session may follow the presentation of the public information specialists.

In the past few years the activities have been concentrated on informing and educating the public on the benefits and risks of Nuclear Power Plants. Major areas of concern were the economics, safety and technology of nuclear power plants. The use of the Javanese shadow play (wayang) and the use of community leaders (religious and tribe leaders, and other informal leaders in the society) have been found to be effective in conveying the desired message to the target audience in the general public.

Since the start of the economic crisis and the emphasis of the government policy to reduce the increasing level poverty, the focus of activities has been shifted to highlight the benefits of radioisotopes and radiation and other nuclear techniques in the field of agriculture, livestock production, industry and human health. A new BATAN initiative, known as the "**AMD**" (Atom Masuk Desa - Atom in the Village)" program has been intensively communicated to the public and has received a very positive response from the beneficiaries, especially from the small farmers in the rural areas.

In the future, in particular after the easing of the current economic crisis, BATAN intends to make a balanced focus between the efforts to popularize the benefits of nuclear fission reactors to generate power on one side and those to highlight the benefits of nuclear radiation and radioisotopes in solving problems connected with the basic human needs, such as food and health.

4. CONCLUDING REMARKS

Despite the very limited budget and the challenges described above, judged from the benefits-costs analysis, the results so far obtained have been generally quite encouraging. The expected output and outcome of the implemented programs as well as their impact have been very good. The policy and strategies developed and implemented by BATAN have been well supported by the government, by the parliament and by the public.

For the future, the program on public information and education is still hampered by the very limited funding. This situation needs to be improved in order to reach more target groups in the population. The number of trained public information specialists needs to be significantly increased. In addition the facilities and the technical infrastructure support needs to be further improved. In addition, links and cooperation at the national and international levels need to be strengthened, and the use of community leaders should be expanded.

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2.6 RADIO CONVERSATION BETWEEN SCIENTISTS AND THE PUBLIC AS A MEAN FOR UNDERSTANDING PUBLIC PERCEPTION OF RADIATION RISK.

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ABSTRACT

Radio broadcasts with phone-ins in which the public can interact directly with scientists in the studios can represent a very useful tool for analysing public understanding of science. An in depth analysis of the listeners' questions and of the scientists' reactions - despite the obviously low statistical relevance - can provide important clues on the spontaneous and emotional components of the attitudes of the citizens toward science, and of the attitude of scientists toward citizens' concerns.

As an example of the opportunities such an approach may offer, a series of live radio broadcasts on radiation and its applications (the first three transmitted in Italy in November and December 1998) is presented. Each broadcast involved an introductory presentation by two or three invited scientists, followed by phone-ins. The questions of the listeners are analysed and commented. A strong need for a deeper understanding of the methodological principle of radiation research seemed to emerge. The broadcasts also stressed how the need of an interaction between scientists and the public is at least as urgent as the transfer of information to the public.

In the future, the same approach will be extended to other fields of science and to other radio channels, with the aim of designing a methodology for the exploitation of specific features of radio broadcasts for promoting the dissemination of scientific culture.

1. INTRODUCTION

Among mass media, a local radio has several characteristics that tend to enhance the sense of friendliness and belonging - essential to any true communication. There are several reasons for this: mainly, the radio is often perceived as an additional "voice in the family", it does not require our complete attention but can be a part of the environment, and keeps company instead of being a mere source of information, etc. A local radio can therefore be a kind of non-intrusive neighbour, easy to turn to, either for a chat, or for discussing some vital problem.

Some radio stations or networks allow a direct contact between the listener and the conductor. Through phone calls, listeners can ask for a favourite song, answer a serious or a jockey quiz, state an opinion, ask a question, communicate with each others, etc.. Radio Popolare di Milano (see section 2.1), since its birth in 1976, has been concerned with this form of access and with keeping an ongoing dialogue with and among the audience. Indeed, it devotes a large fraction of the daily schedule to the participation of the listeners, which is direct, spontaneous and not filtered by the conductor who has no way of knowing in advance who will be on air.

The freedom of access is very valuable when dealing with science related topics. Reporting science in a radio broadcast is not an easy task: "Science is usually presented as a continuous, coherent, concrete activity [...]. Science does not like superficiality, trivialization, or talk of 'breakthroughs'. In its nature, broadcasting is episodic, fragmented, ephemeral [...]. This mismatch between the demands of science and the ability of broadcasting to meet them creates many profound problems in communicating the significance and excitement of scientific discovery to a lay audience."[1]. But, in a radio programme on science, "good broadcasters will rely heavily on analogies to stimulate the imagination. It is not a very precise way of communicating, but it can be very evocative"[2]. A radio broadcast has therefore many limitations and many advantages: for our purpose here, it can represent a possibility for the listeners to express their feelings about science, emphasising the emotional aspects rather than the rational aspects of their personal relationship with science.

Indeed, one of the main problems concerning science communication is a two-sided gap between the scientist and the public. On one side stands the public, for whom the scientist speaks in an arcane and barely understandable language from an unreachable research laboratory, in a separate world. This leads to a perception of the scientific work as the main source of problems associated with modern life-style, or, even worse, to a loss of interest in scientific issues (as if they were not driving changes so forcefully). On the other side stands the scientist: quoting the French physicist Jean-Marc Lévy-Leblond, "If science communication is so inefficient, couldn't it be because it answers questions that were never expressed by the 'public', instead of grasping the real ones – even if their meaning may be confused and mostly implied?"[3]. As a matter of facts, the occasions when a scientist can have a direct contact with the public, and be exposed to questions, comments or criticisms, are very few both for the science student and for the professional researcher. Moreover, the highly demanding effort to devote time and thought to the communication of one's scientific work to the general public, is often not sufficiently rewarded by the scientific community itself. This is particularly true in Italy, characterised by a traditionally humanities-oriented culture and a lack of university programs devoted to science communication (with the exception of the newly created Master in Science Communication in Trieste[4]), but can be extended, with various corrections, to other European countries, among which the activism of British scientists in taking part in public debates is the only notable exception.

A scientific communication event where the interaction between the scientists and the public is possible (such as a conference or, as in our case, a radio broadcast with phone-ins), should therefore aim at making both sides willing to get better acquainted with the other's interests and concerns, and take this opportunity to educate both the public, and the scientists involved, not about science in general - a rather unachievable aim - but to paying due attention to what the other is actually saying.

In this paper, a series of radio broadcasts devoted to radiation and their application in different fields is presented. A brief description of *Radio Popolare* and of the weekly magazine *Il ciclotrone* is presented. Three live "special issues", broadcast every two weeks (5 and 19 November 3 December 1998) within *Il ciclotrone* are analysed. The content of the presentations and explanations by the scientists during the broadcasts are only outlined, and the attention is focused on the questions the listeners asked the scientists.

The broadcasts here presented are intended as preliminary experiments. They will represent the basis for the development of a methodology intended to exploit specific features of the radio for understanding public perception of science and improving the quality of science communication. Due to the inevitably limited number of questions and to their highly scattered nature, a quantitative, statistical analysis cannot be conducted, even when, as prospected, the same approach will be systematically extended to other fields of science and to other radio channels belonging to the Network of Radio Popolare. Indeed, these types of programmes have to be regarded more as live performances than well-planned and organised ones, thus emphasising the spontaneous reactions of the public. In the following, a qualitative analysis is therefore attempted, with the main objective of understanding how these types of interactions could help the scientific community to grasp and interpret the type of information needed by the audience.

2. RADIO POPOLARE AND THE WEEKLY SCIENCE MAGAZINE *IL CICLOTRONE*

2.1 Radio Popolare, Milan (Italy)

Radio Popolare was founded in January 1976 as a "community radio", broadcasting in Lombardy, the richest and most populated region of Italy. It broadcasts mostly news, culture and debates (with phone-ins). At first a co-operative with few underpaid workers and many unpaid volunteers, it is now a company with a staff of 45 people (one third of whom are professional journalists), and with about 150 external collaborators covering specific topics and expertise. Approximately 60% of its stock is owned by over 12,000 shareholders, the rest by the co-operative. Revenues are evenly split between advertising and subscriptions. 13,800 listeners support the radio by freely paying an average annual fee of 180 dollars. In the last five years, Radio Popolare has built a network all over Italy, supplying news and programmes by satellite to 20 smaller local radios. The radio has an average audience in Lombardy of 250.000 listeners a day, with peaks during the news. Most of them (45%) are in the age range 25-44, with middle or higher education curricula.

2.2 Il ciclotrone

Il ciclotrone is a weekly magazine, one hour long, devoted to science and technology. It was started in 1986 by one of the authors (S. Coyaud) and since then has been a regular appointment for the listeners. It is edited by a journalist (S. Coyaud) and a researcher (M. Merzagora) and relies on a pool of experts, doing physics, astrophysics, biology, maths (no chemistry, regretfully), linked by a common taste for science communication and story-telling. The programme attempts to tackle hard science lightly but without oversimplifying (according to Albert Einstein's *motto* that "We should make things as simple as possible, but not simpler").

Apart from few series - on climate sciences earlier this year, or recently on radiation - the format is flexible. Scientific conferences and events open to the public are announced, books reviewed, and one or two core issues discussed with specialists.

During the years, *Il ciclotrone* has evolved. Some aspects, however, remain unchanged. In order to exploit the specific features of a radio broadcast as much as possible, *Il ciclotrone* is often conceived as a conversation between the audience and the scientists in the studio. As opposed to printed media, the radio does not need a reporter: the authors of scientific researches can report on their own work, and the journalist tries to awaken or summarise public curiosity. Moreover, by allowing non-filtered phone calls, the listener can talk directly to a Nobel laureate, or ask an expert about the safety of frozen foods or the means to get rid of space debris and so on. *Il ciclotrone* is constantly seeking the participation of the audience: technology – whether space travel, Information Technology or biotech - kindles heats debates, and so do topics whose social impact is clear, e.g. genetics, neurochemistry of illegal drugs, greenhouse gases and atmospheric chemistry, etc. When treating so called hard sciences, e.g. basic research in physics or molecular biology, the call for participation is somewhat less successful, but over the years listeners' participation has been considerably improving.

Besides merely numerical data on the audience, one of the main assessment of the success of the program is, in the authors' opinion, the satisfaction of the invited scientists with the opportunity to communicate with an intelligent if untrained audience, showing true interest and curiosity for their work.

3. AWASH IN A SEA OF RADIATION

To celebrate the centenary of the discovery of radium, several issues of *Il ciclotrone* are devoted to radiation and to how radiation is involved in various aspects of our daily life. Three issues have been already broadcast at the moment this symposium is being held. Common aspects of the programs were the definition of the technical terms (e.g., dose, radioprotection, e.m. field), and a brief historical background pointing out the evolution of scientific knowledge on the subject. After some 20 minutes of presentation by two or three hosts, the phone-ins started and more specific topics were then selected on the basis of the listeners' requests. Here is a brief description of the content of the broadcasts.

1) <u>Introduction: radiation effects and radioprotection.</u>

Invited scientists: G. Tosi, professor at the Specialization School in Medical Physics, University of Milan, head of the Radioprotection Unit at the European Institute of Oncology (IEO, Milan); G. de Luca, physician specialised in occupational medicine at the National Agency for the Protection of the Environment (ANPA).

Contents: introduction to the term "radiation" and related quantities; introduction of the notion of natural background; discovery of X-rays and natural radioactivity; first acknowledgements of health hazards; definition of stochastic and deterministic effects; basic principles of radioprotection; Italian and European legislation on radioprotection.

2) <u>Radiology and radiotherapy</u>

Invited scientists: R. Orecchia, professor at the Faculty of Medicine, University of Milan; G. Pedroli, director of the Sanitary Physics Division at the Niguarda Hospital, Milan.

Contents: medical applications of radiation; a brief history of radiology and radiotherapy; costs-benefits analysis in diagnostic and radiotherapy; evolution of different techniques, from their origins to recent advancements.

3) <u>Non ionising radiation</u>

Invited scientists: P. Vecchia, director of the Radioprotection Unit at the National Health Institute (Istituto Superiore di Sanità, ISS), president of the Italian Association for Radiation Protection (AIRP); L. Venturi, scientific director of the environmentalist organisation *Legambiente*; M. Fronte, journalist and science writer[5], Zadig Agency, Milan.

Contents: definition of non ionising radiation; present knowledge on health effects of electromagnetic fields; environmental problem of electromagnetic pollution and attitude of various environmentalist groups; the particular attention that the Italian press devoted to the matter in recent times.

Other broadcasts will follow, concerning other specific application of radiation, such as food irradiation, applications in agronomy, the indoor radon emissions, etc. These are scheduled for the first semester of 1999.

4. QUESTIONS LEADING TO MORE QUESTIONS

"Scientific information must be conceived as a means of spreading questions, - not answers"[6]. Although this statement is probably agreed upon and well understood by most researchers and scientific journalists, the common citizen, as it emerged from the questions analysed, wants to obtain from a scientist unambiguous answers.

Three main types of questions can be identified throughout the three broadcasts: a) questions related to personal problems; b) questions aimed at a better understanding of the general issue; c) questions or comments aimed at giving an interpretation of the public attitude towards radiation exposure.

As expected, the first type was particularly frequent during the broadcast on radiology and radiotherapy: understandably, medical issues are of personal concern to everyone, and the listeners tend to take the opportunity of a radio program to get additional medical advises on a specific disease. These type of questions were of greater interest during the *radioprotection* and *non ionising radiation* programmes: after the general presentation by the scientists, people were asking about the risk of living in a house without foundations located in a volcanic area, of placing "possibly radioactive" heat insulator in the house, of living next to a large antenna ("I am feeling a bit nervous lately: shall my wife blame it on the antenna we have over our roof?"), etc. The listeners were demanding precise answers, numbers, and clear-cut definitions: this is what science, according to its widespread perception, is supposed to provide.

These questions induced most of the invited scientists to devote specific attention to methodological matters, introducing the concepts of stochastic and deterministic effects, of non-threshold effects, etc. heavily relying on analogies with easily understandable hazards. As an example, convincing analogies were the speed limits on freeways to explain how to deal with non-threshold effects in legislation (keeping a low speed does not prevent us from having an accident, but respecting speed limits is in any case a good way to lower the probability of an accident), or the risk of smoking or drinking as an example of stochastic effects (almost everybody knows somebody who has been smoking for years without consequences, and somebody who had lung cancer or cardiovascular diseases due to smoking and drinking). As a matter of facts, the authors had the impression that although the listeners were asking for precise data, answers strictly based on data were not considered satisfactory. "The decrease of the dose limit has not reassured the public and may even have increased anxiety because it revealed uncertainty with regard to risk and triggered controversies among scientists. [...] These reactions to ionising radiation further confirm that fear is actually not related to data but to mental models."[7] Thus explanation of the *methods* adopted in the disciplines described, appeared much more urgent than the actual results of the quoted studies.

It appears that the *statistical* association between exposure and incidence of a disease has to face a natural barrier in the common understanding of radiation risk. The fact that in some cases "... the connection between low-level insult and bodily harm is probably as difficult to prove as the connection between witches and failed crops"[8] is not generally accepted by the public. Moreover, there seems to be a natural "appeal", often mediated by the press, related to not clear-cut conclusions, leading to a rationally unexpected greater impact of so called "phantom risks" (see ref. 9 for a discussion on this subject) with respect to well assessed "real" risks. This tendency is enhanced when the source of risk is ubiquitous, but invisible and undetectable through standard household appliances, as in the case of electromagnetic fields, which are presents in our environment everywhere and everyday of our whole life. The conflict between scientific assertions and public perception of the content of the assertions themselves, is in these cases enhanced by the very different meaning of the world "risk" in the scientific and general public domains, as clearly stressed in the ICRP publication 60[10].

Concerning the relationship between scientific conclusions and reports by the press, several other questions induced the invited scientists to stress methodological issues. During the broadcast on electromagnetic pollution ("electrosmog" is a term which is making headway in the newspaper headlines), three listeners quoted a recent observation of an increased tumour incidence in an area in central Italy (Marche), possibly due to the presence of a large military radar. After epidemiological studies, no increase in tumour incidence was found, but public opinion seemed unconvinced. An explanation of statistical significance, and of the so-called "selective attention" effect was therefore needed. The invited scientists then tried to point out how the aims and constraints of a news report are intrinsically different from those of a scientific research. These interactions between scientists and the audience made clear, in the authors' opinion, that a deeper understanding of the media procedures and choices relative to scientific topics, together with a serious consideration of citizen's concerns expressed by self-organised pressure groups[11] (even when obviously driven by irrational fears), is of uttermost importance in defining the criteria for a successful information on radiation effects.

Other questions were clearly intended to get a better grasp of the problem. Examples are: "What is the difference between a radiograph and a long-distance flight in terms of exposure to radiation?"; "Is the intensity of electromagnetic fields influenced by daily and/or global climate change?"; "Does the increased power of mobile telephones increase the associated risk?"; "Does the absorbed dose accumulate over the years?"; "Why, in the current legislation, professional workers are allowed a higher exposure than the general public?".

In this case, the reactions of the invited scientists were strictly professional: the questions are clear, the underlying concern is explicit and not hidden, and in most cases there is a clear answer to those kinds of questions.

Among this type of questions, two listeners who appeared to have had some professional experience in the past, stressed how the doses presently used for a radiograph are considerably lower than a few decades ago. The scientists answered very correctly, quoting many pioneer radiologists who experienced severe diseases, and stressing how technical improvements and a correct evaluation of the risks involved grew very slowly and are still subject to refinements. Explaining science as a constantly evolving "work in progress", quoting failures and mistakes as well as successes can be of extreme value for transmitting the correct messages to the public. Indeed, the claim of authority for a scientific statement can inspire distrust in the public, especially if the specific topic is not yet a well established knowledge. On the contrary, making explicit that science is able to explain many things, but not everything, can help shrinking the gap between the scientist and the public, generating confidence and trust.

A third set of questions tried, as requested by the conductor during the broadcasts, to give an interpretation to the often-irrational attitude of the public towards the risk related to radiation exposure. In particular, two listeners proposed the following, interesting arguments: *a)* due to the extremely high incidence of neoplastic diseases, people tend to associate radiation with the pain that cancer treatment inflicts to the patient, with his distress and that of his relatives. Even if in the case of radiotherapy radiation is "good", an unconscious association is unavoidable. *b)* Concerning electromagnetic fields, the lack of clear cut answers, and the daily exposure to which we are all exposed during our lifetime, generate a state of stress in the citizen. This limits the possibility of adopting a rational attitude toward the problem.

5. CONCLUSIONS AND FURTHER DEVELOPMENTS

The firsts three broadcasts of a series of radio programmes devoted to radiation and its many applications in our daily life were presented. The broadcasts were a first attempt to develop an approach for analysing public understanding of sciences starting from the questions posed to the scientists during a radio broadcast, and the answers of the scientists.

Main advantages of the approach are:

- it allows a direct contact between the public and the scientists, generating confidence and trust;
- it can represent a non-intrusive way to promote public understanding of science;
- it can help educating the scientists to communicate their researches;
- it allows to analyse the spontaneous and emotional feelings of the public toward scientific research, thus representing a possible complement of statistical analyses.

Even considering the limited data set available up to now, the approach described seems to be very promising and a few conclusions can be drawn.

- The dissemination of data and research results is not necessarily reassuring for the population. Often people strongly demand data, but are then disappointed by them, realising that they are much more difficult to "use" than expected. Therefore, the information on radiation related topics should probably focus more on the methodologies adopted in research rather than on their results. Only by clarifying the stochastic nature of low exposure risk, the statistical content of epidemiological studies, etc., a fruitful education of the public seems possible.
- A scientific research and a news report cover the same event in a completely different way. Since the public is exposed to news coverage at first, the mechanisms regulating the work of the media needs to be well understood by the scientific community. In other words, a "wrong" article on a newspaper could be also regarded as a negative experiment, which make us angry but can be very helpful in redirecting our researches.

- The true interrogatives of the public, even when confused and implicit – needs to be carefully considered, also taking into account irrational and emotional aspects, which tend to escape from the quantitative analysis which the scientific community is more likely to accept.

In the future, other specifically designed broadcasts will be edited, transmitted and analysed. Three more programmes on radiation are already scheduled in the next few months, and the same scheme will be applied to other scientific topics, such as biotechnolgies and genetically modified organisms, public founding of scientific research, earth sciences, etc. The same approach will be extended to other local radios of the "Popolare Network", each having peculiar characteristics and a different audience. Also, a retrospective analysis of similar experiences in other European countries would be desirable.

As a larger data base of questions and answer will become available, it will be possible to draw a general scheme on how to exploit interactive radio broadcasts as a mean for understanding public perception of science, and the pros and cons of such approach will be singled out.

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2.7 日本の高等学校における放射線・原子力教育の現状

PRESENT STATUS OF RADIATION AND NUCLEAR EDUCATION AT HIGH SCHOOL IN JAPAN

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日本原子力学会内に設けられている「原子力教育・研究」特別専門委員会では、平成 8 年にその活動の一環として高等学校で用いられている理科および社会の教科書の調査を行った。その結果、エネルギー、放射線および原子力関連の記述のより一層の充実を求める必要があるとの結論に達した。ここではその調査結果の概要を報告し、関連する学習指導要領の改訂に関する要望を述べる。

1. はじめに

環境、エネルギー問題に関してわが国の置かれた状況を考えると、原子力発電の一層の安全性を確保しつつ，使用済み燃料の処理・処分技術を高度化して核燃料サイクル技術の完成を図ることが急務である。このためには、原子力に対する国民の正しい理解を得ると共に、この分野に優秀な技術者を確保していくことが不可欠である。

ところが、現在世の中には若者のいわゆる「理科離れ」、「工学離れ」と呼ばれる現象が見られ、加えて原子力の産業としての定着が進むにつれて「原子力」という言葉が若者に対して、これまでほどに新鮮かつ魅力的な響きを与えなくなってきている。また原子力の安全性に関して、原子力関連技術者・研究者が払っている多大の努力が国民に伝達されておらず、このことが国民の不安を誘発することにもなっており、人材確保に困難を来す遠因ともなっている。このような状況にあって、原子力教育にかかわる大学等の関係者は将来に強い危機感を抱き、初等・中等教育における理科・社会教育ないし原子力教育の改善が必要であると認識し、上記教育に用いられる教科書の調査を行った。

2．高等学校教科書（公民，地理，理科）における原子力関連の記述の現状と問題点

1）社会系教科

（1）社会系教科書（現代社会，政治・経済，地理A）において原子力発電は，①資源・エネルギー及び②環境，の視点から記述されている。前者については，地球的課題としての資源エネルギー問題，国際社会の動向，現代の経済や国民生活等との関連において論ぜられている。一方，後者については，技術の発展が地球環境の破壊をもたらす一例として，チェルノブイリ発電所の事故を取り上げて論じているものが多く，さらには核実験による環境汚染の問題に言及しているものもある。

（2）一般に原子力発電の問題を社会系教科書で扱うとすれば，各発電方法の長所，短所を客観的に併記した上で，その選択について考えさせる立場を取るのが適切と考えられるが，現行教科書ではこの点から見て妥当性を欠くものが見られる。その多くは，記述に公正を欠き，原子力発電の短所の説明には力を入れているが，長所についても極めて簡単な説明にとどめるか，あるいは記述を省略している。これらのケースでは執筆者の原子力発電に対する否定的な主観が根底にあり，それが使用された語句の端々に表れているように感ぜられることが多い。例えば，①極端な事例を示し，あたかもすべてのケースがそうであるかのような印象を与える記述，②曖昧でイメージを損なうような語句や表現を用いている記述，③根拠が不明確であったり誤って伝えられた海外の原子力事情の一面を強調する記述等が多く見られる　。

（3）より複雑な状況を生じているのは，問題の多くが表現上の微妙な言葉の綾に起因している点である。すなわち，不適切と判断される表現のうち，明らかな誤りと断定できる例はむしろ少数で，多くは原子力発電に関する表現に微妙な偏りがあり，記述全体のトーンが感性的又はバランスを欠くと判断される状況である。したがってたとえ一部の語句を訂正しても，全体のトーンはほとんど変わらない。教科書の記述としては本来，より客観的で，中立的な立場からの記述が必要であると判断され，この状況を是正するためには記述の大幅な改訂が必要であると考える。

2）理科（「総合理科」の指導資料を含む）

（1）理科教科書では，物理及び総合理科（指導資料）の中で放射線や原子核，さらには原子炉や原子力発電についてある程度詳しい記述がある。これらは一部を除けば社会系教科書に比べ客観的で，ある程度正しい理解が得られるよう配慮されているとの印象を受ける。記述もバランスが取れており，例えば放射線の危険性について述べると同時にその利用についても記述されているという具合である。

（２）一部の教科書で原子力発電の安全性や放射性廃棄物の処分に関連して，社会系教科書と類似した記述が見られる。これは物理の学習指導要領の中で，「放射能及び原子力の利用とその安全性の問題にも簡単に触れること。」と書かれていることに従ったものと推定されるが，その内容に「理科」の立場から具体的な記述がなく，「問題あり」というような簡単な表現で終わってしまっている。

（３）物理の教科書や総合理科の指導資料の中に見られる放射線や原子力発電などに関連した記述を詳細に見ると，用いられている数値や単位，用語や図面等に誤りや適切でないものが幾つか見受けられる。

（４）化学ＩＡでは５教科書中３点に，生物ＩＡでは５教科書中１点に，地学ＩＡでは１教科書中１点に，環境の保全と資源利用に関連した記述があり，その中で一部原子力発電やウラン資源に関連した事項が取り上げられている。しかし地学ＩＡを除き，その内容は，社会系教科書と類似して極めて希薄であるか，あるいは記述がないに等しい。例えば，化石燃料の使用について温室効果や酸性雨の問題が取り上げられておらず，またそれと対比する形での原子力発電の位置付けがなく，エネルギーの新技術としても原子力に関する記述が全くない（化学ＩＡ）という例もある。

（５）化学ＩＢでは１１教科書のいずれにおいても原子力及び放射線関連の記述は見られない。生物ＩＢの８教科書ではいずれも原子力に関連した記述は見られないが，放射線について突然変異に関連して触れているのみである。地学ＩＢでは４教科書中１点にウラン資源に関連する記述が見られるが，その内容は極めて貧弱である。

（６）理科教科書に関連する最大の問題点は，放射線，放射能や原子力について物理と総合理科（指導資料）の中である程度取り扱われているものの，化学や生物，地学では全く記述されていないか，ほとんど記述がないに等しいことにある。これは生徒が物理を選択しない場合，放射線や原子力について正しい理解を得る機会がないことを意味している。さらに，平成６年度における高等学校理科の全教科書中に占める物理（ＩＡ＋ＩＢ）の採択率は１１％にすぎないこと　，総合理科においては教科書すらないこと，また全体の６０％近くを占める化学ＩＢ（３３．８％）と生物ＩＢ（２４．３％）　に放射線や原子力に関連する記述がないに等しいことを考えると，次世代を背負って立つ若者に与えるその影響は深刻である。これは，ひとり原子力関連分野に対する影響ばかりでなく，ミクロの視点が必要とされる先端科学技術すべてについて同様の影響をもつと思われる。

３．学習指導要領改訂の要望

既に述べたように，我が国において原子力発電は基幹エネルギー源として他に変えがたい地位を占めるに至っており，当面この原子力エネルギーを堅持しながら，核燃料サイクルを健全に完結させていくことが，今後の命題である。そのうえさらに長期的な視点に立って，地球環境の保全，エネルギー資源の確保と有効利用を考えながら，我が国がどのようなエネルギー源の選択を行っていくかは，我が国の将来の発展にとって極めて重要である。

一方，原子力に関連する諸問題には国民の関心も高く，種々の議論があり，原子力は単に科学技術の問題であるばかりでなく，大きな社会問題となっている。

このような状況にあって，我が国の今後の原子力の利用に当たっては，原子力に対する国民の正しい理解を得ながら，それに基づいた適切な判断を求めていくことが不可欠である。このために高等学校における理科と社会の科目の中で取り上げられる原子力に関連した教育が極めて重要な役割を担っている。この期待される役割を果たすためには，現在の学習指導要領の言葉を借りれば，「自然の事物・現象についての理解を図り，人間と自然とのかかわりについて認識させる。」中で，原子核や放射線，放射能に関する理解を深め，「人間尊重と科学的な探究の精神にもとづいて広い視野に立って現代の社会と人間について理解を深めさせる」過程において原子力利用技術に関する正しい知識を得させ，「現代社会の基本的な問題に対する判断力の基礎を培う。」と共に「国際社会に生きる日本人としての自覚と資質を養う。」ことが必要である。

しかしながら，現在の社会系教科書及び一部の理科教科書中での原子力に関する記述は偏って，バランスを欠き，前述の目標を達成するには不十分であると考える。社会系教科書における原子力に関する記述の問題点は既に述べたとおりであり，これらがより客観的で中立的な記述に改善され，その本来の目標が達成されるよう学習指導要領及びその解説の中で指導がなされることを希望するものである。

社会系教科で原子力のように高度に技術的な問題を取り扱う場合には，原子力に関する正しい科学的理解を生徒がもっていることが不可欠であり，誤った知識に基づいては，正しい判断を下すことは困難である。この点に関連して，原子力について正しい科学知識をもつ日本の高校生の割合が国際的に比較して著しく低いという最近の調査結果　に深い危惧の念を抱くものである。

原子力に関連した科学的理解を深めさせるのは理科教科においてであると考えられるが，既に述べたように，現在の理科教科書及び指導資料における放射線，放射能や原子力に関する記述は一部の教科（物理と総合理科）に限られており，これらの科目を選択しない大多数の生徒は放射線や原子力に関する科学的理解を得る機会が極めて乏しい状況となっている。このことが上述の高校生のエネルギー教育の調査結果にも如実に表れたものと推定される。現代の科学・技術の根幹をなす原子・分子に関する理解を生徒に求める上で，放射線や放射能の知識は不可欠のものであり，その記述が物理及び総合理科以外にほとんど見られないことは憂慮するべき状況と考える。理科教科書についてこの点の改善を図り，生徒の科目の選択にかかわらず，放射線，放射能や原子力に関する科学的な理解がある程度得られるよう，前記二科目以外の教科書においても関連事項の記述とその内容の充実を強く望むものである。

参考： 高等学校教科書中の原子力に関する不適切な記述例

以下には調査を行った高等学校教科書（平成５年検定済み，公民，地理，理科）についてすべてを網羅するものではなく，一部の例のみを示す。

1）極端な事例を示し，あたかも全体がそうであるかのような印象を与える記述

①「いったん事故が起こると，放射能の及ぼす影響は大きく，放射性物質によって地球上はおおわれてしまう。」
「高等学校　政治・経済」，第一学習社，p．１０１．

②「核燃料輸送中の事故や核ジャックの可能性があること，原子力関連施設に対する軍事攻撃を受けた場合，通常兵器によるものでも核戦争なみの放射能被害を生じること」
「現代社会」，山川出版社，p．４９．

③「また原子力発電に利用された冷却水や洗浄水なども沿岸の海に放出されている。このような累積する核廃棄物の処理は，運転中の放射能もれや核燃料の再処理工場の安全などとともに人類を核汚染から守るうえで重要な課題である。」
「地理Ｂ」，教育出版社，p．１１５．

④「核分裂による放射能は，直接人間の生命を奪うほか，その放射能によって白血病やガンなどの治癒の困難な病を引き起こし，胎児にも影響を及ぼす。さらに，動植物が被爆した場合でも食物連鎖によって人間の体内に蓄積され，人間に被害が生じる。」
「地理Ｂ」，教育出版社，p．１１４．

⑤「放射能漏れだけでなく，使用ずみの核燃料を含む放射性廃棄物の処理や廃炉の解体などに関連して，安全性を確立するじゅうぶんな見通しがいまのところ立っていない」
「現代社会」，三省堂，p．７７．

⑥「原子力発電所から排出される使用済み燃料やその他の放射性廃棄物は，焼却できないため特殊容器に入れて保存することになっているが，それらは増加する一方であり，最終的な処理技術も確立していないことなどから……」
「新政治・経済」，清水書院，p．１３７．

⑦「放射線の毒性を解決する技術的方法は確立されておらず……」
「新高校現代社会」，一橋出版，ｐ．１９．

２）曖昧でイメージを損なうような語句（下線部）や表現を用いている記述

①「爆発したチェルノブイリ原発の内部」
「新高校現代社会」，一橋出版，ｐ．１９．

②「しかし，核分裂により生ずる「死の灰」の処理など，安全性をめぐる問題が他の代替エネルギーとは異る点であり……」
「新高校現代社会」，一橋出版，ｐ．１１．

③「関西電力美浜原発２号機で，核燃料を冷やす１次冷却水が大量に漏れだし……」
「新高校現代社会」，一橋出版，ｐ．１１．

④「「死の灰」のひろがりは風向に左右された。チェルノブイリに東京を重ねると……」
「現代地理Ｂ」，清水書院，ｐ．１８３．

⑤チェルノブイリ事故に関連して
「……原子炉が爆発する事故が起こった。被災者の数は数十万とも数百万ともいわれる。原子炉は２人の遺体とともにコンクリートで固められ……」
「高校物理ＩＡ」，新興出版社，啓林館，第３部冒頭写真の説明.

⑥「原子力には原子炉の爆発や放射線漏れをいかにして防ぐかという大きな課題がある。」
「高校物理ＩＡ」，実教出版，ｐ．８７．

３）根拠が不明確であったり誤って伝えられた海外の原子力事情の一面を強調する記述

①「１９７９年のアメリカのスリーマイル島の原子力発電所の事故でも，周辺地域に多大な放射能被害をもたらした。」
「高等学校　現代社会」，数研出版，ｐ．２５．

②「使用済み核燃料の廃棄物が年々増加し，ヨーロッパでは，地下の岩塩鉱山跡や大西洋の深海底への投棄が実施されている。」
「地理Ｂ」，教出出版，ｐ．１１５．

③「アメリカでは，スリーマイル島原子力発電所の新設を認めない方針をとってきたが，代替エネルギーの見通しができてから廃止という形で見直しがおこなわれ，１９９１年原子力発電所の増設を発表した。」
「現代社会」，実教出版，ｐ．４４．

チェルノブイリ事故に関連して
④「このチェルノブイリ事故は野菜，牛乳，小麦などの食物を汚染したばかりでなく，事故後５年以上たっても白血病や甲状腺ガンなど深刻な後遺症に苦しむ人びとを増加させている*)。」
「現代社会」，三省堂，ｐ．７６．

⑤「甲状腺やリンパ腺の異常，白血病や各種のガンが多発している*)。」
「地理Ｂ」，東京書籍，ｐ．１３４．

⑥「チェルノブイリ原子力発電所の事故によって，大量の放射線物質が大気中に放出され，周辺地域では甲状腺癌で苦しむ子供がふえている*)。」
「新詳地理Ｂ最新版」，帝国書院，ｐ．１０２．

⑦「……その後の放射線被曝などによる死者は７０００人とする報告もある。」
「現代社会」，三省堂，ｐ．７６．

註

１）下線および波線は本書作製にあたり付したものである。

2）＊国際原子力機関（ＩＡＥＡ）の要請を受けた国際諮問委員会（ＩＡＣ）の調査結果によれば，チェルノブイリ事故の放射線被ばくを原因とする白血病やガンの発生はこの時点（１９９１年）までに確認されていない。なお，その後の調査によれば，１９９４年の時点で事故の放射線被ばくによる影響として白血病が増加していることは確認されていない。ベラルーシ及びウクライナとロシアの一部地域で甲状腺疾患が増加しているが，これとチェルノブイリ事故からの被ばく線量との関係については，今後の調査と研究を待つ必要があるとされている。

2.8 PRESENT STATUS OF RADIATION EDUCATION IN KOREA

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ABSTRACT

Korea is one of the world's most dynamic countries in the use of nuclear energy for power generation. Fourteen NPPs are currently in commercial operation and six additional plants are under construction. According to the country's Long Term Power Development Plan, ten more NPPs will be constructed by 2015. The Korean government has experienced difficulties in acquiring nuclear facility sites and is, therefore, well aware of the importance of public acceptance. Many programs have been initiated to educate the public on the values and benefits of nuclear energy. This paper discusses one of the long-term programs that focus on education for future generations, which include education programs for teachers and students, nuclear facility visit programs, seminars and workshops, scholarship programs, and school curriculum reorganization activities.

1. INTRODUCTION

Korea is one of the world's most dynamic countries in the use of nuclear energy for power generation. Since 1978 when the first commercial NPP (nuclear power plant) Kori #1 unit began operation, the nuclear power generation has been vitalized and currently fourteen NPPs are in commercial operation and six additional plants are under construction. According to the country's Long Term Power Development Plan, ten more NPPs will be constructed by 2015.[1)]

Along with the nuclear power generation, the application of radiation and radioisotopes (RIs) has contributed to the development of industries, scientific research, disease diagnosis and therapy. The areas of application have diversified in parallel with the nation's economic development and the enhancement of the quality of life. As of December 31, 1997, the number of institutions using radiation and RIs had reached 1,315.[2,3)] Table 1 shows the current radiation and RI application statistics.

Table 1. Radiation & RI Applications Statistics in Korea.

Category of Organization		Type of Use		Total	# of Users
		RI	Rad. Gen.		
Industrial Firms	General	536	347	883	800
	N. D. T.	35	34	69	35
	Sales	22	4	26	23
	Subtotal	593	385	978	858
Hospitals		111	40	151	111
Education & Research Org.		204	195	399	339
Others		5	2	7	7
Total		913	622	1,535	1,315

The Korean government has experienced difficulties in acquiring nuclear facility sites, especially radioactive waste management facility sites. From this experience, the importance of public acceptance (PA) was understood and many programs have been initiated to educate the public on the values and benefits of nuclear energy.

One of the long-term PA activities is education programs for future generations. This paper reviews the current status of atomic energy education in Korea and introduces the current activities on the topic.[4)]

2. OVERVIEW OF CURRENT SCHOOL CURRICULUMS

Textbooks play important roles in the education of the youngsters. Especially in Korea, the authority of textbooks is said to be comparable to that of the Bible. The sequences and contents of school education follow those of textbooks and every detail of textbook has important meaning.[5)] Furthermore most schools adopt almost same curriculums and textbooks.

Elementary school (6 year course) curriculums do not cover much of atomic energy. The "Society" subject introduces atomic energy as one of power sources and "Society Investigation" subject deals with the annual electricity generation statistics and the comparison of power sources : hydroelectric, fossil fuel, atomic, etc. It is strange to note that the symbol of power plant does not appear on maps.

Middle school (3 year course) curriculums cover basic knowledge of atomic energy and nuclear power generation in "Science", "Technology", "Industry", and "Environment" subjects. The "Environment" subject deals with the comparison of the fossil fuel and nuclear power plant and the radioactive waste management problems. The "Society" and "Politics" subjects deal with nuclear power generation statistics and the importance of nuclear Non-Proliferation Treaty. It is notable that there are room for role play on the topic that "If radioactive waste management facility is built in our village "

High school (3 year course) curriculums cover comprehensive knowledge on atomic energy uses. The basics of atomic physics such as atomic structures, radiation, RI applications, chain reactions, PWR & PHWR, nuclear fusion, radioactive waste management, are covered in "Science", "Physics", "Chemistry", "Mechanics", "Industry", etc. The statistics of energy resources are dealt in "Geography". The "Ethics" describes the KEDO activities positively in relation to the reunification of Korean Peninsula. The "Electric Power" subject covers the comprehensive knowledge on NPP. The radioactive waste management problems are dealt in "Politics" and some discussion topics related to atomic energy issues were provided in "Literature" and "Narration" subjects. The current educational curriculums and those related to atomic energy were tabulated in Table 2 and 3.[6)]

Table 2. Statistics of Subjects/Texts Related to Atomic Energy(AER).

	# of subjects		# of texts	
	Total	AER	Total	AER
Elementary School	29	5	38	5
Middle School	21	12	168	44
High School	77	42	310	181
Total	127	59	516	230

Table 3. Subjects Related to Atomic Energy.

	Subjects related to atomic energy
Elementary School	Society 1 2 3, Living Guide, Maps
Middle School	Environment, Korean Language, Society, Ethics, History, Industry 1 2 3, Science 1 2 3, Maps
High School	Industrial Chemistry, Physics, Chemistry, Industrial Mechanics, Geology, Introduction to Industry, Politics, Ethics, Power Generation, General Electricity, Food, Biology, Fishery, Environment Technology, Society, Physics Experiment, History of Science, Literature, Writing, Geography, Society & Culture, Narration, Industry, Technology, Geology 1 2, Biology 1 2, Physics 1 2, Chemistry 1 2, Maps, etc.

3. CURRENT ACTIVITIES ON NEXT GENERATION EDUCATION

Next generation education program is composed of lecture courses, nuclear facility visit programs, seminars and workshops, scholarship program, and school curriculum reorganization program.

The purpose of lecture program is to disseminate scientific information on the peaceful use of nuclear energy. This program is composed of lecture courses for teachers and students, and nuclear expert's lectures at schools. In 1997, we held 173 lecture courses and 17,029 teachers and students participated.

In order to build the familiar and sound image on NPPs, nuclear facility visit program is opened and nuclear science camps for students, workshops for professor are organized. The detailed statistics of above programs is summarized in Table 4.

In addition to the above activities, educational aids such as educators' guides and audio-visual materials are prepared and distributed to help them learn and teach nuclear energy extensively and correctly. To inspire an appetite for writing and to foster culture in the youngsters, we invite middle and high school students to enter writing and drawing contests. Contest entrants will have chanced to win overseas trips.

Table 4. Next Generation Education Statistics.

Program	1996		1997	
	# of courses	# of persons	# of courses	# of persons
Lecture Courses	28	5,306	173	17,029
- Teachers	20	3,594	16	2,083
- Students	8	1,712	21	7,383
- Nuclear expert lectures	-	-	136	7,563
Nuclear Facility Visit	9	600	8	1,042
- University students	4	160	4	160
- High school students	5	440	4	782
Seminars & Workshops	12	635	13	818
- Nuclear science camps	2	160	1	300
- Workshop for teacher	6	435	8	468
- Workshop for professor	4	40	4	50

While providing integrated and systematic educational programs for the youngsters, we try to have school curriculums reorganized to deliver an accurate picture of nuclear energy. As shown in Table 5, there are about 2.4 million students and teachers in Korea. Because of the limitations of manpower and fund, the direct educational approaches such as lecture courses, nuclear facility visit program, etc. reach only 1% of students. Thus most emphases are on school curriculum reorganization program.

Table 5. Number of Schools, Students, and Teachers.[7)]

	Elementary	Middle School	High School
# of Schools	5,721	2,720	1,892
# of Students	3,800,540	2,379,963	2,331,725
# of Teachers	138,670	97,931	104,404
Total	3,944,931	2,480,614	2,438,021

As shown at Table 2 and 3, subjects and textbooks related to atomic energy are surveyed and requests for corrections regarding the negative or wrong descriptions, are made to the Ministry of Education. In 1996 for the 18 requested subjects, 6 corrections were made.

Besides the curriculum survey, Next Generation Education Committee was formed to converge the opinions on the atomic energy education, which is composed of educational and nuclear experts. Nuclear facility visits for textbook authors are organized to give them the right knowledge on atomic energy use so that they may describe atomic energy matters objectively. Also supportive activities such as preparation of educational aids and arrangement of topical meeting on atomic energy, are supplied.

4. CONCLUSIONS

In order to bring up our future generations to understand the peaceful use of atomic energy, the proper educations on the topic are very important. This paper reviewed the present status of school education in Korea.

This paper introduced direct educational approaches such as lecture courses, nuclear facility visit program, etc. and indirect educational approaches of school curriculum reorganization program. Considering the efficiency of education, which can be defined by the influence of education, it is concluded that most emphasis should be made to school curriculum reorganization program.

ACKNOWLEDGEMENT

The author wishes to acknowledge the support of the MOCIE and the OKAEA for providing valuable materials.

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2.9 STATUS OF RADIATION EDUCATION AND TRAINING IN THE PHILIPPINES

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ABSTRACT

There are three major sources and levels of obtaining radiation or nuclear education and training in the Philippines: the secondary schools or high schools; colleges and universities; and training courses in nuclear science and radiation protection offered by government agencies such as the Philippine Nuclear Research Institute (PNRI) of the Department of Science and Technology and the Radiation Health Service (RHS) of the Department of Health. This paper summarizes the status, some of the activities and some of the problems of radiation education in the Philippines.

1. INTRODUCTION

At the present time, there is a general negative public perception about anything associated with the word "radiation" or "nuclear". The most comprehensive and effective way to counteract this negative perception would be to educate the young generation in schools and introduce nuclear science topics in all levels of the educational system. Radiation and nuclear science topics are not taught in the elementary school. There is a need to upgrade and effectively implement nuclear science education in the secondary level or high school. There are 6,673 schools offering secondary education all over the Philippines, and there are around 100,000 high school science teachers.

The Philippine Nuclear Research Institute (PNRI), an institute under the Department of Science and Technology (DOST), is the sole government agency in charge of matters pertaining to nuclear science and technology, and the regulation of nuclear energy. The PNRI is tasked with fast-tracking nuclear education and information, together with the Department of Education, Culture and Sports (DECS), the Commission on Higher Education (CHED), and some other government agencies which constitute the Subcommittee on Nuclear Power Public Education and Information, by virtue of Executive Order 243 enacted by then President Ramos on May 12, 1995. This Executive Order created the Nuclear Power Steering Committee and the Subcommittee on Nuclear Power Public Education and Information is one of the subcommittees under it.

The only other govenment agency that provides radiation education/radiation protection training is the Radiation Health Service (RHS), an agency under the Department of Health responsible for licensing users of X-ray machines. RHS provides radiation protection training to X-ray technicians and users.

2. PRESENT STATUS OF RADIATION EDUCATION/TRAINING ACTIVITIES

2.1 Secondary School or High School Radiation Education

The system of secondary school or high school education in the Philippines has a duration of four years; other countries have five or six years. Secondary education follows the completion of six or seven years of elementary education. The secondary school science education program consists of General Science (First Year), Biology (Second Year), Chemistry (Third Year) and Physics (Fourth Year). Each course is taught for two periods equivalent to 80 minutes per day, with a credit of two units. Radiation and nuclear science/ technology including nuclear power are taught mainly in the fourth year science and technology curriculum, under Physics. In the general and specific learning competencies for fourth year high school Physics, radiation and nuclear science topics including nuclear power are taught last, under the chapter on "Matter and Energy." As published by the Bureau of Secondary Education, of the Department of Education, Culture and Sports, Table 1 lists the General and Specific Learning Competencies under "Matter and Energy," which is the last chapter to be taught in the fourth year high school science and technology curriculum.[1]

Table 1. General and Specific Learning Competencies Under "Matter and Energy"[1]

VII. Matter and Energy

1. Demonstrate understanding on the dual nature of matter and energy
   - 1.1 Explain photoelectric effect.
   - 1.2 Use the photon theory to explain fluorescence and the principles of a photo cell, photovoltaic cell and laser.
   - 1.3 Restate the meaning of the dual nature of matter and energy in one's own words.
   - 1.4 Explain Einstein's matter-energy equivalence, mass defect, and nuclear binding energy.
   - 1.5 Differentiate nuclear fission, chain reaction and fusion.
2. Manifest scientific thinking on nuclear radiation.
   - 2.1 Recognize the contributions of Becquerel, Pierre and Marie Curie on radioactivity.
   - 2.2 Distinguish three types of radiations given off by radioactive substances and their effects on living things.
   - 2.3 Write equations on nuclear reactions.
   - 2.4 Cite some uses of radioisotopes in medicine, agriculture and industry.
   - 2.5 Explain the principle of radiation safety.
3. Understand basic physics principles of a nuclear power plant and a nuclear weapon and their effects on man and the environment.
   - 3.1 Compute the energy released in a nuclear reaction.
   - 3.2 Describe the important features of a fission reactor.
   - 3.3 Explain the fission and fusion processes in nuclear weapons.
   - 3.4 Discuss environmental effects of nuclear reactors and weapons.
   - 3.5 Evaluate the findings made by scientists, environmental experts and other technocrats on the use of nuclear power in the Philippines.
4. Explain energy and interactions as unifying concepts in physics.
   - 4.1 Describe and differentiate some elementary particles.
   - 4.2 Explain four basic interactions.
   - 4.3 Discuss briefly the physicists' search for unification in physics.

The main problem of radiation education in the secondary or high school level is that many high school science teachers omit teaching radiation and nuclear topics since they are found in the last chapter, and taken up towards the end of the school year. In addition, a vast majority of the science teachers do not have the necessary qualifications, competence and training to teach these topics. In general, the situation in the Philippines is that only around 20% or even less, depending on the field of science, of high school science teachers are qualified to teach these subjects. This means, for example, that many of the high school Physics teachers are not actually Physics majors. To solve this problem there is an urgent need to educate and train science teachers in order to give them enough confidence to teach nuclear science to their students. There is also a need for the availability of good audio/visual teaching aids that would make radiation and nuclear science topics interesting and understandable. These would include teaching modules complete with visual aids such as transparencies or tape slides, and computer-aided instruction for use in those schools where computers are available to the students. Another approach to solve this problem would be to introduce nuclear science topics in the present secondary school curricula, not only under Physics (Fourth Year) but also in the lower years as well. Some possible entry points for nuclear science topics are shown in Table 2.

Table 2. Some Possible Entry Points for Topics on Radiation and Nuclear Science in the High School Curricula[2]

SCIENCE SUBJECT	POSSIBLE ENTRY POINT
General Science (First Year High School)	Topic on Energy - under forms and transformations of energy, and sources of energy, nuclear energy could be introduced
Biology (Second Year High School)	Topic on Genetics - under gene mutation, radiation could be introduced as producing better strains of plants, as used in mutation breeding
Chemistry (Third Year High School)	Topic on Inside the Atom - under structure of the atom and subatomic particles, radioactivity and transmutation of the elements could be discussed
Physics (Fourth Year High School)	Topic on Matter and Energy - this is the main entry point of topics on nuclear science, nuclear power plants and radiation safety

2.2 College or University Level Radiation Education

In the Philippines, not all curricula for a Bachelor of Science college or university degree incorporate nuclear science/technology as a one semester course (consisting of 3 units). Although recommended by the Technical Panel of the Commission on Higher Education (CHED), it is not a requirement but the option of a particular school to include nuclear science and technology topics as a one semester course in some Bachelor of Science curricula. For example, the B.S. Physics curriculum may include one semester of Nuclear and Particle Physics; the B.S. Chemical Engineering curriculum may include one semester of nuclear chemistry or nuclear chemical engineering. The B.S. Electrical Engineering curriculum includes one semester of nuclear engineering. The B.S. in Radiologic Technology includes one semester of radiation protection. There is only one university offering a masteral degree in Medical Physics, and radiation protection is included as a one-semester course in its curriculum. Although in the past an M.S. Nuclear Engineering degree was offered at the University of the Philippines in preparation for the first nuclear power plant, this M.S. program has been inactive since the government decided not to operate this nuclear power plant.

2.3 PNRI Activities

The Philippine Nuclear Research Institute regularly conducts training courses in nuclear science and technology, and radiation protection to users of radioisotopes in academic and research institutions, hospitals and medical institutions, and different industrial companies. It also conducts training courses in nuclear science and technology for high school science teachers, and college/university faculty. The five-week training courses are: Seminar in Nuclear Science for High School Science Teachers; Nuclear Science for University/College Faculty; and Radiation Cytogenetics Course. Some of the four-week courses are: Radioisotope Techniques Training Course (either for medical, for academe, or for agriculture); Industrial Uses of Radioisotopes Course; and Radiological Health and Safety Course. Two-week courses include the Training Course on Radioimmunoassay, and Radiographic Testing (Nondestructive Testing) Course. A one-week Introduction to Nuclear Science Course is also offered to high school teachers, or university faculty upon request by a particular school or university. A three-day Radiation Safety Course is also offered to industrial companies using radioisotopes in nuclear gauges (for example, level gauges and thickness gauges), to hospitals, and to research institutions.

Some of the common topics discussed in these training courses are: (a) Sources of Radiation; (b) Radioactivity and Radioactive Decay; (c) Interaction of Radiation with Matter; (d) Radiation Quantities and Units; (e) Radiation Detection; (f) Biological Effects of Radiation; (g) Basic Principles and Concepts in Radiation Protection; (h) Radwaste Management Principles and Practices. In addition, the courses for teachers would include topics on nuclear power and nuclear energy.

Up to the present time 6,959 have received some radiation education/training from the PNRI. The trainees include all users of radioisotopes in the Philippines: researchers, practitioners in the medical field and industry, as well as high school teachers and university faculty. Except for those who take the Radiographic Testing (Nondestructive Testing) Courses, the trainees are required to have a minimum of Bachelor of Science degrees in the sciences or engineering. Figure 1 shows the number who availed of training from the PNRI per year, while Figure 2 shows the distribution of these trainees per sector or field (industry, medical, academe, others).

The PNRI also conducts one-day nuclear awareness seminars, held in different high schools, for the students. This seminar usually includes a demonstration of the detection of radiation using a survey meter, as well as the effect of distance on the intensity of radiation. Table 3 shows the number of nuclear awareness seminars per year for the last five years, as well as the number of students per year.

Table 3. Number of Nuclear Awareness Seminars Conducted by PNRI and the Number of Students

Year	1994	1995	1996	1997	1998
No. of seminars	8	12	7	9	7
No. of students	1,135	2,784	2,320	2,167	750

In cooperation with the Radioisotope Society of the Philippines, PNRI developed ten teaching modules in nuclear science for use by science teachers, complete with instructional materials such as script, and transparencies as visual aid. Although these teaching modules had been trialed and received positive feedback, mass reproduction of these modules has not yet been done. These ten training modules are on the following topics: (1) The Atom; (2) Radiation - Where From, and What For? ; (3) The Unstable Nucleus; (4) What is Radioactivity; (5) The Radioactive Clock - How Old Is Old? ; (6) Is Interaction With Ionizing Radiation Exciting?; (7) Biological Effects of Radiation; (8) Uses of Radioisotopes in Industry, Medicine, and Agriculture; (9) Nuclear Power; (10) Environmental Impact of Nuclear Energy.

2.4 RHS Activities

For users of X-ray machines, the government agency in charge of regulations and licensing is the Radiation Health Service (RHS) of the Department of Health. RHS is also actively involved in providing radiation education/radiation protection training to doctors and residents in radiology, X-ray technicians, dental X-ray and industrial X-ray users. There are around 2,000 medical X-ray facilities in the Philippines; of these, 30% are located in the National Capital Region or the Metro Manila area.

Before 1995, the RHS trained, on the average, around 450 personnel per year in the following courses:[3] (a) Six-week "Training on Radiation Physics and Protection, Radiographic Techniques and Film Interpretation of Chest, Skeletal System and Emergency Radiographs"; (b) Three-day "Seminar on Radiation Physics and Protection and Radiographic Techniques for Dental X-ray Units Users and Operators." Starting in 1995, RHS offered the workshop on "Radiation Safety in Medical Radiography for X-ray/ Radiologic Technologists." This 26-hour training/workshop enables X-ray/radiologic technologists to become Radiation Safety Officers, and is a requirement for licensing of X-ray facilities. The radiation-related topics in the syllabus for this training/workshop are: (a) Production of X-ray and Its Properties; (b) Interaction of Radiation with Matter; (c) Radiation Quantities and Units; (d) Biological Effects; (e) Principles of Radiation Protection; (f) Personnel Monitoring; (g) X-ray Room Design.

3. Additional Future Activities

In 1998, as part of a Regional Cooperative Agreement (RCA) and International Atomic Energy Agency (IAEA) project, the Philippines participated in the trialing of distance education or distance learning modules in radiation protection. These distance learning modules were developed at the Australian Nuclear Science and Technology Organisation (ANSTO). Under Phase 2 of the project, these modules will be trialed in the Open University of the University of the Philippines. These modules will also be trialed in Thailand, New Zealand, Korea, and Mongolia. After the trials and once put in their final form, these modules will be published by the International Atomic Energy Agency and will be free for use by countries desiring to do so, and may be translated to the native language of a particular country. These modules could in the future be transformed to electronic format to be availed of using the internet.

As part of the activity of the Subcommittee on Nuclear Power Public Education and Information, 36 additional Teaching Modules on radiation and nuclear topics are being developed by the University of the Philippines - Institute for Science and Mathematics Education and Development. These are designed for use from the First Year to the Fourth Year of high school, and designed for continuity of learning on a spiral method. Each module includes a Teacher's Resource Manual and a Student Resource Manual.

Although at present there are some weekly science programs on television designed for science teachers, high school and elementary students, radiation and nuclear science related topics still need to be incorporated into these television programs.

The Philippines is coming up with an Education Technology Master Plan whose aim is to improve the accessibility and quality of education through the use of Information Technology and other innovative education technologies. The different government agencies involved in this master plan are the Department of Education, Culture and Sports (DECS), the Technical Education and Skills Development Authority (TESDA), the Commission on Higher Education (CHED), and the Department of Science and Technology (DOST). If incorporated into the Master Plan, Information Technology (IT) will be a powerful vehicle for radiation education in the future.

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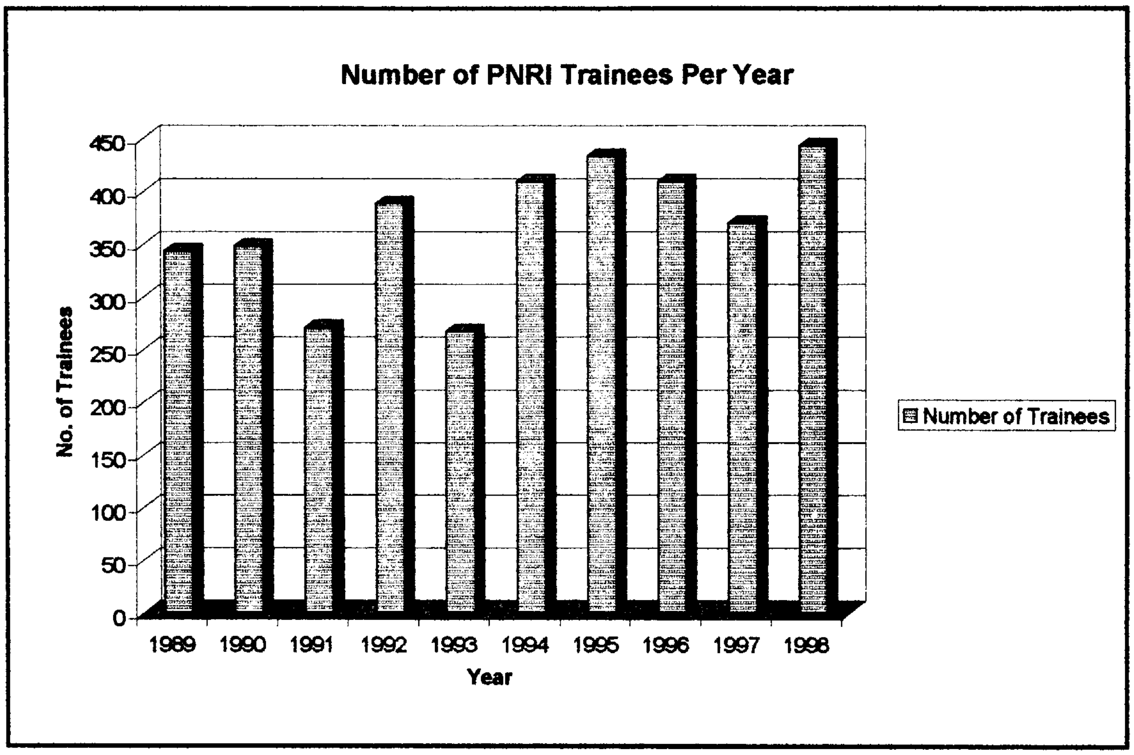

Figure 1.

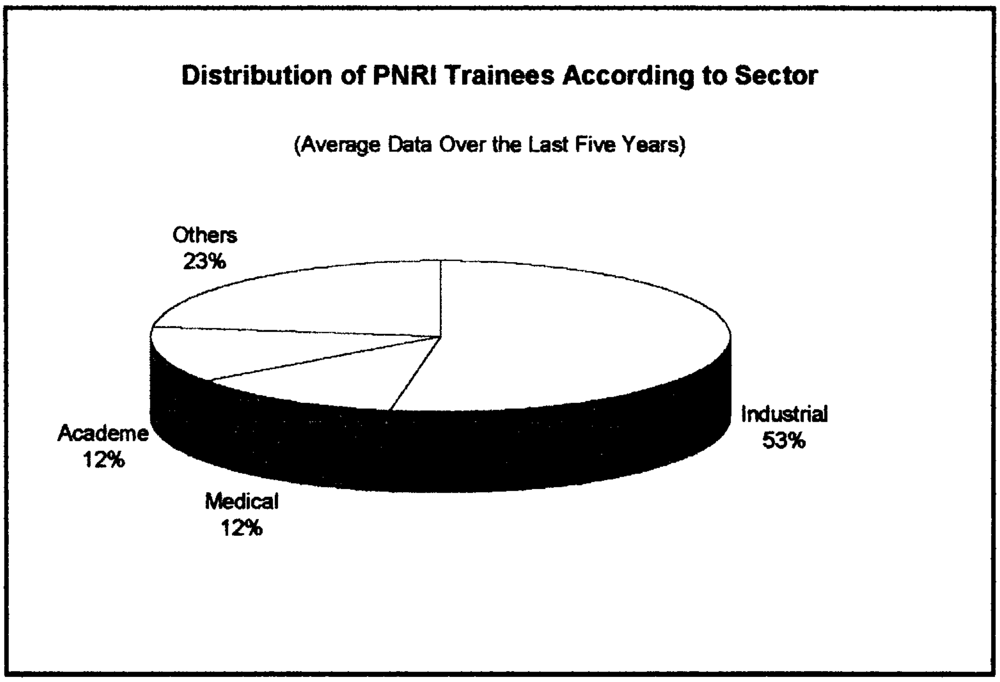

Figure 2.

2.10 RADIATION EDUCATION IN POLAND – THE PRESENT STATUS AND PERSPECTIVES

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ABSTRACT

The necessity for the continued education about radiation (both in nuclear science and the technical application of radioisotopes) in the educational system is obvious.

For many years this subject has been part of a students education in physics as well as nonphysical areas of study, such as chemistry, biology, medicine, ecology and agriculture.

Unfortunately in the wake of the disaster at Chernobyl, a number of negative factors have resulted that have undermined both education in this crucial area and financial investment in Polish radiation institutes. Some sociologists have termed this behaviour/viewpoint "radio - phobia phenomena". Might I be so bold as to recoin it as "nuclear related paranoia" since it has caused a general breakdown in rational, "cause and effect analysis" even within respectable scientific circles, including prominent radiobiologists, who now accept radiation only as a destructive factor in biological and human life.

Unfortunately in Poland there is a good basis for the development of "radio-phobia" amongst the population. Firstly, in the past, the development of the A-bomb coupled with the rise of two diametrically opposed political and military systems (dividing East and West), up until 1989 led to extensive worldwide research which considered only the damaging effects of exposure to radiation in the event of world conflict. This created the basis for the false and totally unscientific belief that exposure to radiation in both high and low doses were strangely equal and therefore harmful to humanity. The voice of reasonable scientific research, that proved that this was patently not the case, was drowned under the insistence, by many, that the use of nuclear physics for the creation of civilian power sources equated that of an S.S.20 or Pershing II nuclear warhead, a few of these misinformed persons going so far as to claim that missles were perhaps even more desirable than civilian nuclear projects because as they put it to the Danes, "at least, unlike Barseback, there not in your backyard".

Now might be the last chance we have to rid society of this hocus-pocus and change their way of thinking about radiation and nuclear physics in general.

The most important factor in this campaign will be the promotion and presentation of radiation in simple-understandable terms through the following outlets, (popular articles, TV programs, objective classroom presentations and so on), designed to be easily understandable to society as a whole. In this support is to be found in some governmental and independent organizations which do attempt to show radiation as bio-positive, human friendly and an economically indispensable factor for the future. However our fight with the so-called "coal lobby" will continue to be difficult. Help by international organizations such as the I.A.E.A will not suffice in this battle.

In this article the author tries to describe the Polish education system and statistical data showing the present status of radiation science, radiation education and the quantity of students and experts in the field.

As a nuclear physicist and specialist in radiation protection, lecturer and an Inspector of Radiation Protection, he provides insights from his own experience and offers his conclusions regarding efforts to encourage and promote radiation science and education.

1. INTRODUCTION

Interest in nuclear science and its applications began before 1970, in connection with the start of designs for the First Polish Nuclear Plant (FPNP). After Chernobyl and a very aggressive negative publicity campaign against all forms of nuclear development, all work in this project was discontinued. This despite the fact that from its inception and throughout the eighth years of its design and construction, FPMP had cost the Polish government, that is the Polish tax payer, over $8 million. Starved of financial assistance, institutes concerned with the development of nuclear related subjects, have fallen into disuse and neglect, many closing altogether. The Polish Nuclear Society coupled with the Technical University of Warsaw has released an elaborate analysis of the present status regarding education about radiation in the Polish education system. Sadly a sorry picture emerges.

Although in some elementary and high schools various elements pertaining to the science of radiation exists it is generally taught within the framework of related subjects – for example - physics, chemistry and ecological studies. This is therefore the first contact a student will have with atomic science related matters. Because this first point of contact with nuclear subjects is of such great significance, one would expect the subject to be introduced in an easy and objective manner which describes both the positive and negative influence on ecology and human life. What is called for here is a rational balanced approach which explains realistically the types of problems associated with nuclear technology, at the same time stressing both the known and potentential solutions. Therefore it is an absolute necessity that a positive nuclear education program be adopted in the Polish education system. Sadly this is not true of the present climate.

Analysis of this problem is overwhelmingly pessimistic. After 1990 many Universities closed post-graduate studies in nuclear related subjects. During the same period large numbers of nuclear specialists and experts rejected their profession, finding new positions in jobs that were more profitable and acceptable to "public opinion". Several scientists have fled the country to seek meaningful employment in less paranoid countries, where their highly skilled educational qualities are appreciated and not scorned.

Also since 1990 the amount of students applying for studies in nuclear related subjects has collapsed. Only a handful of Polish Universities continue to offer courses in the field of nuclear sciences (Table 1) most of the others having capitulated to the irrational demands of political and public “anti-nuclear sentiment”.

Fig. 1 shows the number of university students completing nuclear science and technology related subjects in the period 1985 - 1994. As a direct consequence of the Polish Governments decision to abandon construction of F.P.N.P. we are able to observe a catastrophic decline in the number of students involved in the nuclear field. Fig. 2 and Fig.3 show clearly how this has also decimated the number of students receiving honors at the highest levels (i.e. doctorate and professorial level) and a number of the post-graduated thesis finished in nuclear science and technology (before and after 1990).

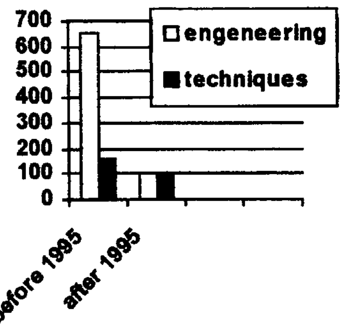
2. CONCLUSIONS

The shortsighted political decision to halt construction of the First Polish Nuclear Plant has all but destroyed nuclear science education in the country, both in regards to its commercial use and its non-energy-related applications.

The political about-face by both the Polish Parliament and Government to revive a Polish nuclear program will require a "Manhattan Project " type program in both educational reform and public awareness if it is to have a chance of success. We will need to use the expertise of all nuclear scientists and professionals to help to create, as rapidly as possible, a new generation of nuclear experts.

Tab.1. Universities and scientific laboratories in Poland involved in "atomic area".

Place	Department
University of Metallurgy and Mine Krakow	Nuclear Physics and Techniques; Electronics and Electrotechniques; Energy;
Technical University Bialystok	Mechanical
Technical University Gdansk	Electric
Technical University Lodz	Institute of Radiation Techniques
Technical University Gliwice	Environmental and Energy Engineering
Technical University Poznan	Radio- and Photochemistry; Physics Institute; Institute of Chemistry and Electrochemistry;
Poznan University	Physics Institute; Institute of Chemistry – Radiochemistry;
Technical University Warsaw	Electric; Electronic; Energetic and Aviation; Land Engineering;
Technical University Wroclaw	Institute of non-organic Chemistry; Rare Earth; Physics Institute; Mechanical Energetic; Experimental Physics Institute;
Nuclear Energy Institute Swierk Institute of Nuclear Problems Swierk	full spectrum
Central Laboratory of Radiation Protection Warsaw	Radiation Protection Environmental Science
Chemistry and Nuclear Techniques Institute Warsaw	full spectrum



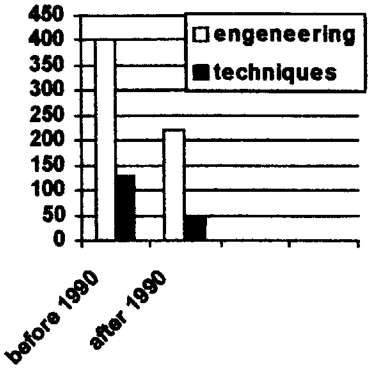


Fig.1. Number of university students finished a nuclear science of technology subjects (before and after 1995).

Fig.2. Number of the highest Universities degree (i.e. doctor and professor's thesis) finished in nuclear science of technology subjects (before and after 1990).

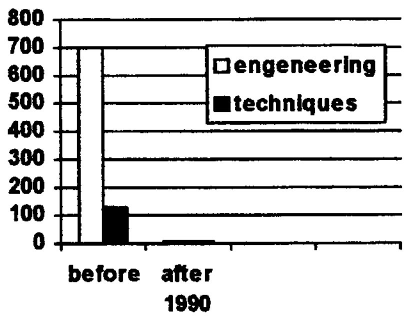


Fig.3. Number of the post-graduated thesis finished in nuclear science and technology (before and after 1990).

Both the Chernobyl incident and the so-called "Hiroshima Syndrome", have had a disastrously negative impact in applied nuclear - radiation studies and subsequently undermined the economic viability of most Polish "Institutes of Radiation R & D".

The sociological impact of years of negative nuclear propaganda is most keenly felt in public attitudes towards both nuclear energy projects and related subjects. The repeated emphasis in the media of the, "negative only", results of nuclear technologies, coupled with unscientific ravings of a few misguided individuals in the scientific community has resulted in a "radio - phobia phenomena" of hysterical proportions.

Only an all out educational drive, using popular articles in the written media, TV documentaries and a school educational program, will enable us to redress this imbalance.

Although there exists some governmental and independent organizations that attempt to present nuclear science in a positive light, i.e. bio - positive, human friendly and as an economically indispensable factor for sustainable growth, we cannot rely on the help of such institutions, including the I.A.E.A., to win the battle we are waging.

The fight against ignorance and short-term economic solutions in the field of energy development, against the "Greenies" and "Coal Lobby" respectively, will continue to be difficult.

Finally the following list of points, I hope will enable all of us attending today's conference, to focus our discussions and perspectives for future actions.

a) an increase in the number of nuclear science related subjects at university level is imperative.

b) an increase in funding in this area is needed by the Ministry of Education in Poland.

c) the use of positive coverage in all forms of media is essential for combating public ignorance in the subject.

d) financial assistance, in the form of grants, have to made available to a Science Research Committee.

e) the introduction of pro ecological techniques for the production of energy, such as nuclear energy, must be explored vigorously.

f) financial incentives to industries engaged in nuclear related programs should be encouraged through "Tax Breaks" and low interest credit opportunities.

g) a concerted effort should be made to explain the relationship both historically and presently in the evolution of the universe and the human species.

h) a full frontal attack must be launched to combat superstition and ignorance about nuclear physics. This should also focus on the necessity of exposing unscientific and sensationalistic postulations made by the uninformed. Every piece of misinformation should be challenged wherever it occurs.

i) an international alliance of all persons dedicated to the proliferation of nuclear related science and technologies should be formed and cemented through regular contact and forums of the kind we are attending today.

2.11 STATUS AND PROBLEMS OF RADIATION EDUCATION IN TAIWAN

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Abstract

In Taiwan, there are few numbers of radiation education, courses this fact makes an impression of insufficiency. This matter is thinkable to be an important problem. There are sets of atomic power stations and 6 atomic reactors are now operating. The electric power production is about 50144MW, which comprises 20% of total electric power in the country. The knowledge for the related to the radiation is not diffuse and there is only frightened impression. The radiation education should be spread to the ordinary citizen, and essential qualities a risk of the radiation should be instructed sufficiently. The radiation literacy of the ordinary citizen is needed to raise the level.

I. Introduction

The country area of Taiwan is nearly 3,6000 sq.km^2 and the population numbered is over 21,000,000.The population density is 585 persons/km^2 which is the secondly crowded in the world, Taipei City has the highest population concentration (2,800,000) of the Taiwan area. The population is greatest along the Taiwan Starct seaboard where the weather is mild and the transportation and industrial facilities are most highly developed. In fact approximately 95% of the nations people live on the strip of coastal plain between Taipei and Kaohsiung. Advancing industrialization has been accompanied by a population shift toward the large cities and a remarkable population decline in the agricultural areas.

The education is available to all citizen over 98%. At the present time, there are about 130 Universities or Academies[1], while most of student enrollment of university is more than 20,000. The Gross National Produce (GNP) reaches US$13,000. Student enrollment of university or academy at present is 856,186 The numbers of doctoral, master's, undergraduate and academic course students are 10,013, 38,606, 373,702, 433,865 respectively, and corresponding ratio is 1:3.75:36.3:42.2.

II. Education and Training 1)

There are 79 Universities and Academies; the other Colleges are 60. The number of university, which employs teachers with radiation license, is 18, and the number of these teachers is 77. Which the college with the same qualification is one and the number of teachers is 2.

Number of university and colleges, which provide the course of various radiation education, are 16 and 1 respectively. There are 20 universities that contain the Department of Chemistry, and the number of student is 4,737. Among these 20 universities only 4 provide the course of various radiation education (the ratio is 20%).

Because the various radiation education in university are not enough, ordinary citizen can not understand radiation well. This situation makes people frightened and they are against to the peaceful use of radiation and the building of new Electric Nuclear Power.

In order to redress the deficiency of various radiation education in university, short course training about radiation education is provides in 4 institutes as follows (Table1).

1. Institute of Nuclear Energy Research: To strength the training of employs in institute.
2. Radiation Protection Association: To provide publicly the course of sealed radioactive source.
3. Taiwan Electric Power Co.: To strength the training of employs in company.
4. Yang Ming University: To train the use of Un-Sealed radioactive source in medicine.

III. Nuclear Reactor

1. Nuclear Research Reactor

There have 2 Nuclear Research Reactors in Tsing Haw University and Instituted of Nuclear Research Reactor. They also educate and train for basic science and technology of Radiation, simultaneously, they produce some Radio Isotopes to supply medical use etc.

2. Nuclear Power Generation

The six nuclear units in Taiwan jointly constituted 20 percent of the total installed capacity. The six nuclear units were housed in three nuclear power stations, all of which are owned and operated by the Taiwan Power Company. The first nuclear power began to operation in 1978. The second nuclear power was started in 1983. The third nuclear power began operating in 1984. The two new nuclear units are building now.

Almost all of the nuclear power reactors are located at North part of Taiwan, and another 2 research Nuclear reactors are also in there. So that North part of Taiwan is exposed to higher density of nuclear reactor dosage than South part (Fig. 1).

IV. The Atomic Energy Council

The Atomic Energy Council, a government supervisory agency under the Excutine Yuan, sets the licensing specification for nuclear power plants and Radiation equipment or users (Table 1,2 and 3). Numbers of license for Medical and Non-Medical are 13,932 and 7,654 respectively, and the number of license for Radiation protection is 1,360.

CONCLUSION

The discovery of radiation has been beyond 100 years. We still feel it's mystery. Henceforth the education of radiation is strengthened from primary school to university. People will understand the importance of radiation and the way to use well. The radiation literacy of ordinary citizen in Taiwan can be raised in the near future.

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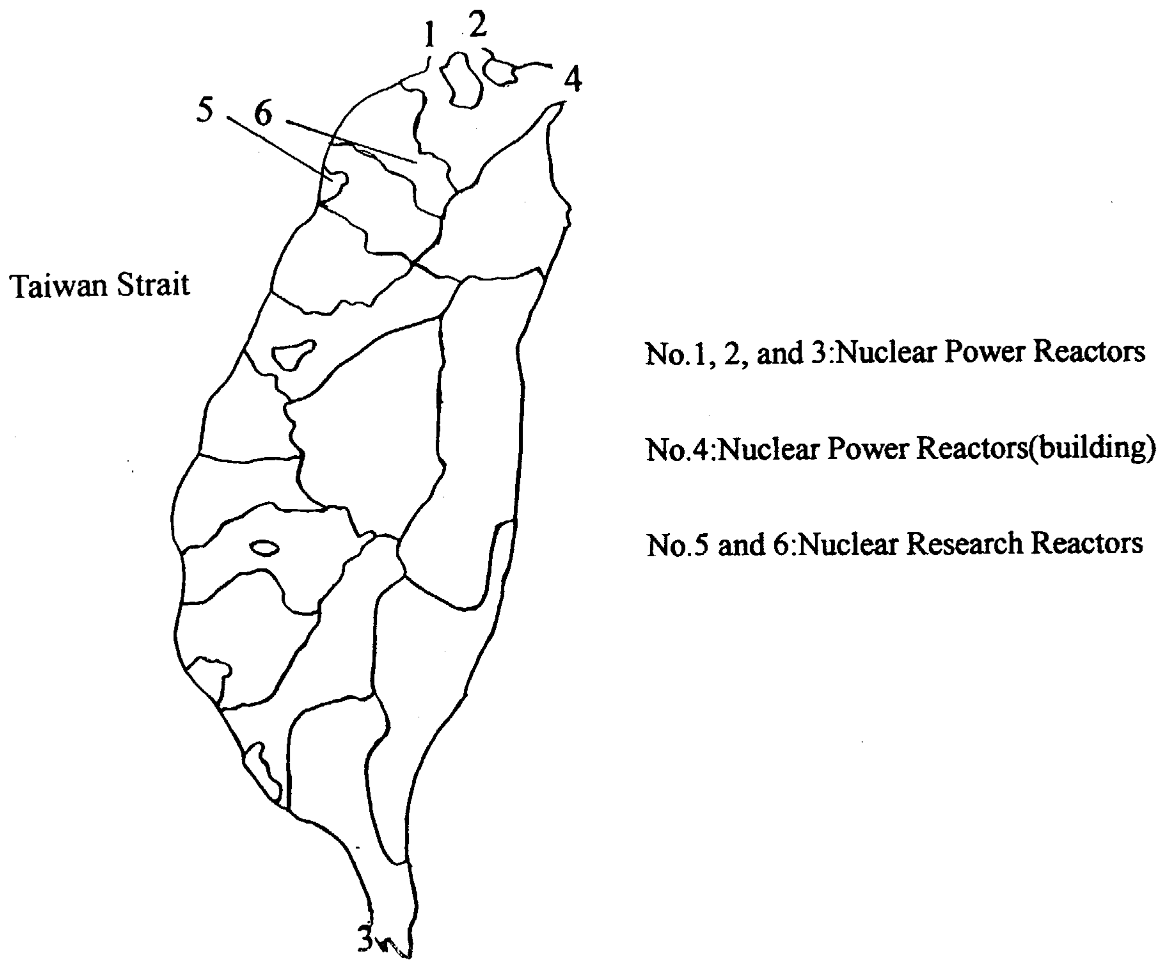

Fig.1 Map of Nuclear Reactors location in Taiwan

Table 1 License for Medical

	To Diagnose	RI	Treatment	Total
Associates Engineers	420	3	12	435
Engineers	2517	148	241	2906
Dentists	6483	0	2	6485
Doctors	3905	85	116	4106
Total	13325	236	371	13932

Table 2 License for Non-Medical

	Sealed Radioactive Material	Un-Sealed Radioactive Material	Ionizing Radiation Equipment	X-ray for Animal	Sealed Radioactive Sources and X-ray	Total
Junior	2266	2707	1812	201	276	7262
Middling	85	190	82	0	3	360
Senior	17	10	5	0	0	32
Total	2368	2907	1899	201	279	7654

Table 3 Number of Radiation Protectors

	Junior	Middling	Senior	Total
Ionizing Radiation Equipment	612	40	1	653
High level Radiation Treatment	44	12	0	56
Radiation irradiation	101	2	0	103
Sealed Radioactive Materials	214	52	3	269
Un Sealed Radioactive Materials	470	63	2	535
Nuclear Reactor	100	40	3	143
Others	28	1	37	66
Total	1569	210	46	1825

Numbers of Licenses : 1360

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2.12 STATUS AND PROBLEM OF RADIATION EDUCATION IN THAILAND

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ABSTRACT

Knowledge of radiation and its application and protection have been routinely taught, discussed and transferred to end users and the public. Limited resource and a strategic plan are identified to be the major obstacle to fully implementation of radiation education in Thailand. Current strategic planning on radiation education in Thailand will be discussed.

1. INTRODUCTION

Peaceful applications of atomic energy in Thailand has been the founding principle of atomic energy applications since its introduction to the Kingdom in 1961. It is clear to us that 'peaceful' means benefit with safety. In practice, Thailand commits and adheres to Non-Proliferation Treaty (NPT) of nuclear weapon regime with a comprehensive safeguard agreement with the International Atomic Energy Agency or the IAEA.

The world wide "**Atom for Peace**" program initiated a national peaceful application of atomic energy program in Thailand. Later, an Atomic Energy Commission, so called Thai A.E.C., was established by virtue of the Atomic Energy for Peace Act 1961 with an Office of Atomic Energy for Peace (OAEP) established as its Secretariat. OAEP is an the key organization in Thailand dealing with all matters on peaceful application of atomic energy. Apart from being the Secretariat to the Thai A.E.C., OAEP has been playing key roles to implement the founding principle and its associated policies to control and regulate safe uses of, to promote and coordinate research and development on, and to conduct its own research and development on peaceful utilization of atomic energy. It is also the counterpart institution of the International Atomic Energy Agency (IAEA).

In the past 36 years, there have been substantial progresses made on peaceful and safe utilization of atomic energy in various Thai research institutions including OAEP. Their main contributions have been in areas of education and training, and for agricultural produce development and treatments, nuclear medicine and nuclear oncology, health care and nutrition, and increasing industrial productivity and efficiency. Such progresses are assured by only with sufficient safety measures. Enforcing of radiation and nuclear safety measures has been a major commitment to the public of the safety inspectors and safety officers at OAEP. It has been clearly successful as there has been no record of any major nuclear accident in Thailand since 1962.

2. CURRENT RADIATION EDUCATION PROGRAM

Office of Atomic Energy for Peace, with the research reactor and modern equipment, is the center of associated with radiation education in Thailand, as the promoter and enforcement. Training of radiation safety and radiation safety officer which are the requirement of nation's regulatory function are also provided. All the training course contain basic radiation interactions with matters, the basic knowledge for radiation education. However, it is at rather technical and for scientists. Therefore, it is recently agreed among the trainers that education plan on dedicated radiation education curriculum is needed for expanding correct knowledge of nature of radiation and its usefulness and danger. Hence, the general public are more knowledgeable, and proper use of nuclear technology in the future will increasing on sound basis.

Knowledge of radiation are recently put in school education, starting in secondary school, radiation applications in food irradiation and sterilization of medical products are taught in everyday science courses. In high schools, the topic on radiation and radioactivity are parts of fundamental physics and chemistry. Furthermore, in more than 600 colleges and universities located in all part of Thailand, every major college and university offers courses in fundamental nuclear physics and related topics in Physics Department. Physical-chemistry concerning of radiation and radioactivity in other aspect is taught in Chemistry Department. Reactor theory is a topic existed in Master degree program of Nuclear Technology at Chulalongkorn University. Among universities in Bangkok area, Kasetsart University has a Department of Applied Radiation and Isotopes which offers many undergraduate courses on applications of radiation technology in agriculture and environment. Radiation and research from accelerator is emphasized in the Fast Neutron Research Facility, Institute of Science and Technology Research and Development, Chiang Mai University at Chiang Mai. For medical application, there are numbers of programs on radiation technology studies in medical fields in major cities; Bangkok, Chiang Mai, and Song Khla. The program produces radiologist for hospitals. Three level programs consist of a program for X-rays technician, a program for overall radiologist and a program for advance radiation physicist, who is a person assisting oncologist in radiation dose calculation and treatment of patients.

OAEP's major roles in above curriculum are:

- giving lecturers for many courses in colleges and universities, providing assistant for laboratory exercises and researches;
- delivering lectures for interested groups and associations, arranging in house courses in radiation technologies and radiation protection; and
- cooperating with IAEA in arranging national or regional training in some special related topics, etc.

Figure 1 shows number of academic courses given by lecturers from OAEP, **Figure 2** shows number of persons doing laboratory exercises and researches, and **Figure 3** shows number of lectures given to groups and associations. In addition, since 1990, OAEP has organized 11 courses on radiation aplications and 59 courses on radiation protection.

It is therefore advisable to say that, except for nuclear power, the utilization of nuclear technology in Thailand is willingly accepted. They are widely used in nuclear medicine, industry, agriculture, research and education.

Besides the 59 courses arranged by OAEP and some courses offered in universities, there seems to be inadequate for increasing needs of the technology. OAEP also negotiate with JAERI, under the bilateral OAEP-JAERI Cooperative Research Agreement, two courses on Radiation Protection for Radiation Safety Supervisor, and on Nuclear Technology and Its Diverse Applications. Course for the two topics will organized twice in the course of three years. JAERI also supports number of essential instruments necessary to conduct the courses. Distance Learning for Radiation Protection training is another approach being planned together with planned certification for radiation protection personnel to be enforced by OAEP.

Currently, simplified and short courses on radiation and radioactivity have been organized for school teachers at Ongkharak Distric, Nakon Nayok Province, where a new nuclear research center is to be established. The courses are simplified and associated with simple laboratories such as radioactive materials in everyday-life products, radioactivity in air, autoradiography, column scan demonstration, etc. The courses proved to be successful, and there are numbers of suggestions such as organization of the nuclear related youth camp, the public information center located in schools in the vicinity, and granting students to further study in nuclear science.

3. CURRENT PROBLEM

As radiation education is recently start in school, there are still lacking of experienced teachers to provide appropriate guidance to students. Many educational colleges are inadequately equipped with laboratory accessories, especially materials for physics experiments. Another major concern is to encourage teaching statistics of probability and risk assessment within the radiation measurement techniques. Many people are not knowledgeable enough to make use of the subjects and, hence, do not know status of risks from natural radiation being experienced in everyday life. Majority of university students refuse to take statistics courses if they can avoid.

4. FUTURE PERSPECTIVES

There are world wide effort to educate general public on peaceful applications of nuclear energy including that of nuclear power. Traditionally, public information officers, most likely being familiar with perception of nuclear scientists, tend to jump to disseminating all available information close to our routine technical work and acquainted environments. It is assumed that the public have certain degree of scientific background sufficient to comprehend the available information. After so many efforts for a long period of time, the public often complain of complexity of nuclear science for them to readily comprehend. They need some simpler reference than scientific terms and formulae. Therefore, some rethinking is necessary to clearly identify how general public perceive events around them, what influence their decision making process, and what kind of personality they respect, listen and follow. It is a huge and difficult task.

Public perception of what explained to them seems to be the origin of all misperceptions. The long standing perception of nuclear energy is destructive while perception on daily exposure to radiation from the origin of mankind remains unnoticed situation. Radiation education seems to possess strong message to the public to be understood and be aware of true ecology of mandkinds and true meaning (perception) of nuclear energy in daily life. Hence, public acceptance is expected to follow spontaneously.

It is, therefore, essential to concentrate on using radiation education as the important vehicle to inform general public of nuclear energy in daily life called sun ray, cosmic ray neutrinos and others.

Public understanding of such naturally occurred phenomena will certainly prepared themselves to listen more carefully on subjects of atomic energy, as they realized of its daily association with life on earth.

Therefore, radiation education is indeed an essential instruments for providing good basis for general public to understand atomic energy in daily life. It will certainly be a strategic approach in Thailand for public information program from now onward.

Figure 1 Number of courses given by lecturers from OAEP

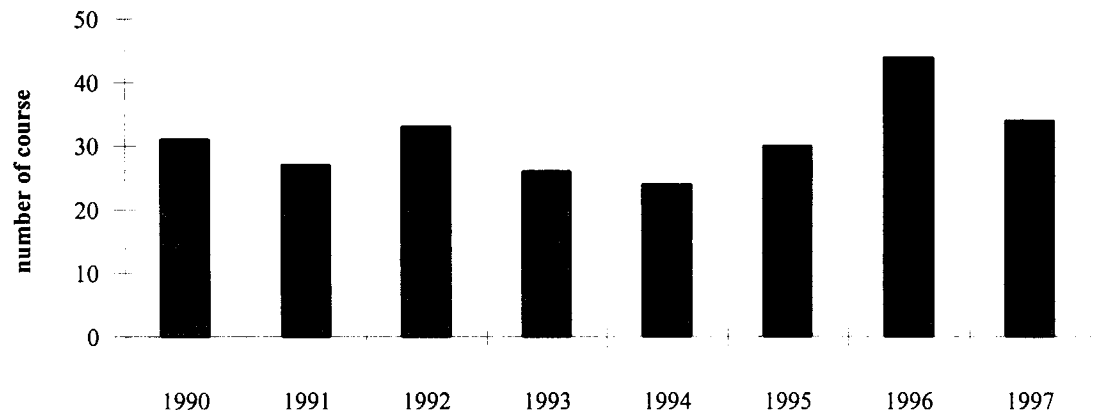


Figure 2 Number of persons doing laboratory exercises and researches

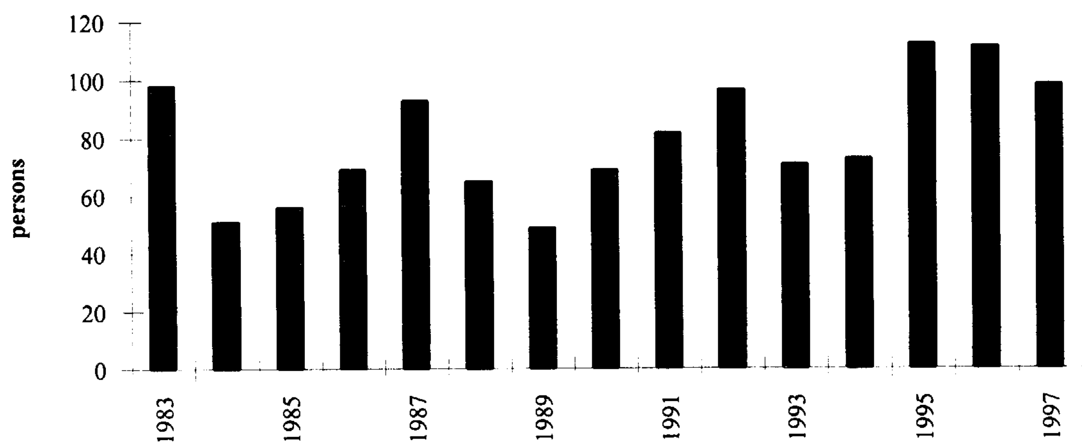
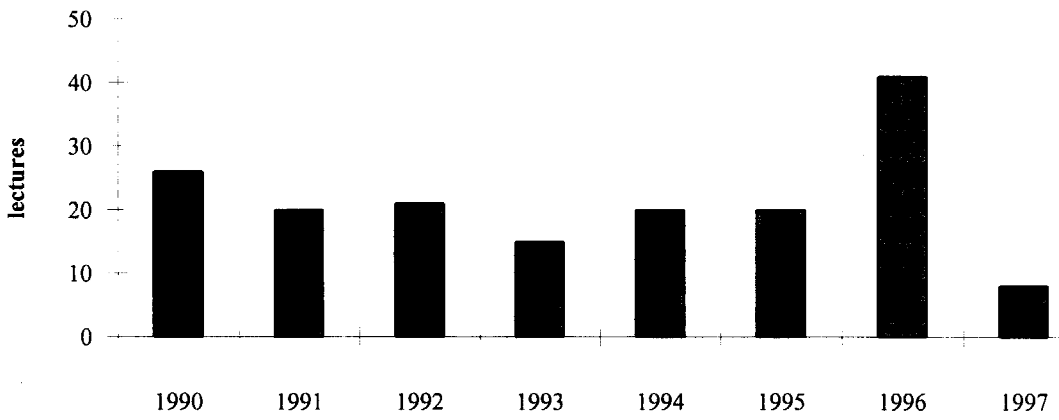


Figure 3 Number of lectures given to groups and associations



2.13 FUTURE PERSPECTIVE OF MEDICAL RADIONUCLIDE PRODUCTION AND RELATED EDUCATIONAL PROBLEMS IN DEVELOPING COUNTRIES

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ABSTRACT

The radionuclide applications are continuously escalation in nuclear medicine. Especially, the development of positron emission tomography (PET) technique has increased very rapidly the use of short-lived radioisotopes in this field, and this has caused the development of compact medical cyclotrons. About 30 cyclotrons operated in the world wide are actually found in the developing countries. In parallel of this progress, the basic nuclear sciences, especially nuclear chemistry and radiopharmaceutical chemistry will probably very important fields in the next new century for nuclear science and technology applications in health care sector. For this reason, the developing countries should eventually revise their academic educational and training programs aiming to ensure the formation of qualified basic nuclear scientists such as nuclear chemist, nuclear physicist, radiopharmacist, etc.

1. INTRODUCTION

The imaging techniques based on the detection of nuclear radiations emitted by the radionuclides incorporated into the specific organs are commonly used in today's health care sector. The single photon emission computed tomography (SPECT) and positron emission tomography (PET) are the fastest growing imaging techniques in nuclear medicine and related branches of medical sciences. These techniques principally use the radiolabeled chemical materials that are known as "radiopharmaceuticals". In recent years, many radiopharmaceuticals bearing different kind of radionuclides have been largely used in diagnostic and therapeutic studies, especially of cancer. The basic principle of radiodiagnosis and radiotherapy is ensuring as low as radiation dose absorption by patients. Sometimes, the radionuclides having very short physical half-lives, and very interesting decay characteristics are required for this purpose. The use of short-lived radionuclides necessitates their productions just at the application sites. This necessity has provoked the development of compact particle accelerators. So, the medical cyclotrons were begun to be used in this field. While the oldest running cyclotron was commissioned in 1948 at the University of Birmingham in England, their commonly using was started following 1970's years, and the radionuclides production using medical cyclotrons has became very largely applicable even in the developing countries not haven other nuclear facilities. Consequently, the number of cyclotrons running in the world wide has increased very rapidly. For example, while there were only 3 medical cyclotron and PET centers in the USA in 1975, today this increased up to about 66. In this context, the number of medical cyclotrons actually operated in the world wide is about 206[1]. Table I shows the numbers of medical cyclotrons installed in the period of 1972 - March 1998. As is seen clearly, the use of medical cyclotrons has consideably grown. Table II shows the distribution of these cyclotrons by countries. It is interesting that about 30 cyclotrons running are actually in the developing countries. It seems also very probable that at the beginning of the next new century nearly all developing countries will be able to have, at least, one cyclotron for own medical applications.

2. CYCLOTRON PRODUCED RADIONUCLIDES

The principal purpose of medical cyclotrons is, of course, to produce the short-lived radionuclides at their application sites. Nevertheless, in the case of a productive nuclear reaction can be applied, the charged particles accelerated by cyclotrons such as proton, deutron, triton, and alpha can also be used for production of any radionuclide having whatever half-life. For this reason, in recent years the production of many radionuclides, for example ^{75}Br, ^{124}I, ^{211}At, etc. which have the potential applications in diagnostic or therapeutic studies, have been subjected by several investigators[2-4]. In this context, some reactor produced radionuclides, as an example ^{99}Mo or directly ^{99m}Tc, have been tried to produce by using cyclotrons[5]. Consequently, the variety of radionuclides has been considerably grown day by day. Table III shows the principal cyclotron produced radionuclides which have the potential applications in medicine and other fields[1].

3. BASIC PRINCIPLES OF PREPARATION OF RADIOPHARMACEUTICALS AND FUTURE PERSPECTIVE OF NUCLEAR CHEMISTS

The use of radionuclides in diagnostic and therapeutic studies is depended on the preparation of appropriate radiopharmaceuticals. The first step of preparation of a radiopharmaceutical is to produce the radionuclide, and the next step is the labeling of a chemical compound with this radionuclide. The third step is its sterilization and quality control procedures. For this reason, the nuclear chemistry and radiopharmaceutical chemistry have the principal roles on the preparation and safely using the radiopharmaceuticals in medical applications.

As outlined in the introduction section the growing applications of cyclotron produced radionuclides in medical studies have clearly indicated the importance of qualified nuclear and radiopharmaceutical chemists. This means that in the next new century these professionals will be the key people for radionuclide applications in this field. A report[5] prepared in 1990 by a group of International Atomic Energy Agency experts (group members : H. Vera-Ruiz, C.S. Marcus, V.W. Pike, H.H. Coenen, J.S. Fowler, G.J. Meyer, P.H. Cox, W. Vaalburg, R. Contineau, F. Helus, and R.M. Lambrecht) also very clearly outlined the important role of these professionals for the preparation and quality controls of cyclotron produced radiopharmaceuticals. It is also interesting to note that in that report the special training of radiochemists and radiopharmaceutical chemists on the specific quality control techniques of radiopharmaceuticals bearing short-lived radionuclides was obviously outlined, and indicated the dangerous role of non-training people to safe and efficacious use of radiopharmaceuticals.

The future perspective of progress envisaged on the application of cyclotron produced radionuclides necessitates the reorganization of academic educational and training programs of basic nuclear sciences, especially of nuclear chemistry.

4. COMMON PROBLEMS ON NUCLEAR CHEMISTRY

As is known well, the public reactions provoked by several politicized groups against to nuclear energy and related technologies influence, of course, the basic nuclear science and technology educational and training academic activities in all countries. In this context, also the nuclear chemistry has been considerably influenced by these negative actions. Surely, this is a common and global serious problem for basic nuclear sciences and related technologies, and particularly for nuclear chemistry. Another important problem of nuclear chemistry is originated from the confusion of "nuclear chemistry", "radiochemistry", and "radiation chemistry" definitions. A careful searching on these three basic definitions in the literature including the main textbooks written by famous authors and published by international press companies clearly shows that there is not an international agreement on these definitions. This means that it is not clear-cut as wished; what is exactly nuclear chemistry, radiochemistry, and radiation chemistry; what relations are exist between them; and exactly what topics should be covered by these chemistry branches related basically to the radioactive materials and nuclear radiations? In addition, what is their place between other chemistry branches? According to some authors, the nuclear chemistry is considered as a principal branch and covers the radiochemistry and radiation chemistry as being two main sub-branches of nuclear chemistry. For example, the textbook prepared by G.R.

Choppin and J. Rydberg and titled as "Nuclear Chemistry : Theory and Applications"[7] has the principal topics of radiochemistry and radiation chemistry. The similar textbook coverage has been also applied by several authors. Other examples are the textbooks written by M. Haïssinsky[8], A. Vértes and I. Kiss[9], H.J. Arnikar[10], and E. Roth[11]. Contrarily, some other authors have considered that the nuclear chemistry and radiation chemistry are basically different, and cover different topics as being not including the radiation chemistry. The textbook written by G. Friedlander, J.W. Kennedy, J.M. Miller[12] is a well known example for this consideration. That textbook was principally covered only the topics related to radioactive materials not including the topics related to radiation chemistry under the title of "Nuclear and Radiochemistry". The nuclear chemistry and radiochemistry have been also very sharply differentiated and very fairly overlopped by R. Guillamont[13]. It is also necessary to outline that the "nuclear and radiochemistry" expression has been also commonly used to refer the discipline of chemistry that relates to radioactive materials including the nuclear transformations. The coverage of radiation chemistry is much more easily distinguished then nuclear chemistry and radiochemistry as being the chemical effects associated on matter with nuclear radiations[14].

If the nuclear chemistry, radiochemistry, and radiation chemistry are considered as well distinguished sub-chemistry branches, it should necessarily be defined a principal chemistry branch that must exactly to cover the nuclear chemistry, radiochemistry, and radiation chemistry, and basically to relate to the chemistry of radioactive materials and nuclear radiations. If so, what definition can be found for this principal chemistry branch? Surely nothing! Nevertheless, in the case of the definition of nuclear chemistry as a principal chemistry branch which covers the radiochemistry and radiation chemistry as its two sub-branches, the problem on the confusion of these definitions will easily be resolved; but, it should eventually be created an international agreement on these definitions. The foundation of the International Nuclear Chemistry Society (INCS) can surely be very helpful for this purpose. If such a society is founded, it may to cooperate with other international scientific organizations such as the International Union of Pure and Applied Chemistry (IUPAC), International Atomic Energy Agency (IAEA), NATO Scientific Committee, American Chemical Society (ACS), etc. In the case of realization of this cooperation, also an international agreement on these definitions can be realized. If not, the confusion will probably continue, and consequently the nuclear chemistry will not seriously be able to into account in international scientific platforms, and to get its real place between other principal chemistry branches. As an actual situation of nuclear chemistry in international platforms, it is not included in the list of principal chemistry branches defined by famous international organizations. As is known well, the principal chemistry branches have been commonly defined as the analytical chemistry, biochemistry, inorganic chemistry, physical chemistry, and organic chemistry. The nuclear chemistry should be included in this list of principal chemistry branches having very different and characteristic application principles and handling techniques as a younger chemistry discipline which basically covers the chemistry related to the radioactive materials and nuclear radiations[14].

5. LOCAL PROBLEMS IN DEVELOPING COUNTRIES

In the next new century, the global energy requirement will probably result the use of nuclear energy with growing intensity in developing countries, too. Actually, the development and advancement of nuclear technologies have been controlled by industrialized countries. As a result of this situation, in that countries the required nuclear engineers and basic nuclear scientists can be formed using the graduate and undergraduate academic programs. In this context, the nuclear chemists, and other nuclear specialists can be formed; but, in the developing countries the situation is much more different than that of industrialized countries. Firstly, while some developing countries has already one or more nuclear power stations, some others have not yet it.

Even the developing countries have the nuclear power station or stations as being already envisaged with the first important step of nuclear technology, this does not means that the formation of nuclear engineers and basic nuclear scientists can be realized in own countries.

The rapid growing of medical cyclotron applications shows clearly that in many developing countries the medical cyclotrons will be grown much more than the nuclear power stations. This means that these countries will eventually need the nuclear chemists and other basic nuclear scientists rather than the nuclear engineers. Table IV shows the distribution of nuclear power stations, research reactors, and medical cyclotrons in some developing countries.

The challenge of nuclear chemists and radiopharmaceutical chemists having special training in medical radionuclide production, radiopharmaceutical preparation, and their quality controls as obviously outlined in the IAEA experts report[5] indicated in the above paragraphs, the quality standards of radiopharmaceuticals which will be used on the patients will not sufficiently be satisfactory and will be able to be dangerous, too. While the easily installation of medical cyclotrons, but the challenge of required qualified experts will probably result the use of non-qualified people for these applications directly related to the health care. Of course, this will cause the envisaging very serious radiation dose problems for patients.

6. SPECIFIC PROBLEMS IN TURKEY

Turkey as a country having very critical geopolitics situation is a political and cultural bridge between Est and West, Russian and Middle-Est, Balkan and Caucasia. The economic potential of Turkey has developed very rapidly, especially in last fifteen years. Also its industrialization has been very considerably realized. Nevertheless, the critic geopolitical situation and earlier economical problems prevented Turkey to have a nuclear power station untill today. Of course, this has had a role negative on the required development of basic nuclear sciences in Turkey, while Turkey has two nuclear research reactors; but, in the first five years of the next new century, Turkey will probably have two nuclear power stations and this will obviously provoke the understanding of importance of nuclear technology and basic nuclear sciences. In addition, at the Ege University a medical cyclotron project has already been started. It is hoped that at the beginning of the next new century it will be able to produce the principal cyclotron produced medical radionuclides used around the Turkey. Of course, these applications will also show clearly the importance of basic nuclear sciences, especially of nuclear chemistry. In spite of these progresses, Turkey has some similar public reactions against to nuclear technology. This is, of course, a serious problem in Turkey, too. Another serious problem in Turkey is originated from the administrative procedures of academic organizations that are controlled by a governmental council. According to regulations determined by this council, a department of chemistry at any faculty of a Turkish University, should be organized by five principal chemistry branches as being analytical chemistry, biochemistry, inorganic chemistry, physical chemistry, and organic chemistry. So, all graduate and undergraduate educational and professional formation programs must be formulated starting from this basic principle. The nuclear chemistry is only considered one of two sub-branches of physical chemistry. Of course, this prevents very seriously the development of nuclear chemistry specialization in Turkey. The complexity of this problem is depended on the difficulty of alteration of governmental high educational council regulations. This means that the problem cannot be resolved neither by an individual University nor by a group interest. As the author of this paper, personally I have been charged since many years to resolve this problem in Turkey; but unfortunately, while the similar problem is not valid neither for nuclear physics nor nuclear medicine and radiopharmacy, a considerable progress could not be obtained for nuclear chemistry. It should be also outlined that the global misconceptions on the understanding of nuclear chemistry has also very seriously influenced the resolving this problem in Turkey.

7. CONCLUSIONS AND GENERAL RECOMMENDATIONS

It is evident that the radionuclide production has became more and more easy by using the compact medical cyclotrons. For this reason, the application of different radionuclides will be able to have an important role in the near future either for scientific and technical applications or medical diagnostic and therapeutic studies. As a consequence of this progress, the basic nuclear scientists, especially nuclear chemists will be seeking professionals in the next new century also in the developing countries. Starting from this point of view, it can easily be understand that the academic formation and in addition the specific training programs aimed to the formation of these qualified professionals should eventually be considered, and all graduate and undergraduate academic programs should be revised as soon as possible starting from the basic principles indicated in the different reports[15-19] by the developing countries which desire to develop their public health care programs. For support these efforts in developing countries the international scientific organizations should similarly support the formation of basic nuclear scientists in industrialized countries, too. In this context, the importance of nuclear chemistry as a principal professional field for radionuclide production, radiopharmaceutical perparation and their quality controls should clearly be shown by everybody who is directly or indirectly related to the application of radioactive materials and nuclear radiations in global science and technology sector. The organization of these actions on nuclear chemistry can be realized by the foundation of the International Nuclear Chemistry Society. All nuclear chemists are invited to support and to realize this idea.

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TABLE I

Number of medical cyclotrons installed in the world wide during the period of 1972 - March 1998[1)]

Years	Number of cyclotrons
1972	4
1973	2
1974	4
1975	3
1976	2
1977	-
1978	-
1979	2
1980	2
1981	4
1982	4
1983	6
1984	3
1985	9
1986	7
1987	10
1988	5
1989	12
1990	15
1991	17
1992	17
1993	6
1994	13
1995	13
1996	8
1997	12
1998 (March)	8 + 12 sold

Total : 195 cyclotrons / 27 years → ≈ 7.2 cyclotrons / year

Last 10 years : 138 cyclotrons → ≈ 14 cyclotrons / year

TABLE II
Distribuition of medical cyclotrons by countries[1]

Country	Number of cyclotron	Country	Number of cyclotron
USA	66	Denmark	2
Japan	33	Poland	2
Germany	20	Spain	2
UK	9	Czech Republic	1
Belgium	8	Egypt	1
Canada	7	Hungary	1
Netherland	7	India	1
Italy	6	Indonesia	1
China	5	Iran	1
France	4	Israel	1
Russion Federation	4	Kazakhstan	1
Australia	3	Norway	1
Brazil	3	Romania	1
Finland	3	Saudi Arabia	1
Republic of Korea	3	South Africa	1
Switzerland	3	Sweden	1
Argentina	2	Syrian Arab Republic	1

Total number : 206

TABLE III
Principal cyclotron produced radionuclides having the potential applications in medicine and other fields.

Radionuclide	Half-life	Radionuclide	Half-life
^{11}C	20.3 m	^{123}Xe / ^{123}I	2.1 h / 13.3 h
^{13}N	10. 0 m	^{201}Pb / ^{201}Tl	9.4 h / 73 h
^{15}O	123 s	^{88}Y	108 d
^{18}F	109.7 s	^{7}Be	53 d
^{64}Cu	12.8 h	^{10}C	19.4 s
^{124}I	4.2 d	^{28}Mg	21 h
^{38}K	7.71 m	^{48}V	16 d
^{45}Ti	0.09 h	^{75}Se	120.4 d
^{62}Zn / ^{62}Cu	9.3 h / 9.8 m	^{87}Y / ^{87m}Y	80 h / 14 h
^{73}Se	7.1 h	^{93}Mo	> 100 y
^{75}Br	1.7 h	^{99}Mo	67 h
^{76}Br	16.1 h	^{99m}Tc	6.0 h
^{82m}Rb	1.3 m	^{147}Gd	35 h
^{94m}Tc	5.3 m	^{195}Au	183 d
^{67}Ga	78 h	^{206}Bi	6.24 d
^{111}In	2.81 d	^{186}Re	90 h
^{123}I	60 d	^{211}At	7.21 h
^{201}Tl	73 h	^{57}Co	270 d
^{22}Na	2.60 y	^{139}Ce	140 d
^{67}Cu	59 h	^{81}Rb / ^{81m}Kr	4.7 h / 13 s
^{103}Pd	17 d		

TABLE IV
Comparison of distribution of nuclear power stations, nuclear research reactors and medical cyclotros in some developing countries.

Country	Number of power stations[20]	Number of research reactors[21]	Number of medical cyclotrons[1]
Argentina	2	5	2
Armenia	1	-	-
Bengladesh	-	1	-
Brazil	1	4	3
Bulgaria	6	1	-
Chile	-	2	-
China	3	10	5
Colombia	-	1	-
Congo, Democ. Rep. of		1	-
Czech Republic	4	3	1
Egypt	-	2	1
Ghana	-	1	-
Hungary	4	2	1
India	10	5	1
Indonesia	-	3	1
Iran, Islamic Rep. of	-	4	1
Israel	-	2	1
Jamaica	-	1	-
Kazakhstan	1	3	1
Korea, Democratic Rep.	-	1	-
Korea, Republic of	12	2	3
Latvia	-	1	-
Libyan Arab Jamahiriya	-	1	-
Lithuania	2	-	-
Malaysia	-	1	-
Mexico	2	3	-
Pakistan	1	2	-
Peru	-	2	-
Poland	-	1	2
Portugal	-	1	-
Romania	-	1	1
Russian Federation	29	27	4
Saudi Arab Republic	-	-	1
Slovenia	1	1	-
South Africa	2	1	1
Syrian Arab Republic	-	1	1
Thailand	-	1	-
Taiwan	-	3	-
Turkey	-	2	-
Ukraine	16	1	-
Uzbekistan	1	-	-
Viet Nam	-	1	-
Yugoslavia	-	2	-
Total	**99**	**106**	**31**

3. Poster Session

（ポスターセッション）

JP0050085

JAERI-Conf 99-011

3 . 1 RADIATION EDUCATION IN BANGLADESH : STATUS NEED & OPPORTUNITIES

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Introduction

Since the emergence of Bangladesh as an independent state, the provision of radiation education and training have expanded greately. Still then, since it is a developing country with high population growth rate, low literacy level and located thousands of miles away from the developed ones, it is difficult to transfer & dessiminate knowledge, particularly about the subject of radiation at a speed & spread as required to meet the challange of future. So, not only professional training but also institutional and formal academic knowledge & skill development is essential in the process of acquisition and transfer of such knowledge. Accordingly the courses on radiation & radioactivety including risk perception in general have to be vigorously pursued for the sake of safety and attaining basic concepts about health effects of different levels of radiation.

Background

For radiation protection purposes, the health effects of ionizing radiation are considered in two classes : deterministic and stochastic. Deterministic effects can occur when relatively large doses are received, causing large numbers of tissue cells to be damaged or killed, with consequent insult to tissue or impairment of organ function. There is a threshold of dose below which deterministic effects are not observed, while above that threshold, the severity of effects increases with increased dose. Radiation protection against deterministic effects can be ensured by keeping doses below the threshold levels.

On the other hand, stochastic effects are usually associated with lower doses and may or may not occur in an exposed individual. The likelihood of occurrence increases with increased dose. No threshold is presumed for stochastic effects and, at low doses, the probability of occurrence of an effect is taken to be directly proportional to the dose received. The most common such effect is radiation-induced cancer, which typically does not become manifest until several years after the initiating exposure.

Scope and Reference of Radiation Education

In consideration of the foregoing, it has to be conceived that at least some general knowledge on the research and application of radoactive materials as well as radiation and radioactivity it self should be imparted to students and concerned members of the public to avoid unmeessary fear of risk and radiophobia.

As such, it is further required to review the current status, need & opportunities of such education in Bangladesh in these fields in the context of National & International regulations and recommendations of IAEA, UNSCEAR, ICRP and Bangladesh Atomic Energy Commission (BAEC). In this connection due provision has been made in Nuclear Safety & Radiation Control Act- 1993 of Bangladesh.

Current Status

Though introduction of Tracer Technology and Nucleonic Control System in Bangladesh is still in the nascent stage,Bangladesh has been experiencing ionizing radiation in the application of X-ray & Gama ray in QA & QC through industrial radiography including food preservation and sterilization of medical products and research investigation in different fields, for example, radio pharmac-eutical, soil science & agriculture, ground water studies, environmental studies, assessment of pollution of air, water, sediments, sewage as well as exploration of coal, oil & gas applications in terms of logging of borehole. Further, so far as gas industry is concerned, all high pressure pipelines and installations are subjected to NDT involving high strength of X-Ray and Gamma-Ray radiography. Inadequate training and in appropriate precautionany and monitoring measures taken there of have already caused some severe and tragic radiation injuries too.

Need of Radiation Education

In an exercise of assessment of need of such radiation education, a comprehension of definitions of basic terms, viz radiation, radiation dose, low (absorbed) radiation dose and dose-response relationship including radiobiological & epidemiological estimates are essential. Further, risk of effects on malignancy, hereditary effects and effects on embrio etc. have to be explained in an attempt to examine the potential day to day exposure of working persons in particular and members of public in general so far as industrial, health care and research application of radioactive materials and protection measures are involved thereof.

Opportunities

This sort of radiation literacy if properly imparted would help to take action or precaution if any and thereby must relive the people at work and in the periphery of the psychological stress resulted from radiophobic feeling so far as peaceful use of nuclear technology is concerned as pointed out by Prof. T. Matsuura at 2ICI,Sydney in October 1997. Such effort to enhance radiation education may not only start with secondary schools/colleges but also include technical, vocational and polylechnic institutes too.

Upgradation of capabilities including evaluation of the scope, extent, rationale & involvement of radiation education methodology in these spheres shall have to be made keeping in view that innovative technologies have made it possible either to reduce the radiation levels or to enable establishment of appropriate protection measures.

Conclusion

Finally,it has to be stressed that an active and collaborative support of the country's partners in progress as well as co-operation & linkage programs of respective organizations of Bangladesh & its friendly countries all over the world are developed on mutual benefits. Simultaneously, national effort as per existing rules and regulations along with recommendations of relevent International agencies may continue.

Acknowledgement

The author offers his sincere thanks to the organizers of this International Symposium on Radiation Education to be held during 11-14 Dec 1998 at Hayama, Japan and particularly Professor Tatsuo Matsuura, for encouragement in developing this paper. He expresses his deep gratitude to the TGTDCL & Petrobangla Management for kind approval in presenting and publishing the paper. In this respect, the author also acknowledges the Co-operation and support recieved from Bangladesh Atomic Energy Commission as well as Bangladesh society for Non- Destructive Testing.

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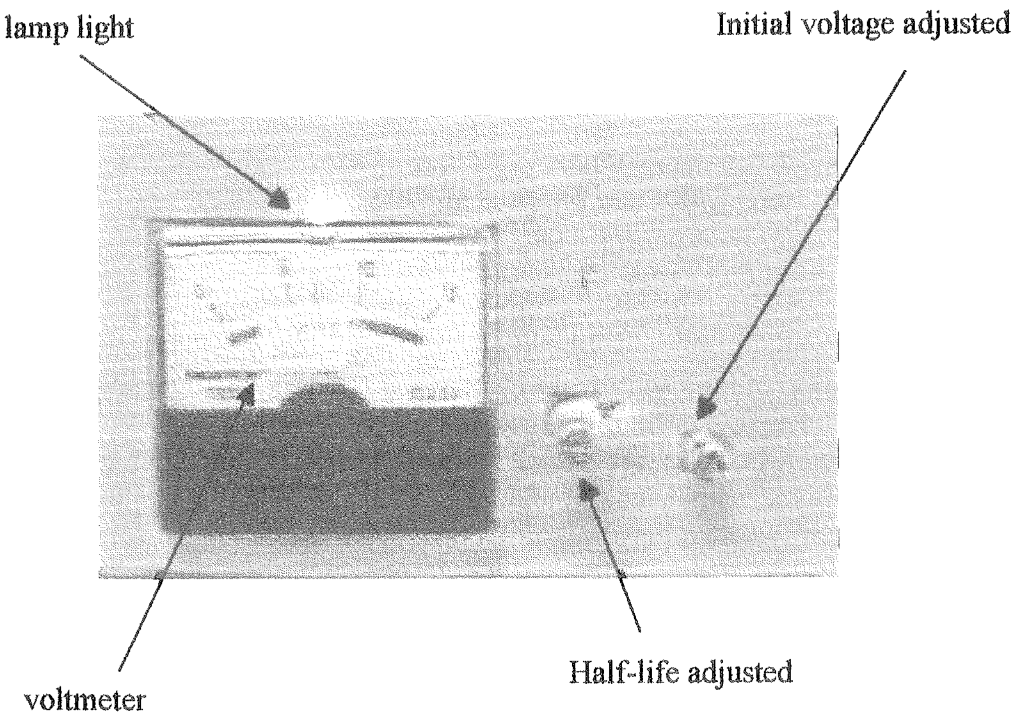

Fig.1 Radioactive Source Simulation Prototype

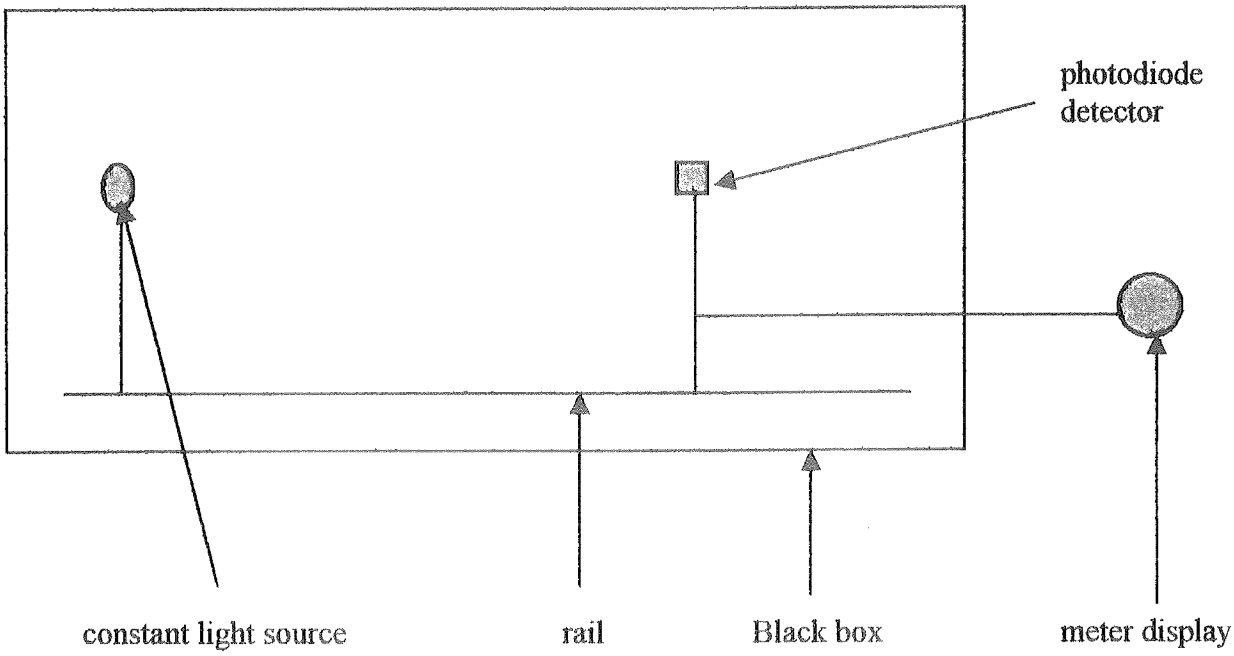

Fig. 2 Diagram of Inverse Square Law Setup

JP0050086

3.2 RADIOACTIVE SOURCE SIMULATION FOR HALF-LIFE EXPERIMENT

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ABSTRACT

A simulation of radioactivity decay by using programable light source with a few minutes half-life is suggested. A photodiode with digital meter label in cps is use instead of radiation detector. Both light source and photodiode are installed in a black box to avoid surrounding room light. The simulation set can also demonstrate Inverse Square Law experiment of radiation penetration.

1. INTRODUCTION

Learning Nuclear Physics in school is quite difficult to understand. One methed of teaching is trying to have the student learned by experiment. Most schools can not afford a laboratory for a fundamental experiment on nature of radiation. Lacking knowledge for handling of radioactive materials and cost of nuclear instruments made impossible in implementing of such laboratory in ordinary schools. This simulation set is aimed at providing simple and low-cost experiment to schools.

2. METHODOLOGY

2.1 LIGHT SOURCE TO SIMULATE RADIOACTIVE SOURCE

A small lamp is used connecting to RC circuit in order to simulate radioactive source. The intensity of light is synchronized with voltage reading from a voltmeter. Student will notice the decrease of light intensity along with the decrease in voltage at the meter. With stop watch, student can determine half-life of the simulated radioactive source.

2.2 FOR INVERSE SQUARE LAW EXPERIMENT

A constant light source is set on a stand located on a rail. A photodiode detector is set on the same rail as light source and marked distance from the light source. Both light source and photodiode are installed in a black box to avoid surrounding room light. Readings electrical current passing through the photodiode detector are observed with varying distance from the light source. Hence, Inverse Square Law is demonstrated.

3. CONCLUSION

Gamma radiation emitted from radioactive source is the same electromagnetic wave as light. The advantage of light is that it can be observed by eyes. The radiation emission of any radioactive source is decreasing with time. It means the radioactive source becomes less active, but the mass is not smaller than previous. Lamp light can show similar effect by decreasing light intensity. A voltmeter is provided for determination of half-life because the decreasing in light intensity could not determine by eyes.

If half-life of a radioactive source is long compared to observing period, the radiation emission rate assume to be constant. For inverse square law experiment, constant light source can be used. Since light and gamma radiation have the same natural phenomena, Inverse Square Law can be demonstrated.

The radioactive source simulation by light source may find their application in secondary school, if it is desired to put the subject of radiation and radioactivity into school level. Cost of the simulation set is substantially less than the true radioactive source set. The problem on handling of radioactive source is also eliminated.

JP0050087

3.3 小学生における放射線教育
Radiation Education in Elementary School

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要旨

平成７年度から東京都練馬区光が丘第四小学校の５、６年が理科の時間に簡易放射線計測器「はかるくん」を用いて小学校校内及び周辺の自然放射線を測り、身の回りに自然放射線があり、高い所や低い所があり零の所はないことを実験を通じて学んでいる。食物を撮ったイメージングプレートで食べ物からも放射線が出ていることを知る。霧箱でアルファ線の飛跡も観察している。この体験授業は、予備知識がなく好奇心の旺盛な時代に自然放射線の存在を素直に認識するために非常に有効である。さらに、子供たちの家族にも理解が広まり相乗効果がある。

Radiational education in elementary school [The Lessons to Measure Natural Radiation]
ABSTRACT
Lessons to measure natural radiation have been given at the fourth elementary school of Hikari-gaoka, Nerima-ku, Tokyo, for three years.
The Method of Lessons: After hearing a brief explanation about natural radiation and usage of a simple instrument of gamma ray named "Hakaru-kun."by a lecturer (Fig.1), every child participates to measure dose rate at several measured points within the range of school campus(Figs.5 ～14). They calculate the average value of measured dose rate(Fig.2) and affix tags written the average value (Fig.3). In addition, by looking at the photographs, through the imaging plate, of radiations released from vegetables and pork,they are surprised at the fact that all the food have such activities. Finally, they watch marks of alpha particles released from the ore of samarskite in a cloud chamber.The alpha particles fly in alkohole vapor oversaturated cooled with dry ice(Fig.15). They express their impression of lesson for finding out the existance of natural radiation in their reports(Table 1 and Fig.4).

１．はじめに

高校生が修学旅行中『はかるくん』という簡易放射線計測器で場所場所での自然放射線の変化を測定しているという話をしたところ、当時の小学校長に『小学生に自然放射線が測れますか』と聞かれたのがきっかけとなり、東京都練馬区光が丘第四小学校で平成八年の三月に、同校ではじめての放射線の授業が環境教育の一環として理科の２時間の授業で６年生の３組に行われた。

「開かれた学校」に向けた取り組みが全国で進められているが、東京都練馬区でも数年前から「地域に根差した教育」を目指して、その地域に在住する人材を学校の裁量で招き、人材のノウハウを生かす特別な授業を行っている。校長先生は『小学校では目に見えな

いものは教えられないのですが、「地域に根差した教育」としてお願いします。』と話された。播磨は小学校の西隣の高層住宅に住んでおり、運動場で元気よく走り回る子供たちを毎日ベランダから眺めている。小学校の先生の中にも、原子力反対の人がおられ、転居して１年余りの播磨には周辺の人々の考えが分からず、どのような対処を必要とする問題が起こるか予想もつかなかった。

授業を始めるに当たり、問題の対応のできる後ろ盾のある日本原子力文化振興財団の派遣講師の制度を利用して、放射線の授業は子供の扱いに習熟した派遣講師にお願いした。授業の始めに「はかるくん」の使い方の説明を聞き、学校内の自然放射線を測る、測定結果を付箋に書いて校内の大きなマップに貼る。最後に感想を書く。最初の年は、３０分余り、子供たちは「はかるくん」で校内好きな所を測って回った。二年目は「はかるくん」の測定に加えて、イメージングプレートで撮られた野菜や豚肉などの食べ物からも放射線が出ている様子をＯＨＰで見る。三年目は、さらにアルファ線の飛跡を霧箱で見る。

授業の終わる前に記録用紙に授業の感想を書いてもらい、それをお借りして、レポートにまとめている。この体験授業を通じて、小学生の理解度に応じた内容を検討したり、理解の深まる説明の言葉を捜したり改善を重ねている。また子供むきの簡単な放射線の説明がしてある「放射線探偵団」やキュリー夫妻のラジウム発見１００年に当たり、キュリー夫妻の伝記が日本アイソトープ協会で刊行された。

次章から、小学校の対応や、授業の内容、今後の問題を項目ごとにくわしく述べる。

２．小学校側の対応

放射線の授業を始めるに当たり、平成７年暮れ校長と理科担当の先生と話し合いを持った。その前に放射線計測協会から身の回りの放射線に関係のあるパンフレットをいくつか送って頂いたがそれらは皆小学生には難し過ぎるものばかりであった。先生方と小学生で理解できること、子供の興味の持ち方、授業の進め方等を話し合った。理科の先生は、最初新しい授業に尻込みしておられたが、いろいろ資料を差し上げて冬休みの間に勉強していただいたところ、段々乗り気になってこられた。小学校のこの体験授業には小学校の先生方の子供へ対応のご経験が生かされている。例えば、”実験：身近な場所の放射線を測る”の記録用紙の形式がある（表１）。「はかるくん」の測定は３回測って合計と平均を計算する。（注：高校生は１０回測っているそうだが、小学生ではとても１０回の繰り返しは無理ということだった）又、子供たちに「はかるくん」の値段をあてさせるのも理科の先生の発案である。今の子供たちは、ファミコンに親しんでいるので、興味を引き出す手段と、高価なものは慎重に扱うことに役立つということであった。授業の終わりには『「はかるくん」で測って”０”だった人は手を上げて』と問いかける。誰も手を上げない。『何処にでも放射線があるのがわかったね』と授業をしめくくることで、この授業の一番の目標を徹底するーー等等。授業のあと、校長先生からは『子供たちがこんなに大喜びした授業は初めて』と評価していただいた。

小学校では、一人一人に実験器具を使わせてもらうような授業はないということで、普段、おとなしくて、活発な子の影にかくれていたと

実験　：　身近な場所の放射線を測る

測定場所		理科室	校庭	石がき	プールの水の上	トイレ
測定回数	1	0.044	0.019	0.080	0.022	0.054
	2	0.041	0.020	0.081	0.020	0.058
	3	0.042	0.019	0.080	0.023	0.060
合計		0.127	0.058	0.241	0.065	0.172
平均		0.042	0.0195	0.08	0.022	0.057

わかったこと・質問したいこと

・放射線は、身近にあることが分かった。
・放射線は、さえぎる物があったり、遠くなったりすると、少なくなったりすることが分かった。
・放射線はふきそくにでていて、アルコールの気体をきゅうげきにひやしてみるとその放射線の通ったあとが見れた。とてもおもしろかった。

測定器番号	
測定者氏名	6年　組
測定年月日	平成10年11月5日11時
天気	晴れときどきくもり

Table１：記録用紙

思われる子が嬉しそうな顔で測定していたのが印象的だった。又、放射線については予備知識がなく、全員同じスタート台にだった授業であるため、子供一人一人の個人の能力が試される授業でもある。これらが原因となって、緊張感のある授業になるのかも知れない。主事さんの一人が『トイレを掃除していたら、生徒さんが放射線の測定に入ってきて、トイレに放射線がいっぱい出ているって教えてもらいました。身の回りに放射線がいっぱいでていると知りませんでしたので良い勉強をさせて頂きました。』とお礼を言われた。原子力反対の先生からも父兄からも反対の声は無かった。記録用紙は、預かって帰り、この新しい授業の結果をまとめ、子供たちの小学校時代の思い出に、また子供たちのご両親にこの授業をご理解いただく為に、レポートを作ることにした。現在のレポートの形式は校長先生のご提案で子供たちに呼びかけるように"「はかるくん」で自然放射線を測ってわかったこと "、"考えよう"、"しらべよう"、"答"、"比べてみよう"、"おぼえておこう"、"わかったこと、質問したいこと"が構成された。同じ場所を複数の子どもが測っている場合、平均値を記載し測定結果には括弧の中にクラス名を入れた。『これは子供たちが喜びますよ』と校長先生。レポートは記録用紙と共に子供たちに返され、関心のある人にも配られている。放射線をどのくらいあびると死ぬのかなという質問には、教頭先生の助言があった。－－－死ぬことはないという表現がよいということだった。「理科室に１年間いたとして受ける放射線の量の２万倍の放射線を一度に全身に受けないと死ぬことはない。同じ量の放射線を体の一部に受けても死ぬことはないと。

本授業のように校長の裁量で行われる授業では、先生の異動の激しい小学校で継続していくために、普段から小学校の行事へ参加、歓迎されるような奉仕活動を通じて人間関係を構築することが重要である。

平成８年校長先生も理科の先生も他校へ転勤されたが、申し送りで、新しく来られた校長と理科担当の先生のもとで自然放射線を測る授業は継続された。両先生に授業を理解して頂くため、授業内容や子供たちの反応、他の職員、父兄の反応等お話し、ご理解頂いた。理科の先生には資料をお届けしながら放射線に関係のあるお話をしたり、先生が担当しておられる栽培委員会を手伝って先生や子供たちと信頼関係を高めた。

３年目は、放射線計測協会のお勧めで霧箱を加えた。　計測協会の職員から霧箱の作り方の講習を受け、理科の先生とご一緒に小学校で練習してみた。『これは子供がすごく喜びますよ』とご自分でも試みて同僚に見せたりしておられた。この年の夏休みには、３月に実験した６年生でもっとやりたいと言っていた１０数人が自由研究に光が丘の周辺の自然放射線の測定を行った。１１月の授業から受け持ちの先生も授業に参加されるようになり、他の先生方も霧箱は初めてと見て下さるようになった。子供たちと一緒に「はかるくん」をもって走り回っておられる先生、霧箱を子供たちと歓声挙げて見ておられる先生の姿を拝見して、やっと定着してきたなという感触を掴んだ。この授業の様子や子供たちを取材したナショナルピーアールの記者が当社の"ENERGY for the FUTURE"に「小学生、放射線を測る、学校と専門家が模索する新たな教育」[1]という見出しで掲載している。また、三菱重工業株式会社、原子力ＰＡ推進センターの"あとむぱわー"に「僕ら放射線探偵団」[2]として授業が紹介されている。

４年目は理科担当の先生の交代があり、新しい理科の先生には６月に行なった光が丘第三小学校の授業を見学していただいたり、資料持参でお話に伺ったりした。同じ学校に経験のある前の理科の先生が居られるので、先生の興味が上がるのに役立った。最初に放射線の授業のきっかけを作って下さった前校長先生が、光が丘のお知り合いの校長先生に声をかけてくださったので、一度に３校も増えた。そして、それらの小学校では、『５、６年生お願いします』といわれて、一度に忙しくなった。新しく加わった小学校は担任の先生が理科を教えておられるので、前もって授業内容の説明に伺った。授業には担任の先生

も参加され、霧箱ではお手伝いも頂いた。

小学校も2002年の週休二日制にむけて、総合学習が導入されることになるが、カリキュラムは各学校に任されており、どのような授業をするか、先生を悩ませている。この放射線の授業は「環境とエネルギー」の分野に相応しいということで関心が高まっている。

3．自然放射線の存在を知る

3．1「はかるくん」で自然放射線を測る

放射線は地球ができたときからでている。宇宙から、大地から、建物の壁から出ている、というお話を聞く。　放射線の多いところ少ないところがある。建物の中と外と比べるとか、トイレのタイルとプールの水の上や屋上を測って比較してみよう、と説明を受ける。そこで、放射線を測る「はかるくん」の器械を一人一人が手にする。この『「はかるくん」はいくらするか』と聞かれて、てんでに値段を付けた。安いのは２，９００円、高くても６５，０００円だった。１３万円もすると聞いて『高いなあ。大事にしなくちゃ』と一気に緊張感がただよった。「はかるくん」の使い方を聞く（写真１）。待時間の表示が消えて数字がでる。理科室では４人が一つの机に座っているが夫々の数値が違うので『どうして』とか『器械が故障かな』と騒ぐ。ここで放射線の出方にはばらつきがあるという説明を聞く。このように自然放射線の測定値にばらつきが多くあるときは、大勢で測るか、何回も測って平均するとばらつきを小さくすることができると説明を聞く。今年からクラスの測定値を棒グラフにすることにした（図１）。ブザースイッチを押すとピッピッという放射線の入射音で更に理科室全体に放射線の存在感が深まる。

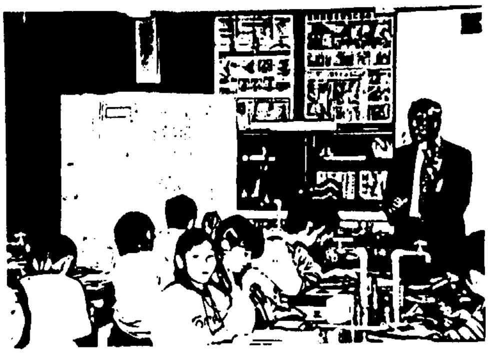

Photo.1「はかるくん」の使い方を聞く

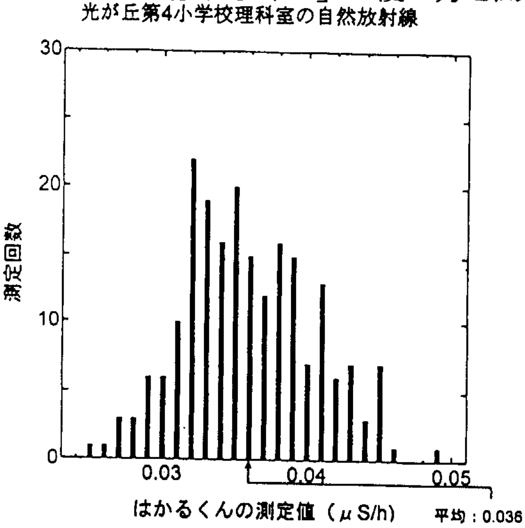

Fig. 1 理科室の自然放射線の棒グラフ

平均は５年生で習うが、実験する時期に習っていない場合もある。しかし、平均という言葉は日常生活やスポーツの得点でもよく出てくるので、誰かが３で割ればよいんだよといい出す。電卓で計算する子、筆算で計算する子もいる（写真２）。四捨五入は４年生で習っているのだが、忘れている子がかなりいる。基本的なことも繰り返し出てくると身につくのであろう。

Photo. 2:平均を計算する

その後、第１回目は『校内なら何処測ってもいいよ』という校長先生のお声を頭の後ろで聞きながら教室から蜘蛛の子のように飛び出していった。教室外の危険と思われるところ、例えば、屋上とかプールとかには手分けして監視に立った。３０分程であったか子供たちは満足気に理科室に戻ってきた。派遣講師から、放射線の多そうなところ少なそうなところを聞いていたが、校内くまなく測られていて、筆者らが予想もしていなかった新し

い発見もあった。そのひとつが焼却炉のレンガで、『オーイ、たかいぞー』と叫んだ男の子の声に、数人が走って行った。焼却炉の中まで手をいれたのか煤だらけになって宝物をみつけたように興奮して戻ってきた。筆者らは煉瓦が高いというのに気付いていなかったので、良い勉強になった。３日のうち一日、朝、雨が降った。屋外の放射線の量は理科室より高くなった。これは、雨の降り始め、ラドンやトロンと埃が雨と一緒に降り、高くなるのだが、いい体験ができた。将来の科学者の卵かと思わせるような綿密な測定をした子供。例えば、教室の日の当たる場所と当たらない場所を比較したり、廊下の両端を比較したり、各階の教室、トイレ、廊下を高さで比較したり。繊細な神経の持ち主なのか、図書室の本の間を測ったり、下敷きの両側を比較したり。好奇心の旺盛な子供は、普段入れない場所、例えば、校長室、給食調理室、エレベータの中、体育館の屋上によじ登って測ったり。優しい心の持ち主は、飼育室の兎や鶏を測ったり、自分の靴の中を測ったり。理科室に戻り、平均値を求めた後付箋に線量値を書き、校内の拡大されたマップの上に貼って行く（写真３）。この実習は、同じ場所を測っても測定値はある値の回りにばらついていること、理科室と比較して場所により高いところ、低いところがあることを実験を通じて学ぶことにある。最後に”わかったこと、質問したいこと”の欄に感想を書く（写真４）。

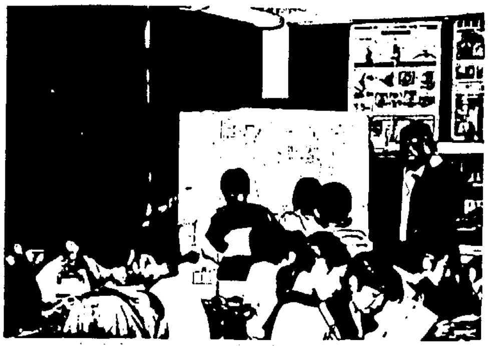

Photo. 3 ： 測定値をマップに貼る

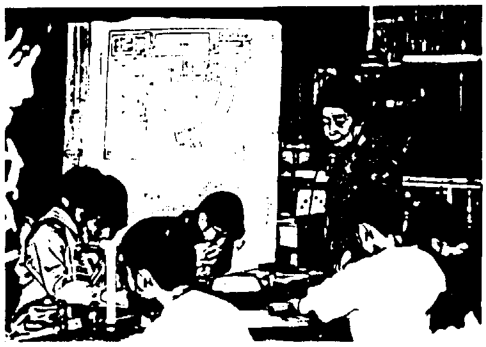

Photo. 4 ：感想を書く

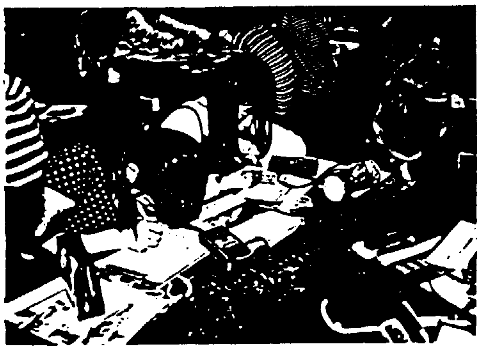

Photo. 5: 理科室を測る

Photo. 6: 運動場を測る女の子

Photo. 7: 運動場を測る男の子

Photo. 8: トイレのタイルを測る

二年目の授業は５年生の３組に行われた。カリ肥料や湯の花からも出ているベータ線の測定をＧＭ計数装置を使って入射音とともに実演してみせる。光が丘はモニュメントや石垣に花崗岩が多く使われていて、小学校の隣の保育園の石垣も花崗岩である。「はかるくん」の測定を放射線の高いところ低いところを体験できるように、理科室（写真５）、土の運動場（写真6、7）、トイレ（写真8）、プール（写真9）、歩道橋の上（写真10、11）、花崗岩の石垣又は焼却炉のレンガと限定し、時間も短くした。しかし、それ以上測りたい子は、余白に測定値を書いてもらうことにした。花崗岩の石垣は0.100 μＳｖ／ｈぐらいもでていて、理科室に比べてかなり高いので、子供の印象が大きかったのか、女の子が写真１２に示すようなすばらしい絵を描いてくれた。測定記録用紙のあちらこちらにもマンガがかかれていた。

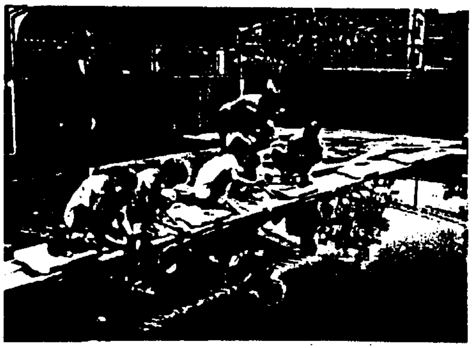

Photo.9: プールの水の上を測る

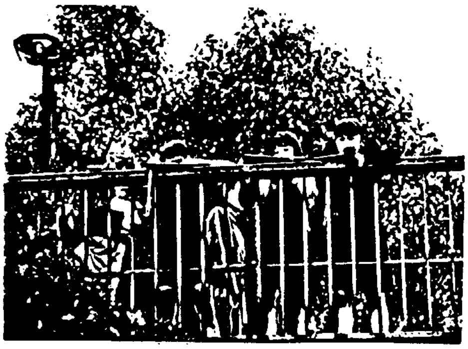

Photo.10:歩道橋の上で測る

Photo.11: 歩道橋の測定を終わって教室に戻る

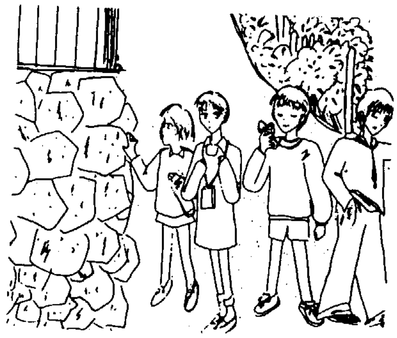

Photo.12: 石垣を測る（女の子の絵）

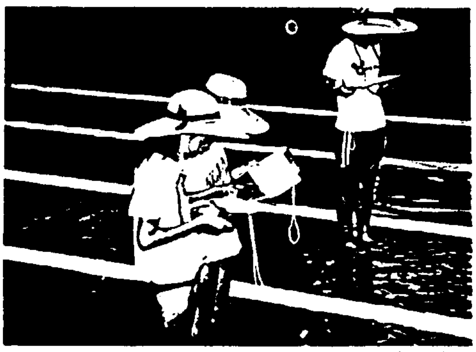

Photo.13：プールの水を抜いた時に測る

Photo.14: プールサイドを測る

自由研究の中で、水で放射線がさえぎられていることを確かめるために夏休みのプールの水がぬかれたときに測り、プールサイドと同じであることを確かめ、水で放射線がさえぎられることを体験した（写真13,14）。

３．２　食べ物に自然放射線が含まれている

子供の理解力に合わせて「はかるくん」の測定以外に名古屋大学の森先生がイメージングプレートで撮られた野菜や豚肉などの食べ物からも放射線が出ている様子をＯＨＰで見せる。食べ物の放射線は肥料に含まれているカリウムで野菜から放射線が出ている。それを食べている豚肉からも放射線が出ていると説明している。子供たちにとってインパクトが大きかったのか感想に殆どの子供が驚きを伝えている。豚肉の脂身のところは放射線の出方が少なかった訳を聞く。またたけのこからは放射線がほとんどでていないのも不思議だとの感想があった。

３．３　霧箱で放射線の飛跡を見る


Photo.15: 霧箱で放射線の飛跡を見る

三年目は、サマルスキーという鉱石からのアルファ線の飛跡が見られる霧箱を加える（写真15）。霧箱は飛跡をみる装置であるが、放射線を見たと感想を書いている子もかなりいた。まがりなりにも、放射線が見えたことで、自然放射線の授業は「目に見えるものなら小学校で教えられる」という大義名分が整った。感想には子供らしい表現で飛跡をみた印象を書いている。例えば、ときどきぴよっときりがでてくるのがわかった／ふわふわしているようにみえた／放射線がまがったりまっすぐいくのがおもしろかった／白い線のようなものがいっしゅんスーとして見れた／まるでおいておいたみそ汁をはしでかきまぜたみたいだ／ピュンピュン飛んでいたのでちょっとちがうけどオーロラみたいでした／放射線を見て生きているみたいで感動した。

３．４　放射線に関係したお話

最初の年の派遣講師の放射線の授業は『レントゲンって知っている？』という問いかけで始められた。レントゲンという言葉は胸の集団検診で知っていた。その年は「レントゲンのＸ線発見１０１年」であった。レントゲンの顔写真を見て、人の名前だと聞いてびっくり。ノーベル賞の物理賞の第一号をもらった人、ベクレルやシーベルトも彼らの功績により単位に名前が使われていると聞いて、「僕の名前も残るかな」と発言した子供がいた。校長先生が「一生懸命勉強して立派な研究をしたら君の名前も残るよ」と声をかけられた。感想に「お父さんが放射線科に勤めているので、いっぺんやってみたかった」と書いていた子供がいた。何らか放射線に関係している仕事についておられる両親の子供はかなりいるのではないかと考えられる。その人々が、自分の仕事の内容を誇りをもって我が子に話してもらえば、子供たちの関心も高くなるであろう。

３年目には派遣講師が小学校の授業の経験から日本アイソトープ協会で「放射線探偵団」というパンフレットを作った。この冊子は子供むきにまる文字でかかれており、放射線のことが易しく書かれている。派遣講師は小学生を対象としていたが、一般の人、特に家庭婦人に「これなら放射線のことがわかる」、と好評である。考えてみれば、放射線について何も知らされていなかった人には、新しい知識の導入は小学生と同じようなレベルで始めるのが、拒絶反応がなくてよいのではないか。この表紙の絵は子供たちに返すレポートの表紙に借用させて頂いている。

４年目の今年はキュリー夫妻のラジウム発見１００年にあたり、子供むけのキュリー夫妻の伝記も派遣講師が書き日本アイソトープ協会から刊行された。最近はキュリー夫人の伝記は、小学校の教科書から消えてしまっているということだが、名前だけは知っている子供がかなりいた。感想にキュリー夫人がノーベル賞を２度も受けた話を聞いて彼女の功績を書いた子供がかなりいた。ただ、キュリー夫人のあの血のにじむような研究を支えた

のが、祖国の独立への強い願をこめた小さい時からの不屈の精神であったことは、豊かな日本で育った子供たちにはわかってもらえたであろうか。

４．今後の問題：小学生に理解できる内容を検討

放射線を測らせる授業は「はかるくん」で測るだけから始まって、食べ物に放射線がはいっていることを知らせる、霧箱で放射線の飛跡を見せると増やしていった。子供たちは今まで学校で教えられていなかったこと、子供の周囲の社会や家庭でも知らされていなかったこと、まさに初体験の授業にびっくりしながら、しかし抵抗なくはいっていった。この初体験の授業は予告なしに行われる方が効果がある。予習している子供がいると、同じ土俵でなくなり、予習の中で自分が持った興味や疑問が邪魔して初体験の感激の度合いが分散し、授業中に話を折るような質問がでて全体の緊張した雰囲気を壊してしまう。あらかじめ学校には、この授業が子供たちの”驚きと発見の初体験”に重点を置いていることをご説明し、子供たちにこの授業の予告や予習をしていただかないようにお願いしている。私どもは小学生では「自然放射線は０でない、高いところ低いところがある」を理解してもらえばよいと考えている。小学校の時は学校で習ったことを親に話すであろうし、レポートも読んで頂けるであろう。最近授業を受けた子供の祖母が孫から放射線授業のことを聞いたという話を聞いた。おかしなもので子供や孫が学校で習ってきたことは簡単に受け入れられる。それは長い教育の歴史の賜物ではなかろうか。これが常識になれば、”日本は変わる”。

授業内容の量と質は小学校の２時間の理科の授業としては、これが限界ではないかと考える。これ以上になにか増やせば、消化不良を起こすであろう。

同じ光が丘の中でも、子供たちの家庭環境により、また指導される先生方の影響もあるのか、子供たちの授業の受け止め方に変化のあることがわかり、この授業を広げていくのには、絶えず子供たちの環境の変化に対応ができるような緻密な準備を心がけることが必要である。そのためには、小学校の先生方を陰で支え、子供たちの質問に的確に答えたり、子供たちの理解がより深まるような言葉で説明する方法を考案して、小学校の先生方の良き相談相手になる専門家の協力が是非必要である。

レポートを書く時、使っている漢字を子供が習っているか、使っている言葉が子供に理解できるか、小学生にわかる表現をしているか、をチェックして頂いている。その交流を通じて子供の今の関心の対象や考え方など小学校の先生方に教えて頂いている。

総合学習が導入され、時間に余裕ができたら、放射線教育を４年生ぐらいからはじめて５年生、６年生と理科の体験的学習を増やしたい。「はかるくん」で測る時間も、もっと増やしたい。最初の授業のように、高いところ低いところを捜している子供の目は輝いている。高くなったり低くなったりするわけを子供にわかるように説明し、その中で、子供たちが広い視野で物事を考える力をつけてあげたい。

自分の理科室の測定結果をクラスの友達全体で集めるとガウス分布に近いグラフになり、平均の意味を理解したり、全国の測定値と比較したりもできるだろう。これを通じて物事を一点で判断せず、広く眺めて物事の判断をする習慣がつけばと考える。

また、放射線が身近かにあることが認められれば、原子力の勉強もできるだろう。放射線が身の回りの生活にいかに多く使われ、自分の生活を豊かにしてくれているかを、自分達で調べ、放射線を無闇に恐れることなく、技術革新の道具として受け入れられる。将来、放射線を利用した開発研究をする子供がこの中にいるのではないかと夢が膨らむ。

１）「小学生、放射線を測る、学校と専門家が模索する新たな教育」"ENERGY for the FUTURE"、1998 No.1 、38-39 、ナショナルピーアール株式会社
２）「僕ら放射線探偵団」三菱重工業株式会社、原子力ＰＡ推進センターの”あとむぱわー”Vol.42(1998)

JP0050088

3.4 How would we deal with radiation related issues in high school educational programs?

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Motivation and Purpose:

We imagine that current educational curriculums we rely on will be more improved and the materials in schools will be somewhat different by the year of 2002 when students have two days off in a week. Unfortunately, it is a well known fact that recent Japanese people's level of understanding about Science and Technology is the second from the bottom among OECD nations and, as a matter of fact, few schools are dealing with scientific issues such as atomic energy or radiation. If the day comes when those issues become very close to our ordinary lives, or it might have come already, we would hardly expect most of the people to be ready for the situation.

I consider that we, teachers, should be more involved in planning the school materials and educational curriculums that directly cultivate thoughts and knowledge of young adults who are going to lead this country in the near future. And then, we should actually encourage the Ministry of Education or the committees of education to reconsider current educational programs and to increase materials that include more issues related to nuclear power and radiation.

Since I have a freshman class this year, I surveyed what students know about atomic power and radiation, how deep they studied in previous schools and what kind of interest they have in conservation of world energy sources or environmental issues discussed today.

Method: Obtain information from 328 students (7 classes) by the questionnaire method.

Date of the Survey: April 8, 1998 (A week after the entrance ceremony of freshman classes)

Results: Following

Questionnaires

This year is the 100th anniversary of discovery of "Radium" by Marie Curie. Now, I would like to ask you following questions; please circle the most appropriate ones for you.

(1) Do you know what Radiation is? ① Yes ② No

(2) Do you know what Radioactivity is? ① Yes ② No

(3) Do you know the difference between "Radiation" and "Radioactivity"?
① Yes ② No

(4) Please write anything that Radiation and Radioactivity remind you of.

	Reasons
①	
②	

(5) Are you familiar with the word "Nuclear power generation"?
① Yes ② No

(6) If YES, please answer the following questions.

(a) When did you learn about it for the first time?
When you were in ①Elementary School ②Junior High School

(b) How did you learn about it?
①In class(____grade) ②Mass media

(c) What do you want to know more about nuclear power generation?
① The effects of radiation and radioactivity on others
② Accidents and break downs
③ Management and nuclear wastes disposal
④ The mechanism of nuclear power generation
⑤ Future plans and something else

(7) I would like to ask you about the energy sources and their scarcity.

(a) Since when have you been interested in them?
① Elementary School (____grade)
② Junior High School (____grade)
③ Never

(b) How did you learn about them? ①In class ②Mass media

(c) Please write anything that you want to learn about the energy sources and their scarcity.

(8) Please circle the subject(s) you know and explain briefly.

① X-ray pictures	
② Radiotherapy	
③ Nuclear wastes disposal methods	
④ Nuclear power generation mechanism	
⑤ Atomic Bomb	

(9) We would like to ask you about various environmental issues.

(a) When did you learn about the word "environmental issues" for the first time?

When you were in ① Elementary School (____grade)

② Junior High School (____grade)

(b) How did you learn about them? ①In class ②Mass media

(c) What do you want to learn more about environmental issues? Please write whatever you want to know or study.

(d) Please write all you know about environmental issues.

The results of questionnaires

(1) Do you know what Radiation is?

	Yes	206 students (62.9%)
	No	121 students (37.1%)

(2) Do you know what Radioactivity is?

	Yes	215 students (65.7%)
	No	112 students (34.3%)

(3) Do you know the difference between "Radiation" and "Radioactivity"?

Yes	21 students (6.4%)
No	306 students (93.6%)

(4) Please write anything that Radiation and Radioactivity remind you of.

1. Atomic Bomb, War, Nuclear Missile	92 students (28.1%)
2. Medical treatment, X-ray picture	40 students (12.2%)
3. Chernobyl, Nuclear power plant accident	37 students (11.3%)
4. Nuclear power plants	34 students (10.4%)
5. Skin cancer, Leukemia, Diseases	34 students (10.4%)
6. Fearful, Noxious, Bad for health	23 students (7.0%)
7. Light	19 students (5.8%)
8. Uranium, Plutonium	9 students (2.7%)
9. Godzilla	7 students (2.1%)
9. Hiroshima, Nagasaki	7 students (2.1%)
11. Bikini islands, H-bomb test	5 students (1.5%)
11. Baldness	5 students (1.5%)
11. Air pollution, Pollution	5 students (1.5%)
11. Radiation, X-rays	5 students (1.5%)
Other	34 students (10.4%)

Radioactive wastes, Russia, USA, Aomori, Fukui, Infrared, Ultraviolet, Microwave, TV, Sun, Acidic rain

(Total of 22 students: 2 students of each topic)

Ozone layers, Green house effect, Black cloud, Atom, Universe, Smoke, Melt, Movies, Malformed child, Hadashi No Gen (Cartoon), UV protection glasses, Electrocardiogram

(Total of 12 students: 1 students of each topic)

(5) Are you familiar with the word "Nuclear power generation"?

Yes	305 students (93.3%)
No	4 students (1.2%)

(6) When did you learn about it for the first time?

When they were in	Elementary School	207 students (63.3%)
	Junior High School	120 students (36.7%)

How did you learn about it?

	In class	154 students (47.0%)
	Mass Media	146 students (44.6%)
	No answer	27 students (8.4%)

What do you want to know more about nuclear power generation?

① The effects of radiation and radioactivity on others	137 students (41.9%)
② Accidents and breakdowns	67 students (19.7%)
③ Management and nuclear wastes disposal	87 students (26.6%)
④ The mechanism of nuclear power generation	61 students (18.7%)
⑤ Future plans and something else	51 students (15.6%)

▲ Notice

Among 207 students who said "Elementary schools," they learned

In class	106 students (51.2%)
Mass media	101 students (48.8%)

Among 120 students who said "Jr. high schools," they learned

In class	48 students (40.0%)
Mass media	72 students (60.0%)

(7) & (8) Please circle the subject(s) you know and explain briefly.

	Who became <u>interested</u> in the topic of the energy sources and their scarcity when they were in (From question (7a))		
	Elem. School. (41 students)	Jr. High School (142 students)	Unconcerned (134)
① X-ray pictures	16 (39.0%)	60 (48.6%)	94 (70.1%)
② Radiotherapy	6 (14.6%)	36 (25.6%)	14 (10.4%)
③ Nuclear wastes disposal	11 (26.8%)	22 (15.5%)	8 (5.9%)
④ Nuclear power mechanism	8 (19.5%)	57 (40.1%)	43 (32.1%)
⑤ Atomic Bomb	16 (39.0%)	57 (40.1%)	43 (32.1%)

(9) We would like to ask you about various environmental issues.

(a) When did you learn about the word "environmental issues" for the first time?

When you were in①	Elementary School	181 students (55.4%)
②	Junior High School	122 students (37.3%)
	No answer	24 students (7.3%)

(b) How did you learn about it?

① Elementary School

In class	97 students (53.6%)
Mass Media	77 students (42.5%)
No answer	7 students (3.9%)

② Junior High School

In class	49 students (40.2%)
Mass Media	71 students (58.2%)
No answer	2 students (1.6%)

▲ Notice:

The students who answered "I'm Interested" in section (7)&(8).

(a) When did you learn about them?

1. Elementary School	134 students (69.4%)
2. Jr. High School	39 students (20.2%)
No answer	20 students (10.4%)

(b) How did you learn about them?

1. Elementary School

In class	69 students (51.5%)
Mass Media	58 students (43.3%)
No answer	7 students (5.2%)

2. Jr. High School

In class	20 students (51.3%)
Mass Media	17 students (43.6%)
No answer	2 students (5.1%)

The students who answered "Unconcerned" in section (7)&(8).

(a) When did you learn about it?

3. Elementary School	47 students (35.6%)
4. Jr. High School	83 students (62.9%)
No answer	2 students (1.5%)

(b) How did you learn about it?

3. Elementary School

In class	28 students (59.6%)
Mass Media	19 students (40.4%)
No answer	0 students (0.0%)

4. Jr. High School

In class	29 students (34.9%)
Mass Media	54 students (65.1%)
No answer	0 students (0.0%)

(c) What do you want to learn more about environmental issues?

	(Interested)	(Unconcerned)	Total
How to solve the issues	33 students (18.0%)	26 students (19.4%)	59 students (18.6%)
Global environmental problems	3 (1.6%)	8 (6.0%)	11 (3.5%)
Greenhouse Effect	15 (8.2%)	7 (5.2%)	22 (6.9%)
Garbage disposal	4 (2.2%)	6 (4.5%)	10 (5.7%)
Ozone Layers	12 (6.6%)	6 (4.5%)	18 (3.2%)
El nino	3 (1.6%)	2 (1.5%)	5 (1.6%)
Deforestation	5 (2.7%)	2 (1.5 %)	7 (2.2%)
Air Pollution	6 (3.3%)	1 (0.8%)	7 (2.2%)
Environmental Hormones	8 (4.4%)	0 (0.0%)	8 (2.5%)
Topics less than 5 students:			
What can we do?	0	2	2
Acidic Rain	3	1	4
Influence on Human body	3	1	4
Freon	0	1	1
Desert expansion	2	0	2
Water	1	0	1
Diminution of nature	2	0	2
Next car generation	2	0	2
Clone	1	0	1
Chernobyl	2	0	2
Land subsidence	1	0	1
The Kyoto conference	1	0	1
New energy sources beside oil	1	0	1
Dioxin	0	2	2
Total	19 students	7 students	26 students

(d) Please write anything that you know of environmental issues.

	(Interested)	(Unconcerned)	(Total)
Greenhouse Effect	68 (37.1%)	41 (30.6%)	109 (34.4%)
Garbage disposal	9 (4.9%)	8 (6.0%)	17 (5.4)
Ozone layers	46 (25.1%)	41 (30.6%)	87 (27.4%)
El nino	7 (3.8%)	5 (3.7%)	12 (3.8%)
Dioxin	7 (3.8%)	10 (7.4%)	17 (5.4%)
Deforestation	20 (10.9%)	34 (25.6%)	54 (17.0%)
Acidic rain	62 (33.9%)	20 (14.9%)	82 (25.9%)
Air pollution	18 (9.8%)	12 (9.0%)	30 (9.5%)
Desert expansion	25 (13.7%)	13 (9.7%)	38 (2.9%)
Diminution of nature	3 (1.6%	4 (3.0%)	7 (2.2%)
Topics less than 5 students			
Freon	2	0	2
Land subsidence	4	0	4
The Kyoto conference	1	0	1
New energy sources beside oil	3	0	3
Minamata diseases	1	0	1
Surface of ocean	1	1	2
Milk container	1	0	1
Radioactive wastes	1	1	2
Medical treatment	1	0	1
Recycled paper	1	0	1
Food additive	1	0	1
Recycle	0	1	1
Soil contamination	0	1	1
Noise	0	1	1
Photosynthesizing plants	0	1	1
Influence on human body	0	4	4
Total	17 students	10 students	27 students

Conclusion

I was able to obtain very interesting results that something I have never thought of. For this time, I would like to present here just what I have noticed throughout this survey.

Question 1.2.3

Results were as I expected. Students are familiar with the words, but they do not seem to know those exact meanings. They would need to lean much deeper in high schools.

Question 4

They seem to have both negative and positive impression, and it was also interesting that there were almost the same number of students who thought of Godzilla and Hiroshima or Nagasaki from the same words: radiation and radioactivity. This might be suggesting that generations are certainly shifting.

Question 5

93.3% of the students know about Nuclear power generation.

Question 6

Two third of them learned it when they were in primary schools and, among those students, more than half: 51.2% said they studied in classes. On the other hand, 60%, out of those who have known about it since junior high schools, said they learned it through papers or TV programs. Namely, they do not teach much about Nuclear power generation in junior high schools probably because the topic is not very much related with problems of high school entrance examinations.

The topic that was the most interesting to them (41.9%) about Nuclear power generation was the effect of radiation or radioactivity on any kind of things in the environment. We could include it in our educational curriculum in the near future.

Question 7

About problems related energy sources and their scarcity on earth, 43.3% of the students have been interested since junior high schools, and 64.8% of those students said they learned in classes. We can see teachers are emphasizing the topic in Junior high schools. However, we also have to pay attention to the fact issues at all, and 59.7% of those students learned about those problems in schools. This seems more problematic to me.

Their particular interest about the topic varies, but more than one third of them are worried about the shortage of oil and the emergence of new energy sources that can be replacing it.

Question 8

56.5% of the students know about X-rays, and even 70%, out of those who said they were unconcerned at all in the question 7, also know about it. Next well-known topic was about an atomic bomb, and 36.6% of the total and 32.1% of those who were unconcerned about energy related issues seem to know about it well.

Question 9

About environmental issues, 69.4% of the students have known since primary schools and 20.2% have known since junior high schools among those who said they were concerned about or interested in the problems (in question 7) somehow. It seems that more students learned about problems related to nature and environments for the first time when they were in primary schools than in junior high schools, and 51.1% of them said they have seen those issues in classes.

On the other hand, 60% of the students, out of those who said those issues were interesting and they came to know when they were in junior high schools, learned through papers, magazines or on the TV. It is also interesting that large number of students (62.9%), who first studied about the issues in the classes of junior high schools, were not concerned about them at all.

The topic they want to know the most (in question 9) is solutions for those problems such as Greenhouse effect, Ozone layers and Garbage disposal (18.6%).

Topics they already know well are also Greenhouse effect, Ozone layers, Acidic rain and Deforestation, and Air pollution, Desert expansion, Garbage disposal problems, Dioxin are following.

3.5 物理１Ｂでの「原子と放射線」のカリキュラム

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要旨

物理１Ｂの授業では原子の単元が非常に簡単に扱われると共に時間の確保もできない状況があった。しかし、物理授業において現在の文化の中で利用されているエネルギーにまったく触れずに終了していくことに疑問を感じ、授業の中で原子力エネルギーを取り上げていく取り組みを数年前から実施してきた。現在では約１０時間の「原子と放射線」のカリキュラム実施している。今回はその内容を発表することとした。

１、 はじめに

日本の一般家庭で利用する電気約 30%が原子力発電所によるものである。このような現実の中で生徒たちに原子力と放射線に関わる正しい知識を持ってもらうことを今回の授業の目的とした。カリキュラムとしては下記の点をポイントとした。

a,放射線発見から戦争を背景とした核爆弾の開発、そして原子力平和利用への歴史を教える。

ｂ、放射線について知識を放射線計測協会の実験キットを利用した放射線実験から学ばせた

ｃ、原子力施設の見学ビデオなどを取り入れた授業を展開することにした

ｄ、原子力発電に対する生徒の意識調査を授業の始めに実施し、最後に生徒たちとの意見交流をしながら生徒たちの意識の変化を確認してみた。

２、 内容

A, 実施した授業カリキュラムと内容を表に表わしてみました

項目	内容	実験・実習
核エネルギー発見と開発の歴史	①放射線発見から核分裂発見 ②核爆弾開発から原爆投下 ③戦後の平和利用 （学ばせること） 核が戦争に利用させたことがマイナスイメージとなっていることをしっかりと理解させ、エネルギーとしての価値	核の時代 Ｎｏ１ 「ＮＨＫ作成」

	を認めていく必要を説いていくこと	
放射線と放射線発生のメカニズム	①電子と原子 ②放射線とはなにか ③放射線とその種類 ④原子核と放射線 （学ばせること） 電子と原子について学び 原子核内から発生す放射線について正しい知識を持たせる。	教科書を使った授業 ＊クルックス菅 ＊偏向板付きクルックス菅
放射線計測１ 自然放射線と身近な線源	①放射線計測の方法 ②自然放射線の計測 ③放射線の危険性について （学ばせること） 放射線は自然界にあることを理解させ、生活の中でいろいろな物質が放射線を発していることを教えていく。 放射線とは特別なものではないことを教え、放射線の危険性についても学ばせる	「はかるくん」
放射線計測２ 放射線からの距離と線量との関係	放射線源と距離の関係を実験から求める （学ばせること） 放射線を安全に取り扱うためには線源との距離が重要な要素となることを学ばせる。	「実験キット」
放射線計測３ 放射線の遮蔽効果実験	アクリル・鉄・アルミ板・鉛による遮蔽効果を確認する実験 （学ばせること） 放射線を遮蔽するとはどのようなことなのかを教える。 放射線を出す物質を取り扱うながで遮蔽するための知識を学ばせる。 放射線計測２と合わせて放射線を安全に取り扱うための知識を理解させる	「実験キット」
キリ箱の観察	手作りキリ箱によるアルファー線の飛跡を確認する実験 （学ばせること） 放射線を目で確認することで感覚として認識させる。 キリ箱の原理にも触れていく。	自作キリ箱 （ドライアイス型）

核分裂	① ウランの核分裂について ② 連鎖反応 （学ばせること） ウランの核分裂原理と連鎖反応を学び、核爆弾と原子炉の違いを教えていく	チェレンコフ散乱ビデオ
原子力エネルギーの原理	①原子炉の原理 ②原子炉の構造 （学ばせること） 原子炉がどのようにエネルギーを作り出しているのか教えていく	核施設見学時のビデオ
核燃料と核廃棄物	①核の燃料について ②核廃棄物について ③ 廃棄施設について （学ばせること） 核燃料と使用後の核廃棄物について学ぶ。 核廃棄物をどのように処理しようとしていると考えているのかを学んでいく	
エネルギーとしての原子力について	生徒の意見をききながらディスカッションを行なう （目的） 授業を通して生徒たちの考えがどのように変化していったのかを知り、エネルギーの問題に感心を持たせていく	

B，授業に取り入れた実験紹介

①放射線計測１「自然放射線の計測とその他物質からの放射量の計測」

この実験で放射線量の測定についての方法を教えます。

基本的に１０回測定し、その平均を求めることでそのときの線量が求められることを教えます。はかるくんは１０秒ごとにその前の１分間の平均値を求めているので、測定するためには、まずはかるくんを測定状態にして１分間放置しその後１０秒ごとのデーターを１０回測定させます。自然計数より多いものを選ばせ、全体で確認していきます。 一般に花崗岩、塩化カリウムからの線量が自然計数より多くなります。

放射線はどのように場所にもあり、身近なものからも発生していることを確認させことができます。

②放射線計測２「距離と線量の関係を求める実験」

実験用キットには線源としてセシウム１３７が入っていますので、線源を実験用の台座にのせ、はかるくを１０ｃｍ，２０ｃｍ，３０ｃｍ，４０ｃｍ，５０ｃｍの位置において各点での１０回ごとの測定をし平均を求めます。 この実験から、線量が距離の二乗に反比例することを確かめます。

放射線を発するものから十分に距離を置くことで安全が確保できることを確認していきます

③ 放射線計測３ 「遮蔽効果についての実験」
実験用キットを使った遮蔽実験です。 遮蔽物による線量の違いを確かめる実験
同じ厚さのアクリル板、アルミ板、鉄板、鉛板を線源の前に置き、線量の違い
を確認します。鉛板以外はほとんど遮蔽が出来ないことが分かります。
材料を選ぶことで放射線が遮蔽できることを学んでいきます。

④ 放射線実験 「放射線を目でみる」
ドライアイスと透明タッパを使った自作のキリ箱によるアルファー線の飛跡を
観察します。放射線を目で確認することで実感として放射線を体験させます。

キリ箱の材料と作成手順

＜材料＞

1、容器（底が透明で文字の少ないものなら良い）半径 10ｃｍ程度
＊今回はマリスのシール容器（丸型）を利用します。底が透明のプラスチック容器であれば利用できます。マリス製品の値段１個約 200 円
６個セットで販売しています。（製品名シール容器　丸型ＳＶ－９）

2、カラーアルミ板（厚さ 0.3mm で裏が黒のものを利用）20cm×20cm

3、アルミ板（0.3mm）の物に黒い紙や布を張ったりしたものでも良い枚 130 円

4、すき間テープ（幅約 1cm、長さ 30cm）
一巻き、長さ 5m、幅 1 cm　約 200 円

5、針金（30cm）

6、アルミテープ（幅 2cm、長さ 40cm）
一巻き＝長さ 4m、幅 2cm 約 450 円

7、スポイト

8、エタノール（少量）

9、ドライアイス　10cm×10cm×5cm　　1Kg＝500 円

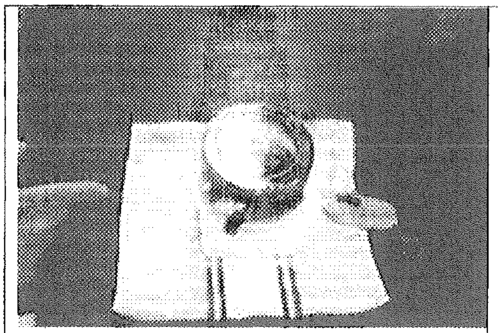
10、ゴム栓 ＃０　（12×10.5×12mm）　　約 150 円

＜作成方法＞

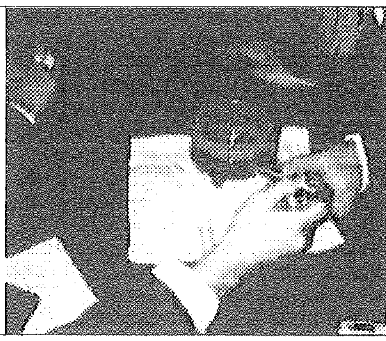
（準備として容器の開け口から高さ 2cm 程度の所に直径 1cm の穴を開けておく。＊ケースが壊れ安いので半田コテで穴を開け、リーマーで広げる方法が良い）

①容器の開け口を下にしてアルミ板の上に載せ、鉛筆やマジックなどで容器の外側の大きさに沿った線を書く
②はさみでアルミ板を①の線に沿ってきり円盤状にする。
③すき間パットを容器の内側に合う長さで切り、容器の底の側面に沿って張る
④針金で③を押さえるように取り付ける
⑤アルミの板を開け口に取り付ける。（容器側が黒い面になるようにする）
アルミのテープで密封状態を保てるようにする。

＜観察＞



セットした状態



観察の様子
懐中電灯を横から当てて観察をする。

３、 授業を実施したことの対してのまとめ

ａ，授業をやる前の生徒の意識調査（対象 約１２０人）

問１、　原子力についての印象

危険なもの・危ない物＝３３人
発電所　＝１８人
原子爆弾や兵器　＝１７人
分からないなど　＝２０人

問２、　放射線・放射能についての印象

戦争・原爆・被爆・戦争＝３４人
危険・恐い　＝５５人
レントゲン。治療など　＝１８人

問３、　原子力のエネルギーへ必要だと思うか

必要　３４人
不要　１０人
分からない７４人

問４、　エネルギーの需要は増加していますがどうのようにしたら良いと思いますか

省エネルギー　５１人
（法的な規制の必要がある）
代替エネルギーの開発　２０人
発電所を増やして対応　６人

原子力についてまったく教えない段階では、原子力と原爆が結ぶついていることがわかります。また、放射線や原子力に対して危険であるとのイメージが中心となっている。

ｂ、授業終了後の生徒との話

原子炉について知識に関して

1) 放射線についての正しい知識があれば、恐れる必要がない
2) 原爆と原子炉とはまったく違ったものである
3) 放射線について良く分かった
4) 原発の原理が分かった

授業を通して一定の知識を伝えることはできた
しかし
エネルギーの問題や原子力発電所を作ることについてはいろいろな意見が出てきた
＠日本ではエネルギーを無駄に使っている。規制が必要ではないか
＠自分としては豊かな生活を失いたくないが原発には問題を感じる
（動燃問題がイメージの中にあるようです）
＠自分の町に原発を作るといわれたら反対する。
（完全に安全といえないのではないか）
＠エネルギーを無駄にしないようにていくことが一番のポイントではないか。

C,授業の成果

この授業を通して、放射線や原子炉について正しい知識を教えることができた。
放射線を実験を通して理解させることができた。
生徒達に原子力発電の原理を理解させながらエネルギーの問題を考えるきっかけとなった。

3.6 高等学校における放射線指導実践上の課題

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〔アブストラクト〕
１９９５年１２月８日の高速増殖炉「もんじゅ」のナトリウム漏れ事故の直後に、当時高校１年生の２０５名を対象に「放射線に関するアンケート調査」を実施した。その調査項目は、1. 放射線に対する興味、2. 放射線とはなにか、3. 身近な放射線、4. 放射線の被害、5. 放射線の利用　であった。この調査結果は、高校入学時つまりはほぼ義務教育終了時点での生徒の放射線に関する興味・知識・理解の度合いを示す内容であった。

その後、２年後の１９９７年１２月に物理を選択した理系の生徒３クラス１２５名を対象にして、２年前と全く同じ調査項目でアンケート調査を実施した。この時点で高校物理の学習を一通り終えていて、２年間の学習の成果を測定する意味もあったわけであるが、これら２度の調査によって放射線指導実践上の課題を一層明確化することができた。

生徒の放射線に関する学習環境としては、マスコミによる報道を通した情報入手の機会があったであろう。学校教育では、教科書の記述内容による学習、及び筆者が補足的に取りあげた教材（副読本、霧箱、γ線遮蔽実験、簡易ＧＭ管、オートラジオグラフィ、陰極線の観察実験など）による学習の機会があったことになる。これらの学習機会の成果としては、興味度の向上、α線・β線・γ線などへの理解向上、自然放射線に関する理解向上があげられるが、放射線の被害と利用については指導上の課題が多く残された。

これらの放射線に関する指導実践を通して、(1) 生徒（親）サイドの課題、(2) 教師サイドの課題、(3) 指導条件の課題　を明確にすることができた。つまり、危険な代物と思われている放射線とそのことによって予想されるトラブルを回避したい教師側のモーチベーション上の課題、教材である教科書の記述上の課題、入手が容易な実験教材の提供上の課題などがあげられるが、これらは近未来のエネルギー供給問題を解決する上で避けて通ることができない解決を求められる課題と思われる。

1. はじめに

1995年12月８日に起きた高速増殖炉「もんじゅ」のナトリウム漏れ事故から２年の歳月が流れた。その当時高校１年生であった本校34期生10クラスの内、５クラスの生徒２０５名を対象として「放射線に関するアンケート調査」[1]を実施した。その調査結果は、高校入学時点、つまりは義務教育終了時点での生徒の放射線に関する興味・知識・理解の度合いを示す内容であった。それから２年が経過し、「もんじゅ」はその後どのような経過を辿ったのかは詳らかではないが、本校34期生は２年時で理系３クラスの生徒が物理を選択し、３年時ではそのほぼ全員が継続して物理を学習し、1997年12月に一通りの高校物理の学習を終えた。その時点で、この２年間の学習成果の一端を測定するために、２年前と全く同じ調査内容の「放射線に関するアンケート調査」を３クラスの１２５名の生徒を対象に実施した。

本論では、生徒が主に２年間の物理の学習指導を受けることによってもたらされた放射線を巡る認識の変化を、指導実践の一事例として紹介する。

2. 放射線を巡る生徒の学習環境

生徒の放射線を巡る学習環境として学校内と学校外の区分して考えることにする。テレビとラジオ及び新聞の報道内容を逐一調査してはいないが、学校外では様々なマスコミ報道を通した放射線に関わる情報入手の機会があったであろうと想像される。例えば、核関連施設事故とか核廃棄物処理場建設や核兵器処理の原子力関連の報道など。一方、学校内では高校物理の授業内容を通した学習が中心になることと思われるが、放射線に関わる教科書の記述内容としては、物理ＩＢの第５編「電子と原子」で「放射線とその性質」及び「原子力の利用」さらには教科書の口絵写真、物理Ⅱの第３編「原子」では「核エネルギー」と口絵写真があげられる。

その他に私が授業で補足的に取り上げた教材は次の通りである。

副読本としては「生活環境と放射線」（原子力実験セミナーのテキスト）の一部を著者の許可を得て複写し、生徒に配付して授業中に用いた。生徒実験としては「液体窒素を用いた霧箱によるα線とβ線の観察」（森式霧箱[2]）及び「はかるくんによるγ線の遮蔽実験」（放射線計測協会から借用）を４名程度の班単位で実施した。演示実験としては「簡易ＧＭ管によるα線とβ線の観察」、「オートラジオグラフィの写真観察」（ラットといんげん豆）「各種クルックス管による陰極線の観察」及び「クロス真空管による陰極線の観察」を行なった。これらを組み合わせて放射線の学習指導を展開した。

3. 調査用紙

『放射線に関するアンケート調査』

年　組　番・氏名）

※ 次の設問に該当する番号に○印を記して下さい。

1. 放射線について

(1) 興味をもって調べたことがある
(2) 調べたことはないが興味がある
(3) 興味がない

2. 放射線と思うものはどれか？ ＜複数選択可＞

(1) 紫外線、 (2) 赤外線、 (3) レーザー光線、 (4) 電気通信用電波、
(5) 宇宙線、 (6) 中性子線、 (7) Ｘ線、 (8) γ線、 (9) β線、 (10) α線

3. 放射線が日常生活のどんな身近なところにあるか？ ＜複数選択可＞

(1) レントゲン検診車、 (2) ＴＶ、 (3) 大気中、 (4) 蛍光灯、 (5) 地中、
(6) 原子力発電所、 (7) 歯科医院、 (8) ガン治療病棟、 (9) 核廃棄物貯蔵施設
(10) 変電所、 (11) カメラ、 (12) 食物、 (13) 電子レンジ、 (14) 酸性雨、
(15) その他（　　　　　　　　　　　　　　　　）

4. 放射線（放射能）の被害と思うものはどれか？ ＜複数選択可＞

(1) ボケる、 (2) 免疫力が低下する、 (3) 骨が弱くなる、 (4) 筋肉痛をおこす、
(5) 遺伝子に異変をおこす、 (6) 障害をもつ子供が生まれる、 (7) ガンになる、
(8) 植物が枯れる、 (9) 髪が抜ける、 (10) 白血病になる、
(11) その他（　　　　　　　　　　　　　　　　）

5. 放射線（放射能）を利用している思うものはどれか？ ＜複数選択可＞

(1) 物体の内部構造や厚さの測定
(2) 化学反応を促進させる
(3) 農作物の品種改良
(4) ジャガイモの発芽防止
(5) 害虫の駆除
(6) ガンの治療や骨の診察などの医療
(7) 生物体内の移動物質の観察
(8) 遺跡発掘物の年代測定
(9) エネルギーを取り出す（発電）
(10) 新しい物質（元素）を作り出す
(11) その他（　　　　　　　　　　　　　　　　）

4. 調査結果

放射線に対する興味度	第１回〔1995年12月〕（２０５名中）	第２回〔1997年12月〕（１２５名中）
(1) 興味をもって調べたことがある	2 名（ 1%）	7 名（ 6%）
(2) 調べたことがないが興味がある	100 名（49%）	85 名（68%）
(3) 興味がない	103 名（50%）	33 名（26%）

放射線と思うもの	第１回〔1995年12月〕	第２回〔1997年12月〕
(1) Ｘ線	181 名（88%）	115 名（92%）
(2) 紫外線	74 名（36%）	56 名（42%）
(3) レーザー光線	56 名（27%）	22 名（18%）
(4) 赤外線	55 名（27%）	33 名（26%）
(5) 宇宙線	54 名（26%）	97 名（78%）
(6) β線	40 名（20%）	114 名（91%）
(7) 中性子線	37 名（18%）	79 名（63%）
(8) α線	35 名（17%）	108 名（86%）
(9) γ線	29 名（14%）	116 名（93%）
(10) 電気通信用電波	16 名（ 8%）	20 名（16%）

身近な放射線	第１回〔1995年12月〕	第２回〔1997年12月〕
(1) レントゲン検診車	171 名（83%）	120 名（96%）
(2) 原子力発電所	160 名（78%）	117 名（94%）
(3) 核廃棄物貯蔵施設	122 名（60%）	101 名（81%）
(4) ガン治療病棟	115 名（56%）	105 名（84%）
(5) 歯科医院	54 名（26%）	80 名（64%）
(6) 電子レンジ	45 名（22%）	50 名（40%）
(7) 大気中	42 名（20%）	94 名（75%）
(8) ＴＶ	32 名（16%）	41 名（33%）
(9) 蛍光灯	30 名（15%）	61 名（49%）
(10) 酸性雨	30 名（15%）	16 名（13%）
(11) 地中	26 名（13%）	62 名（50%）
(12) 変電所	16 名（ 8%）	23 名（18%）
(13) 食物	15 名（ 7%）	57 名（46%）
(14) カメラ	15 名（ 7%）	23 名（18%）

放射線の被害	第１回〔1995年12月〕	第２回〔1997年12月〕
(1) 髪が抜ける	152 名（74%）	103 名（82%）
(2) 遺伝子に異変をおこす	139 名（68%）	116 名（93%）
(3) 障害をもつ子供が生まれる	136 名（66%）	113 名（90%）
(4) 白血病になる	104 名（51%）	83 名（66%）
(5) 植物が枯れる	97 名（47%）	64 名（51%）
(6) ガンになる	92 名（45%）	97 名（78%）
(7) 免疫力が低下する	75 名（37%）	76 名（61%）
(8) 骨が弱くなる	47 名（23%）	29 名（23%）
(9) ボケる	16 名（ 8%）	7 名（ 6%）
(10) 筋肉痛をおこす	5 名（ 2%）	8 名（ 6%）

放射線の利用	第１回〔1995年12月〕	第２回〔1997年12月〕
(1) ガンの治療や骨の診断などの医療	143 名（70%）	109 名（87%）
(2) エネルギーを取り出す（発電）	110 名（54%）	87 名（70%）
(3) 物体の内部構造や厚さの測定	99 名（48%）	107 名（86%）
(4) 新しい物質（元素）を作り出す	72 名（35%）	89 名（71%）
(5) 遺跡発掘物の年代測定	42 名（20%）	92 名（74%）
(6) 生物体内の移動物質の観察	40 名（20%）	50 名（40%）
(7) 農作物の品種改良	38 名（19%）	80 名（64%）
(8) 害虫の駆除	38 名（19%）	41 名（33%）
(9) ジャガイモの発芽防止	38 名（19%）	110 名（88%）
(10) 化学反応を促進する	37 名（18%）	36 名（29%）

5. 考　　察

(1) 興味度の推移〔図1〕

第1回の調査では半数程度の生徒が示していた放射線に対する興味が今回の調査では4分の3程度の生徒に増加していることが伺える。
これは、授業中の学習指導の中で特に実験・観察による関心の高まりであると思われる。

(2) 放射線と思うもの〔図2〕

X線は第1回の調査では最も高い回答率であったが、今回の調査ではさらに高い回答率を示した。　第1回の調査で低かったα線・β線・γ線が特に回答率の大幅な増加を示している。また、中性子線と宇宙線も次いで高い回答率を示している。
しかし、放射線に分類されていない紫外線と電気通信用電波の回答率が増加している点と、レーザー光線と赤外線も依然として放射線と考えている生徒が5分の1前後もいる点が気掛かりである。実験・観察による指導効果が現れたと思われる調査結果も見受けられるが、放射線の定義に関わる指導が徹底じていなかった点も反省材料としてあげられる。

(3) 身近な放射線〔図3〕

第1回で低かった大気中・地中・食物といった自然放射線に関する回答率の増加が著しい。これはバックグランドとしての放射線への関心が高まった成果とも思われるが、回答率自体は半数から4分の3程度であることを考慮すると、残りの半数から4分の1程度の生徒に対する指導が足りなかったことにもなる。
電子レンジ・酸性雨・変電所・カメラからも放射線が出ていると考えている生徒が見られるが、特に電子レンジについては高周波の電磁波と放射線を区別できなかったことによるものと思われる。

(4) 放射線の被害〔図4〕

放射線の被害と関わりが薄い「骨が弱くなる」、「ボケる」、「筋肉痛をおこす」は少ないものの、「骨が弱くなる」は4分の1程度の生徒が依然として被害と考えていることが伺える。「筋肉痛をおこす」については回答率がやや増加している点が気掛かりである。
その他の項目については、遺伝子レベルの損傷によって引き起こされる各種の被害・障害を考慮した回答が増加していることが伺える。

(5) 放射線の利用〔図5〕

全てが放射線の利用に該当する項目であるが、項目毎の回答率に差がみられる原因として、授業中の解説や教科書の口絵写真等を生徒が様々な受け止め方をしたことが推測される。
回答率では「ガンの治療や骨の治療などの医療」「物体の内部構造や厚さの測定」「ジャガイモの発芽防止」が高く、今回の調査では特に「遺跡発掘物の年代測定」と「ジャガイモの発芽防止」に大幅な回答率の増加を示した。
これらの項目の指導には、適切な実験実習教材やシミュレーション教材の開発が必要と思われる。

6. 放射線指導実践上の課題

(1) 生徒（親）サイドの課題

放射線に対するイメージ　：　危険な代物

① 原子爆弾・水素爆弾による被爆
② 原子力発電所事故
③ その他核関連施設を巡るトラブル

⟹ われわれの身近にある物で、一市民として必要な科学的知識のひとつであり、適切な判断をするために必要な知識である。

(2) 教師サイドの課題

放射線指導のモーチベーション

(1)との関連で、積極的に取り上げることによって起こるであろうトラブルを回避したい.

⟹ CO_2，CH_4，O_3，NO_x，フロン，騒音，紫外線，ＥＭＦ等と同等の地球環境を構成する一要素である.

(3) 指導条件の課題

教育課程及び教材整備

① どの教科・科目で実施するか？
② 教材をいかに入手するか？

⟹ 教育課程上の位置づけ、及び容易に使える実験教材の開発

参考文献

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4）笠　耐（1989）「放射線と私たち」，プロジェクトサイエンスシリーズ１，コロナ社.

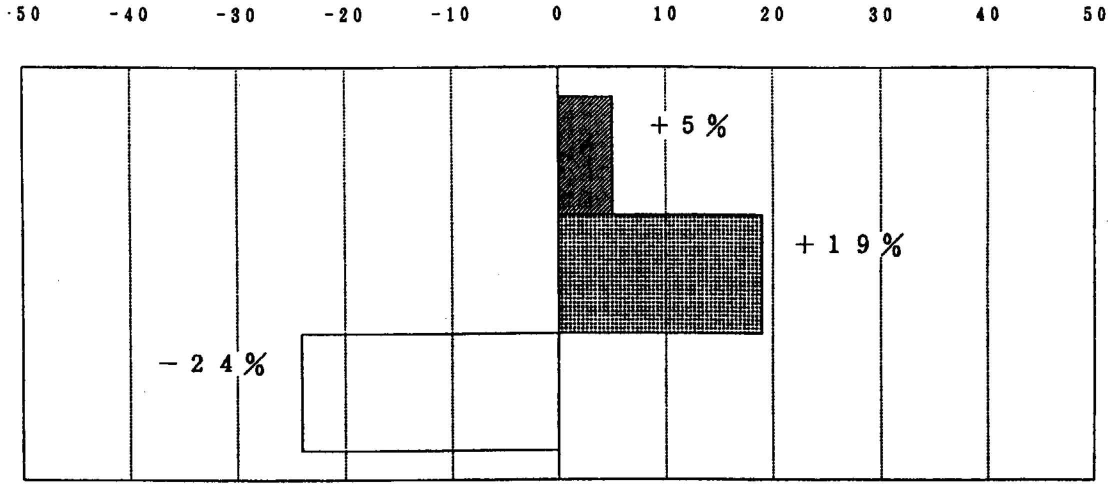


図 1　興味度の推移

(1) 興味をもって調べた

(2) 調べたことはないが興味がある

(3) 興味がない

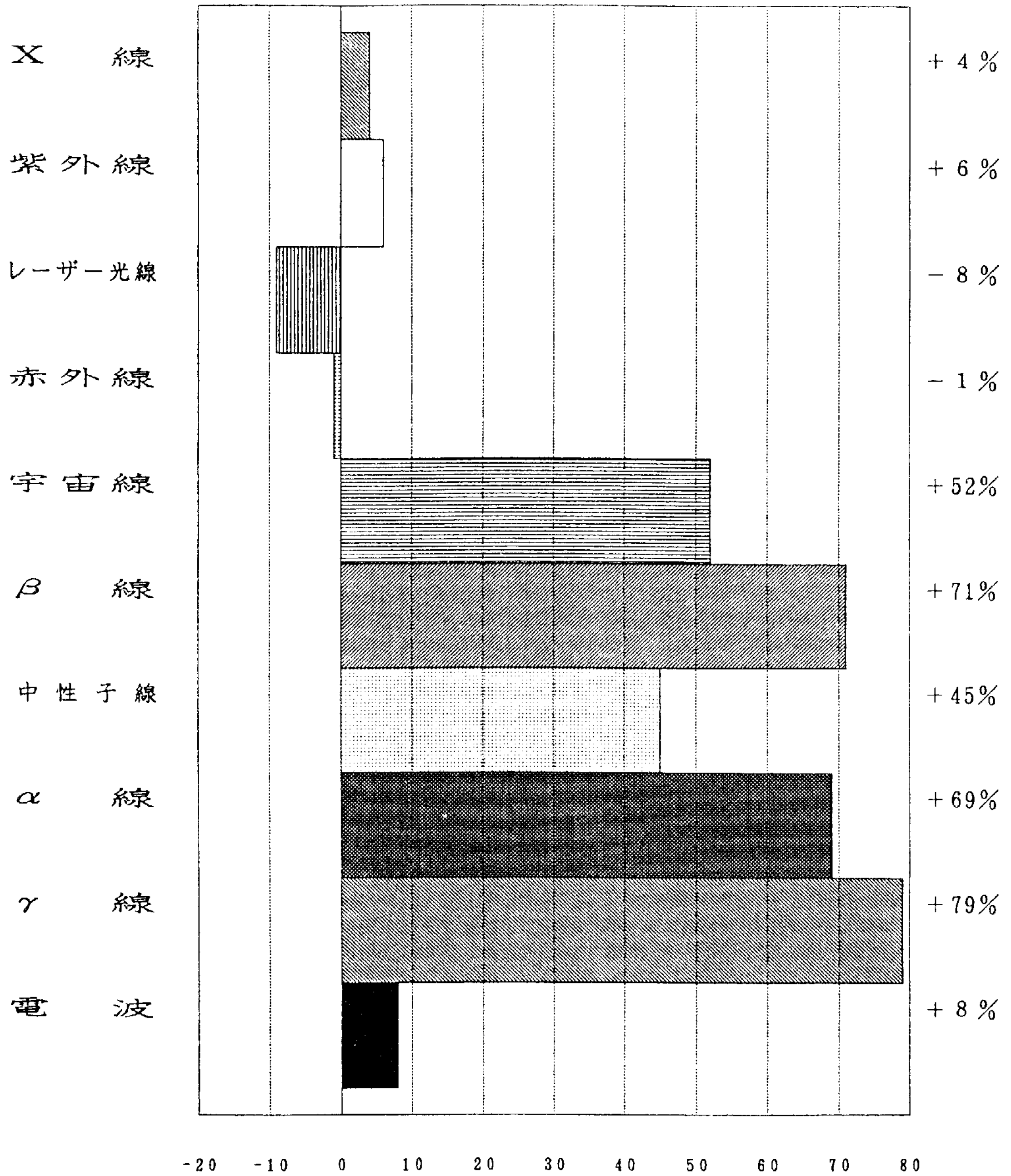
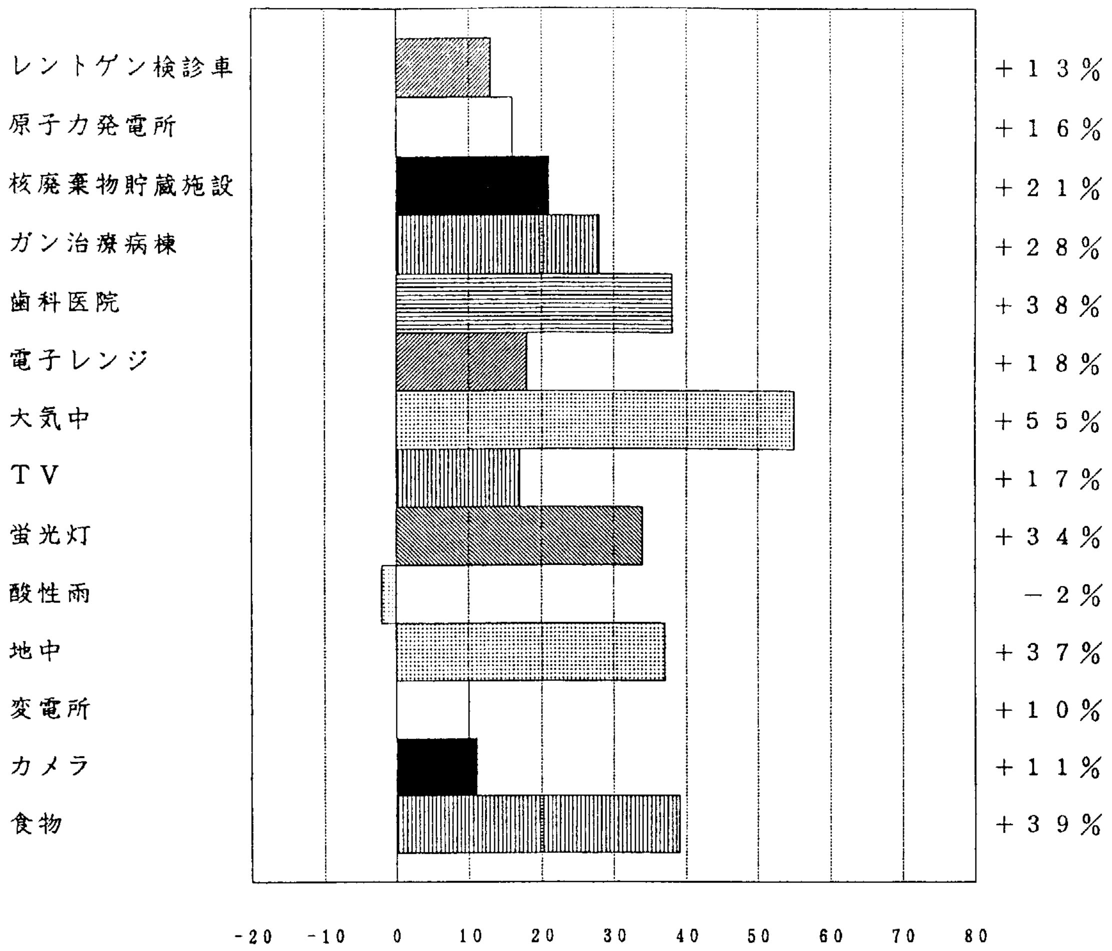
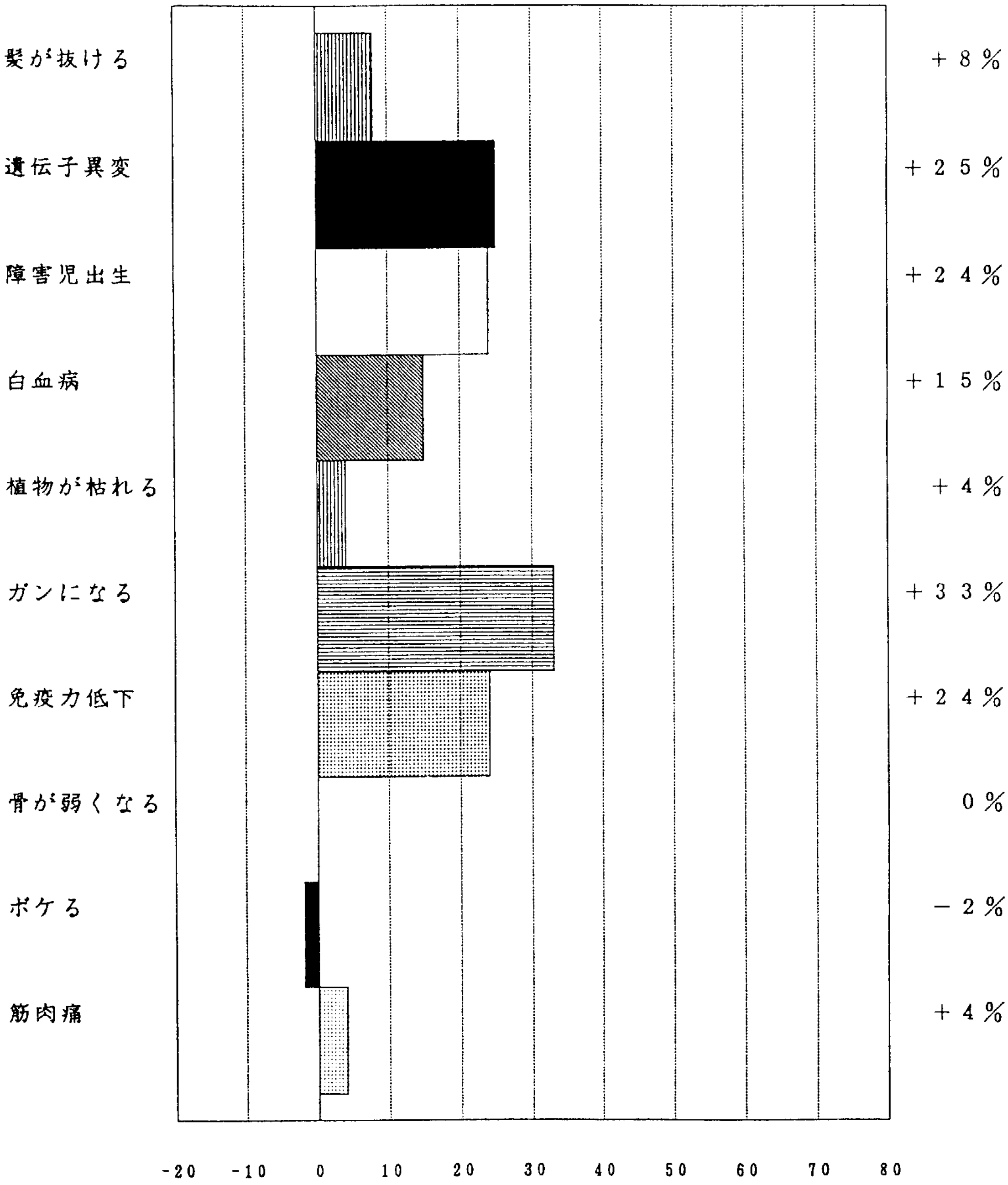

X 線
紫外線
レーザー光線
赤外線
宇宙線
β 線
中性子線
α 線
γ 線
電 波
+4%
+6%
−8%
−1%
+52%
+71%
+45%
+69%
+79%
+8%
-20
-10
0
10
20
30
40
50
60
70
80

図 2 放射線と思うもの



レントゲン検診車
原子力発電所
核廃棄物貯蔵施設
ガン治療病棟
歯科医院
電子レンジ
大気中
TV
蛍光灯
酸性雨
地中
変電所
カメラ
食物
+13%
+16%
+21%
+28%
+38%
+18%
+55%
+17%
+34%
−2%
+37%
+10%
+11%
+39%
-20
-10
0
10
20
30
40
50
60
70
80

図 3　身近な放射線


髪が抜ける
遺伝子異変
障害児出生
白血病
植物が枯れる
ガンになる
免疫力低下
骨が弱くなる
ボケる
筋肉痛
＋８％
＋２５％
＋２４％
＋１５％
＋４％
＋３３％
＋２４％
０％
－２％
＋４％
-20
-10
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70
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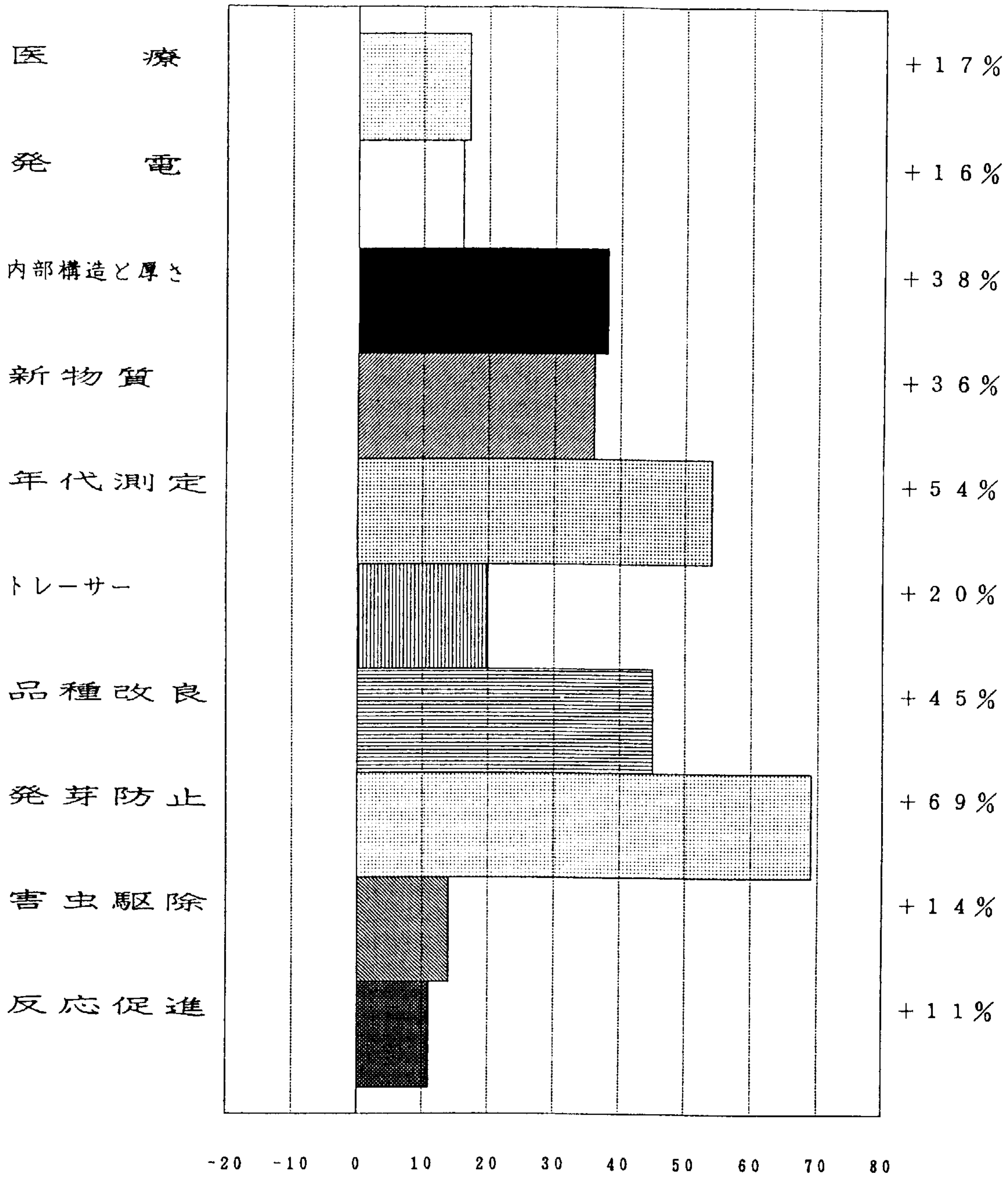
図４　放射線の被害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反応促進
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図５　放射線の利用

JAERI-Conf 99-011
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3.7 TEACHING MATERIAL FOR RADIATION EDUCATION USING RADIOGRAPHY TECHNIQUE.

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Abstract

In order to develop a teaching material that helps learners to understand the interaction between substances and radiation, a periodic table was prepared on which pure pieces of nearly thirty element were fixed and radiographic images of the periodic table were taken using X ray and neutron beam under several conditions. Obtained images are so clear that they can be expected to be very helpful in intuitive understanding on the magnitude of the interaction.

1.Introduction

Figure 1[1] illustrates that X-ray can be shielded effectively in case the shielding material is composed of heavier elements and that the interaction of X-ray toward substance is completely different from that of thermal neutron. However, it is not easy for learners to grasp the magnitude of these interactions intuitively even if they can read the data in Fig.1 correctly. This is not only because radiation itself is insensible and invisible, but also because we have almost no opportunity to be conscious of the intensity of radiation in our daily lives. Radiation is something too far away from our daily lives and most of us do not have rigid concept on it.

Despite this situation, a radiographic image for medical use is something exceptionally familiar to us. Besides, it includes quantitative information on X ray transmittance across substance, or the magnitude of interaction between X-ray and substance. This means that most people, who are well acquainted with normal optical photographs, can read (or image) the intensity of radiation from optical density of the radiographic images.

From such a viewpoint we made a periodic table on which pure pieces of many elements were fixed and took its radiographic images under several conditions.

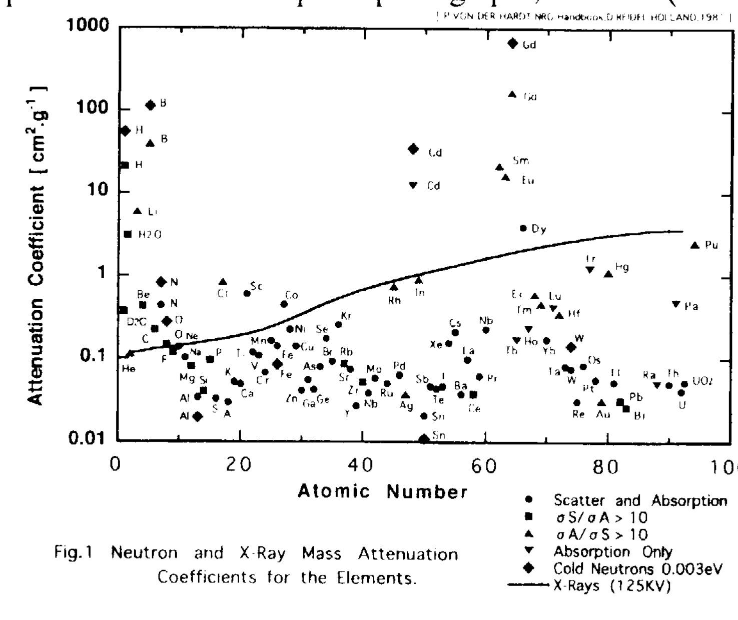


Fig.1 Neutron and X-Ray Mass Attenuation Coefficients for the Elements.

2.Experimental

2.1 Preparation of a periodic table

The number of samples used in this work is about 30 and they are schematically illustrated in Fig.2. The length and the width of each sample is equal to or smaller than 10mm and 8mm, respectively and its thickness, which accords with the direction of radiation, is 0.014mol/cm^2 (corresponding to 1mm in case of iron). In case of X-ray radiography, these samples were fixed on a plastic sheet with a thickness of 0.7mm, and in case of neutron and gamma ray radiography, they were fixed on an aluminum sheet with a thickness of 1mm.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	**	Unq	Unp	Unh	Uns	Uno	Une									

Fig.2 Periodic Table (Prepared elements are hatched)

2.2 X-ray and Gamma radiography

X ray was irradiated to the periodic table as shown in Fig. 3 and the irradiation was repeated varying X ray energy from 50kV to 150kV in order to clarify how transmittance of X ray across a substance depends on its energy. The intensity of X ray that passed through the sample was recorded on an imaging plate and was read out with an IP reader BAS5000(FUJI).

For gamma radiography (GR), the neutron radiography facility of Kyoto University Research Reactor Institute (KURRI) was used. As shown in Fig.4, the facility has two beam shutter; one is made of lead to shield Gamma ray and the other one is made of boron carbide to shield neutron. GR of the periodic table was taken with the former one opened for 5 min.

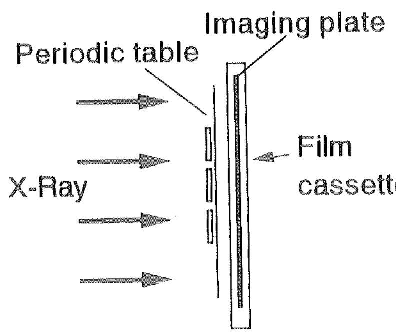


Fig.3 Arrangement for X-ray radiography

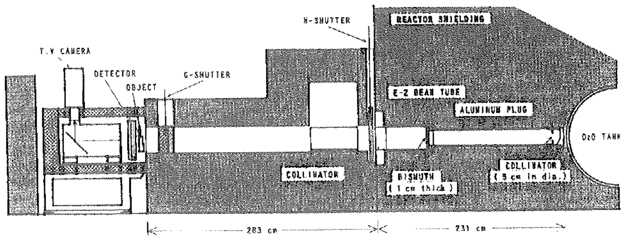


Fig.4 NR facility (KURRI)

2.3 Neutron radiography

Neutron radiography facility and CNS facility (Fig.5) of KURRI were used to take thermal neutron radiography (TNR) and cold neutron radiography (CNR), respectively. Yayoi Facility of Tokyo University (Fig. 6) was also used to take fast neutron radiography (FNR). Although the principle and arrangement for neutron radiography is similar to those for X-ray radiography (XR), imaging plates for neutron (Fuji) were used for TNR and CNR while Kodak SR (X ray film for industrial use) was used with the converter F20 for FNR. Irradiation time was 3 and 20 minutes for TNR and FNR, respectively. In case of CNR, the beam size is 10mm in width and 100mm in height. Since width of the beam is narrow, the periodic table was traversed in sideward with an imaging plate during 8 minute irradiation at the rate of 300mm/8min.

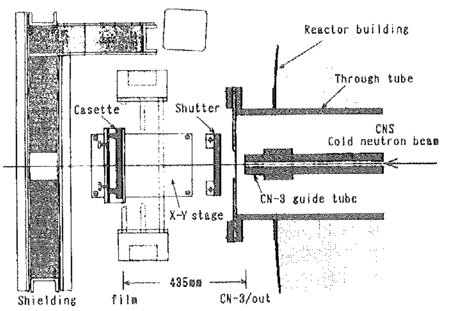


Fig.5 CNS facility (KURRI)

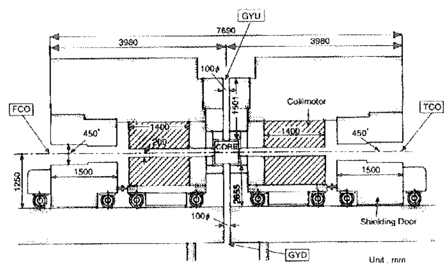


Fig.6 Yayoi facility (Tokyo Univ.)

2.4 Neutron activated autoradiography

When the periodic table is irradiated with neutron for relatively long period, some of the samples are activated. This work was designed to visualize which elements are easily activated and decay in relatively short time.

After the periodic table was irradiated for 9.5 hours in the neutron radiography facility of KURRI, it was enclosed in a film cassette with an imaging plate so that the surface of the periodic table was kept in good contact with that of the imaging plate for tritium use as long as 1.5 hours. Seven and half hours after irradiation, this procedure was repeated to obtain the image that illustrates how activated elements would decay.

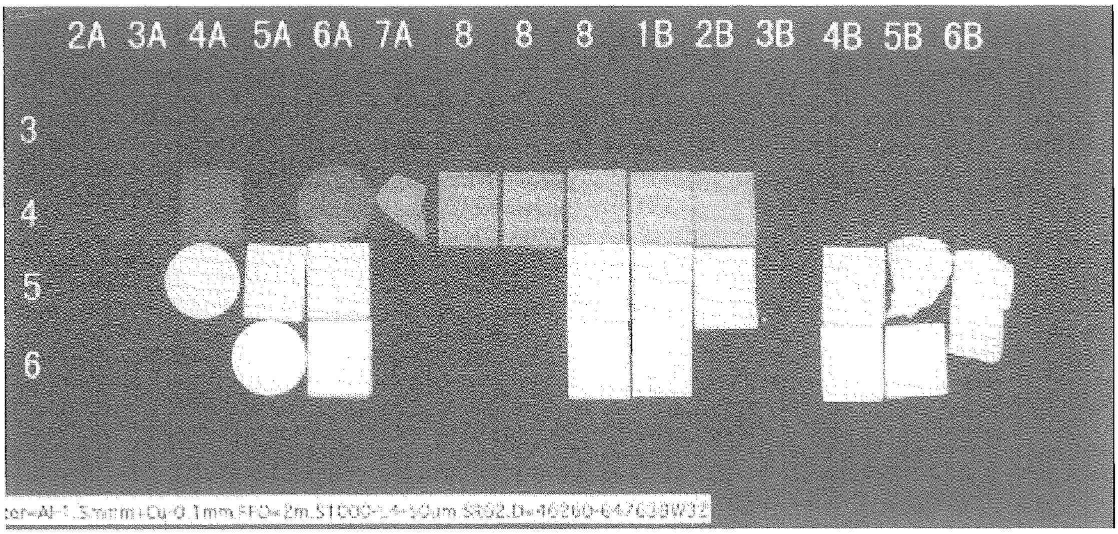
3. Results and Discussion

3.1 Results of XR and GR

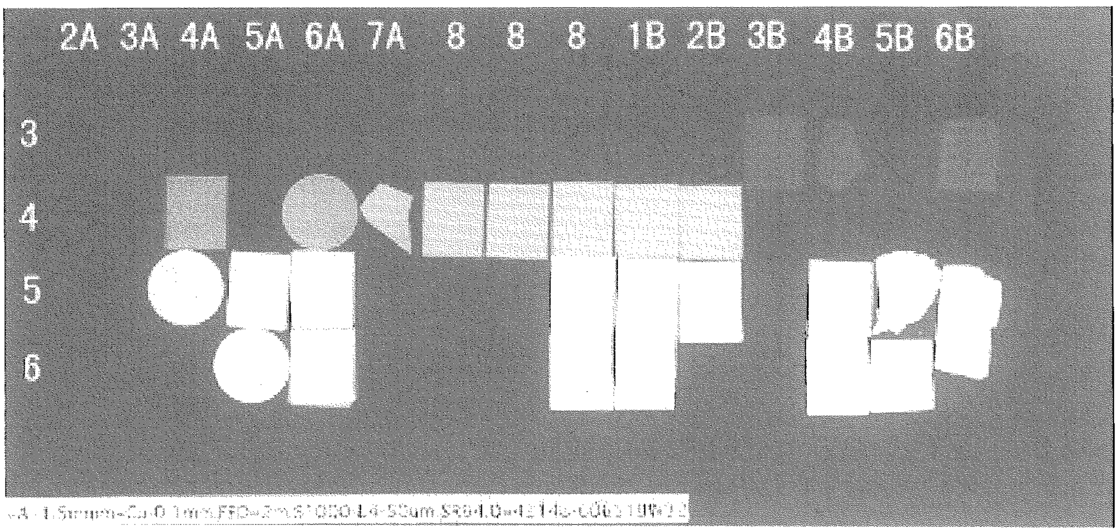
XR images of the periodic table were presented in Fig.7. Since the image of each sample is getting white according to the increase of atomic number, it can be easily understood that the ability to shield X ray increases according to the increase of atomic number of the substance, which reflects the fact that electrons in an atom play an important role in the interaction between X-ray and substances.

In case of Fig. 7(a), all samples in 3rd period are black and invisible. This means that they are too transparent to 150kV X ray. In case of Fig.7(c) elements in 3rd period are visible and those belonging to 5th and 6th period are all white. Thus, the energy dependence, as well as atomic number dependence, of X-ray transmittance has been visualized in these three photos.

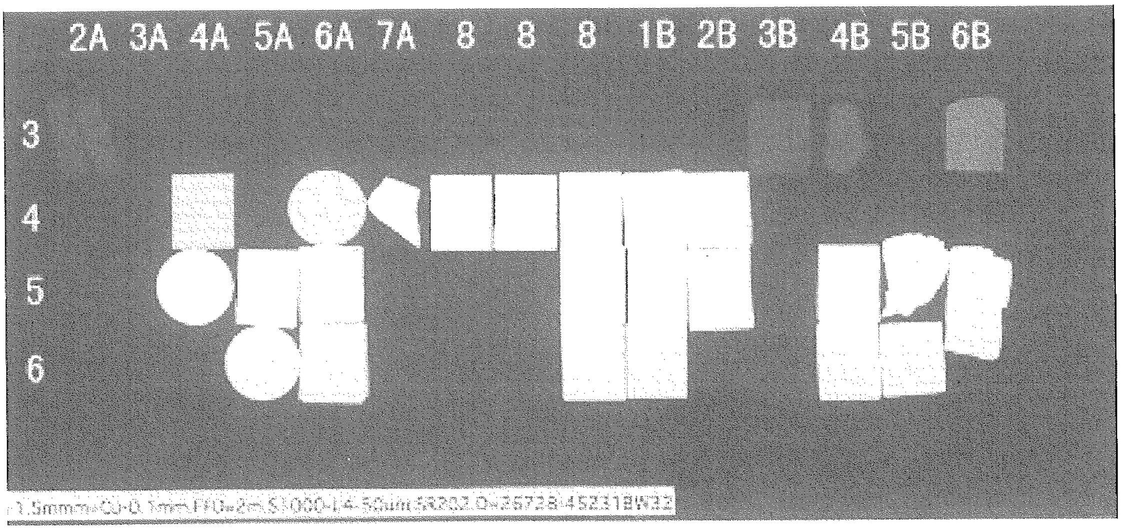
As for GR in Fig. 8, it can be seen that gamma ray can penetrate through heavy substances such as Pb or Bi that can shield 150kV X ray almost completely.



(a)



(b)



(c)

Fig.7 X-ray radiographic images (a)150kV (b)100kV (c)50kv

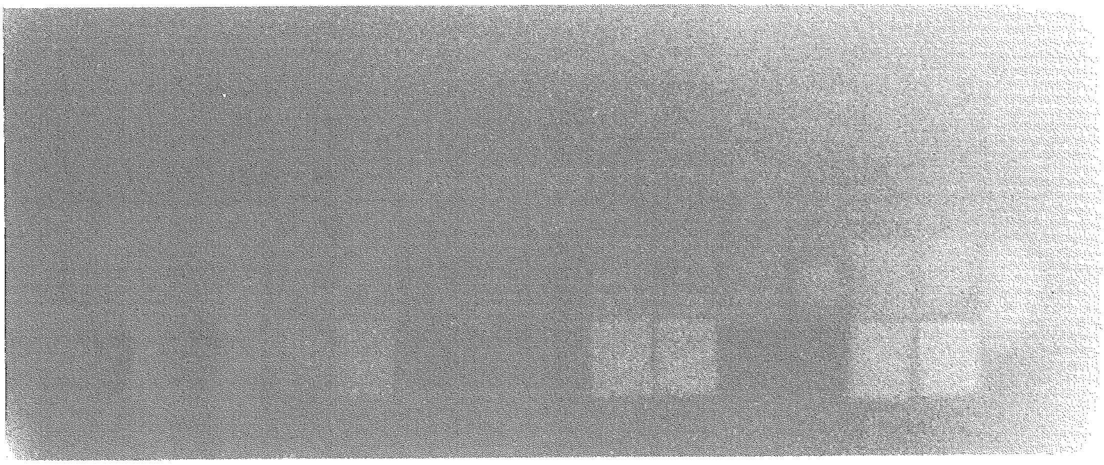


Fig.8 Gamma radiographic image

3.2 Results of TNR, CNR and FNR

The obtained images of TNR, CNR, FNR are presented in Fig. 9. Since neutrons do not interact with electrons around a nucleus but nucleus itself, the obtained images are completely different from XR images. Take B and Pb in Fig. 9(a) for instance, B is opaque and Pb is transparent to neutron, which is exactly the opposite result of what was seen in Fig.7.

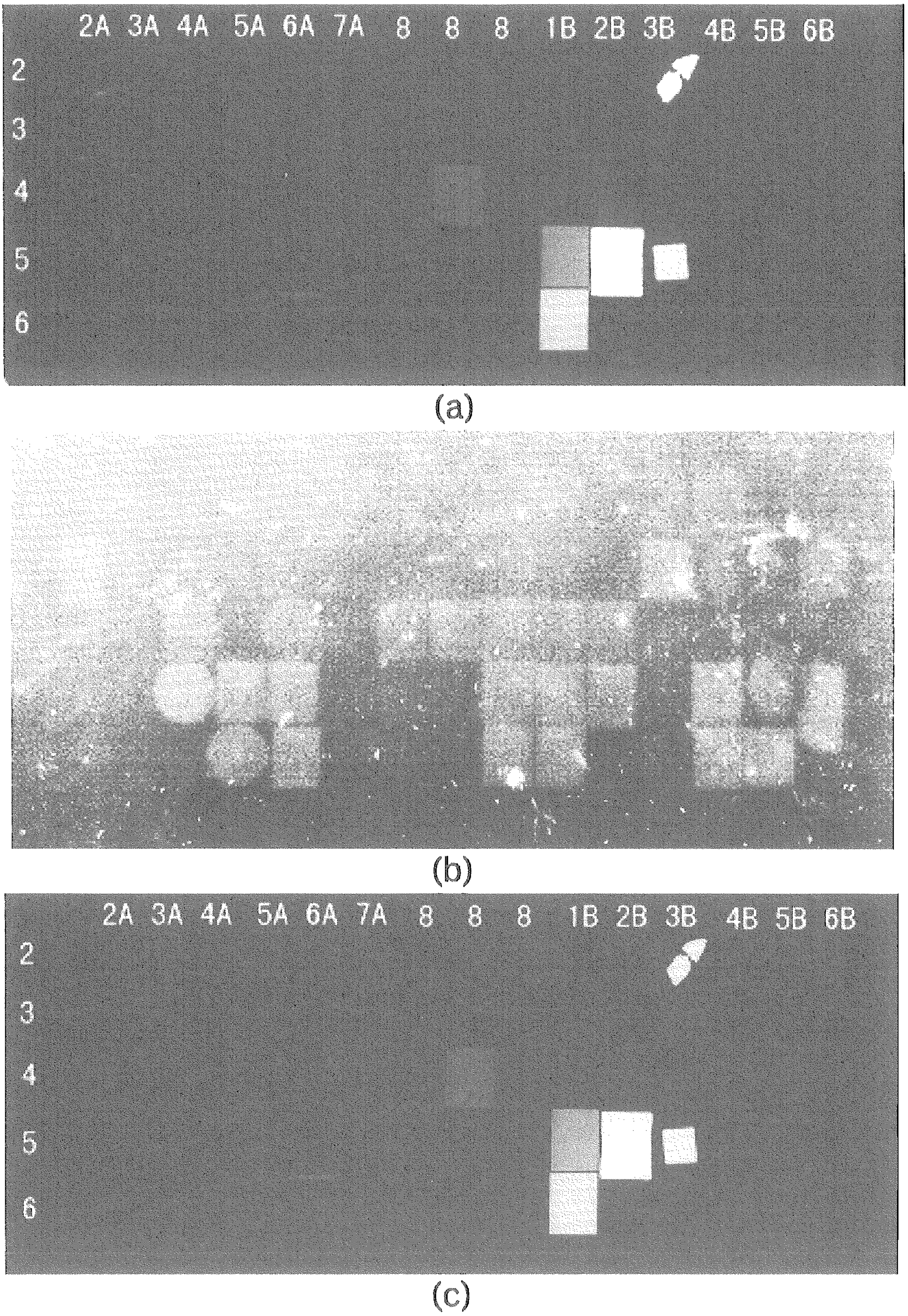


Fig.9 Neutron radiographic images
(a)TNR (b) FNR (c)CNR

In case of thermal neutron, neutron transmittance Io/I for each element can be approximately evaluated by the following equation;

$$Io/I=\exp(-N\sigma x) \qquad (1),$$

where, N, σ and x denote number of atoms in unit volume [cm^{-3}], total cross section to neutron [barn] and thickness of the sample [cm], respectively. In Fig.10 the calculated values were plotted against the measured ones that were derived from digitalized data of the NR image, which was obtained using Rikkyo University Reactor instead of KUR. Although they are in coincidence to certain degree, the deviation is not negligibly small. It is considered that the imaging plate used in this work has some sensitivity also to the Gamma ray as well as neutrons.

Generally, as energy of neutron becomes larger, peculiarity among species become less conspicuous because elastic interaction become more prominent. Thus the image of FNR(cf. Fig. 9(c)) is similar to that of GR while the image of CNR (cf. Fig.9(b)) is more contrasted in comparison with the image of TNR.

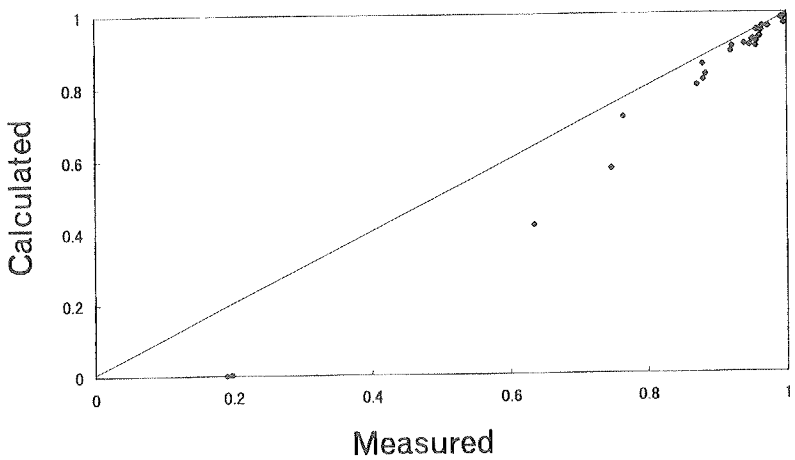
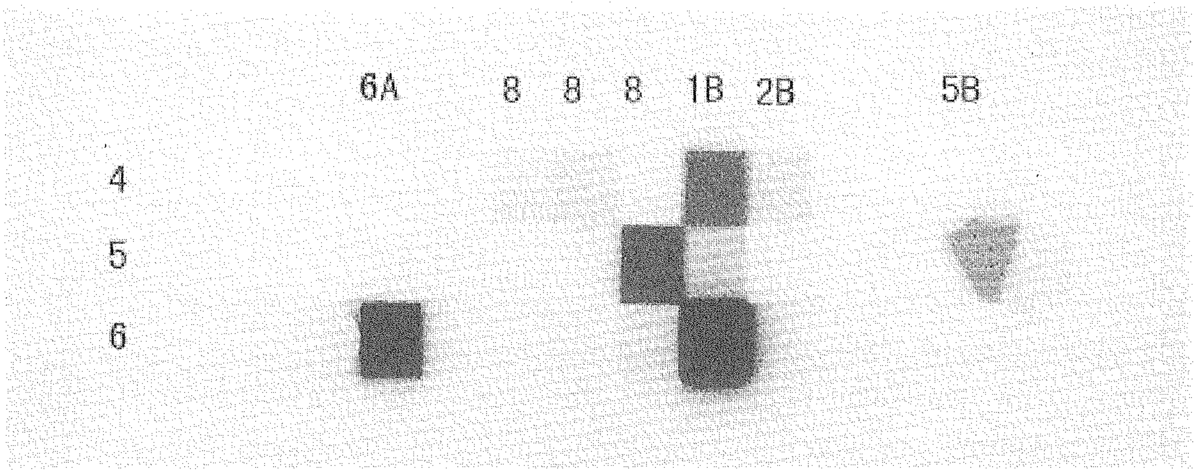


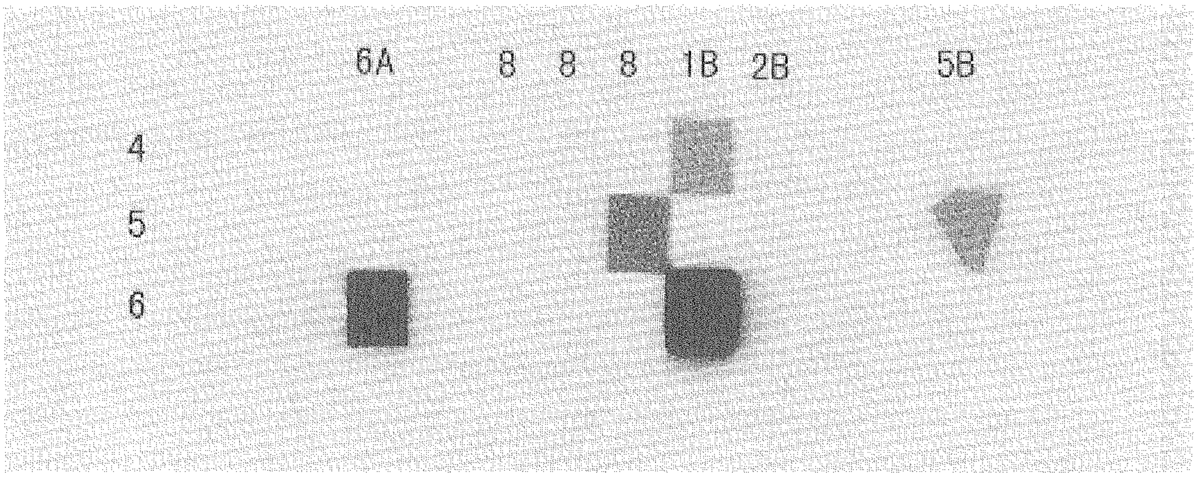
Fig.10 Neutron transmittance of various elements

3.3 Neutron activated autoradiography

As shown in Fig. 11, the elements such as Fe, Co, Cu, Zn, Pd, Ag, Sb, Te, W, Pt ,Au are easily activated by neutron irradiation and Cu, Pd, At, W, Au are still radioactive even after 7.5 hours. These images illustrate how the activity of the irradiated element is determined by the half-life and the cross section for activation. Take Cu and Ag for instance, activation cross section of Ag is nearly ten times larger than Cu, but the image of Cu is much denser than that of Ag. This means, since half life of activated Ag is 2.41min and that of Cu is 12.8h, the activity of Ag was saturated during the irradiation.



(a)



(b)

Fig11 Neutron activated radiographic images.
(a) Immediately after irradiation (b) 7.5hours after irradiation

4. Conclusion

A couple of photographic teaching materials have been developed which help learners

1. To understand how X-ray transmittance through a substance depends on atomic number of the substance as well as X-ray energy,
2. To understand that the interaction of neutron toward substances are completely different from those of X ray.
3. To understand which species are easy to be activated and how soon they decay.

Reference

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3.8 EDUCATIONAL EXPERIMENT FOR STUDENTS USING NATURAL RADIOACTIVITY. I
(Radiochemical Analysis of ^{214}Bi in ENA and IKEDA Mineral Spring Water)

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Abstract

A couple of educational experiments have been developed using natural radioactivity contained in mineral spring water and a small GM counter. These experiments are safe and inexpensive enough to be conducted at high school or university, nevertheless they are quantitative enough for learners to observe half-life of ^{214}Pb and ^{214}Bi, and to help them understand the concept of radioactive equilibrium between them.

1.Introduction

After being A-bombed, most Japanese people have been so nervous to radiation/ radioactivity that it is sometimes difficult to conduct an educational experiment at school using radiation or radioactive material however safe it is. Although they show the same negative attitude toward the radiation/radioactivity used in other fields such as medical treatment and power generation, they have exceptionally accepted natural radioactivity included in mineral spring water as harmless one since before World War II. This means if natural radioactivity in mineral spring water is available as a material for an educational experiment, it can be easily conducted at school. From such a viewpoint, we have developed several kinds of experiments for high school or university students using natural radioactivity[1-8] and this paper will present a couple of examples which use mineral spring water of Ena in Gifu prefecture and Ikeda in Shimane prefecture.

2.Experiment

2.1 Natural radioactivity in mineral spring water of Ena and Ikeda

Mineral spring of Ena and Ikeda belong to the most radioactive spring in Japan along with Misasa spring in Tottori prefecture and Masutomi spring in Yamanashi prefecture. These four springs are used and loved as spas for long time and even now a large number of people visit for a hot- spring cure. Ena spring is located in the middle part of Japan, 4km northeast of Ena station of JR Chuo Line. The water used in this experiment was sampled at Rousoku spring (TEL:+81-573-72-5047). Ikeda spring (TEL:+81-8548-3-2833) is located in the western part of Japan, near (20min by taxi) Oodashi station of JR San-in Line. The maps and photographs of the sites where water was sampled are presented in Fig.1.

The results of gamma spectrum of these two spring water are presented in Fig.2. The results indicate that the radioactivity contained in these samples belong to uranium decay series and that the radioactivity of ^{222}Rn was 3500Bq/L in case of Ena spring water and 2400Bq/L in case of Ikeda spring water.

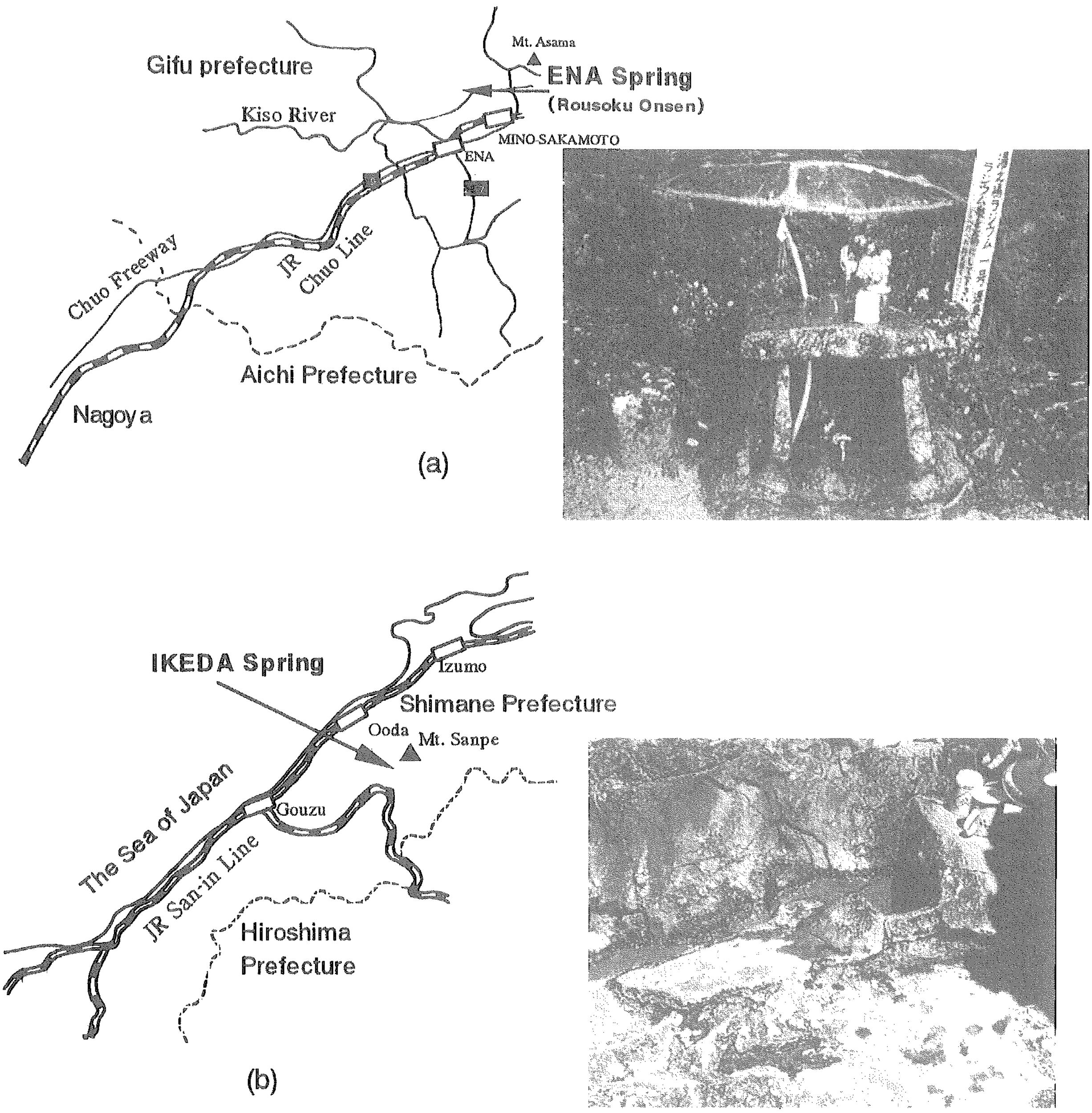
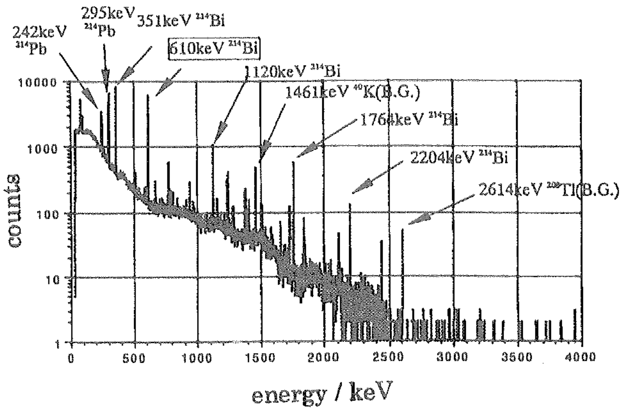


Fig.1 Maps and photos of the sampling sites.

(a)Ena Mineral Spring (b)Ikeda Mineral Spring



(a)

Sample

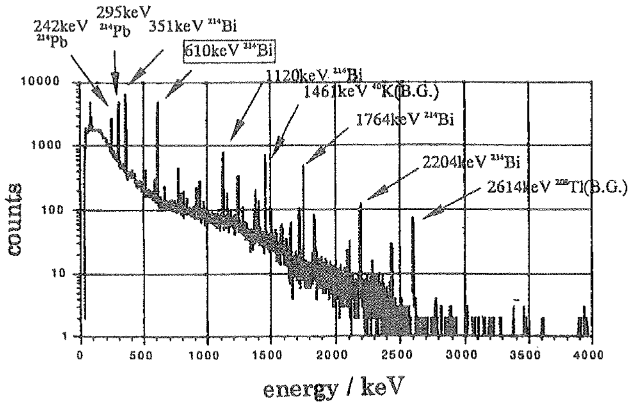
220mL of Ena spring water

Counting Time

20000 sec

Detector

EG & G ORTEC GEM-10175



(b)

Sample

280mL of Ikeda spring water

Counting Time

20000 sec

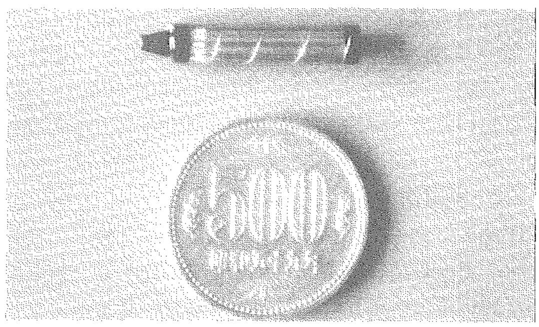
Detector

EG & G ORTEC GEM-10175

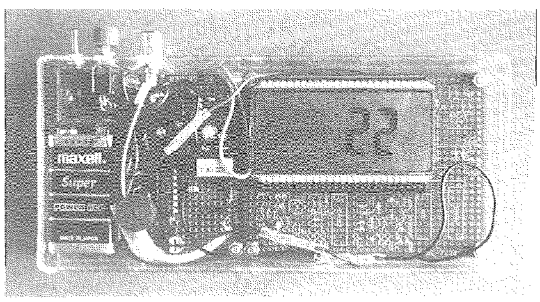
Fig.2 Gamma spectrum and measuring condition
(a) Ena spring water (b) Ikeda spring water

2.2 Measuring device (GM counter)

A GM counter used in this work is sold from Akizuki Denshi Tuusho (http:// www.tomakomai.or.jp/akizuki/) as a do-it-yourself kit at the price of 10,000 yen (less than 100 dollars). A GM tube used in it is HAMAMATSU D3372 which consists of a cylinder-shaped cathode (5mm in diameter, 24mm in length) and is designed for the detection of gamma rays and high-energy beta ray which is larger than 0.5MeV. Since only ^{214}Bi emits high energy beta ray with large emitting ratio among daughter species of ^{222}Rn, this tube is suited to measuring the radioactivity of ^{214}Bi settled radiochemically out of Ena or Ikeda spring water. The outside appearance of the GM tube and assembled kit is presented in Fig.3.



(a)



(b)

Fig.3 Outside appearance of GM counter
(a) HAMAMATSU D3372
(b) Assembled kit

2.3 Educational experiments to measure the activity of ^{214}Bi

Following three experiments were designed and conducted.

Experiment 1.:
To precipitate ^{214}Pb and ^{214}Bi together out of the spring water and to measure the radioactivity of ^{214}Bi in the precipitate.

Experiment 2. :
To precipitate ^{214}Bi out of the spring water while leaving ^{214}Pb in water phase and to measure the radioactivity of ^{214}Bi in the precipitate.

Experiment 3:
.To precipitate ^{214}Pb out of the spring water while leaving ^{214}Bi in water phase and to measure the radioactivity of ^{214}Bi in the precipitate that is generated from ^{214}Pb in it.

Flowcharts of these experiments are illustrated in Fig.4

The precipitate containing ^{214}Pb and/or ^{214}Bi is gathered on Kiriyama filter paper with the diameter of 21mm, covered with thin polyethylene film, and fixed around the GM counter tube as illustrated in Fig.5. Counting rates (cpm) were calculated every 10 minutes using the counts accumulated during that period.

Add 10mL of HNO_3 and 100mg of $Bi(NO_3)_3 \cdot 5H_2O$ to 80mL of the spring water and stir for 5min.

↓

Precipitate $Bi(OH)_3$ by adding $(NH_3)_{aq}$ until pH exceeds 10

(a) Experiment 1

Add 10mL of HNO_3, 100mg of $Bi(NO_3)_3 \cdot 5H_2O$ and 100mg of $Pb(NO_3)_2$ to 80mL of the spring water and stir for 5min.

↓

Precipitate $Bi(OH)_3$ by adding NaOH (8-9g) until $[OH^-]$ is approximately equal to 1mol.

(b)Experiment 2

Add 10mL of HNO_3, 100mg of $Bi(NO_3)_3 \cdot 5H_2O$ and 250mg of $Pb(NO_3)_2$ to 160mL of the spring water and stir for 5min.

↓

Precipitate $PbSO_4$ by adding 6.5g of Na_2SO_4.

(c)Experiment 3

Fig.4 Flow charts of experimental procedure

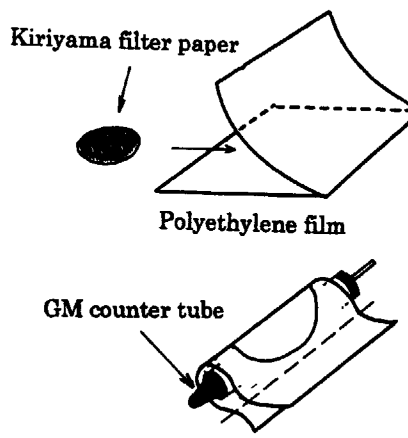


Fig.5 The way of holding the sample around GM tube

3.Results and Discussion

The typical results of Experiment1,2,3 are presented in Fig6. The vertical axis of each graph presents a counting rate of the GM counter and the horizontal axis presents time from precipitation of ^{214}Pb and/or ^{214}Bi.

The counting rate, or emitting rate of beta ray from ^{214}Bi, is proportional to the number of ^{214}Bi, N_2, which can be calculated as;

$$N_2=\{\lambda_1/(\lambda_2-\lambda_1)\}N_{10}\{\exp(-\lambda_1 t)-\exp(-\lambda_2 t)\}+(\lambda_1/\lambda_2)N_{10}\exp(-\lambda_2 t) \quad (1)$$

in case of Experiment1,

$$N_2=N_{20}\exp(-\lambda_2 t) \quad (2)$$

in case of Experiment 2, and

$$N_2=\{\lambda_1/(\lambda_2-\lambda_1)\}N_{10}\{\exp(-\lambda_1 t)-\exp(-\lambda_2 t)\} \quad (3)$$

in case of Experiment 3,

where λ_1 and λ_2 denote decay constant(s^{-1}) of ^{214}Pb and ^{214}Bi respectively; N_{10} and N_{20} denote the numbers of ^{214}Pb and ^{214}Bi at t=0 respectively.

These three equations were derived from following two differential equations;

$$dN_1/dt=-\lambda_1 N_1 \quad (4)$$

$$dN_2/dt=\lambda_1 N_1-\lambda_2 N_2 \quad (5)$$

under the initial conditions of

$$N_1=N_{10},\ \lambda_1 N_1=\lambda_2 N_2 \quad \text{at } t=0 \quad (6)$$

in case of Experiment1,

$$N_1=0,\ N_2=N_{20} \quad \text{at } t=0 \quad (7)$$

in case of Experiment2,

$$N_1=N_{10},\ N_2=0 \quad \text{at } t=0 \quad (8)$$

in case of Experiment3.

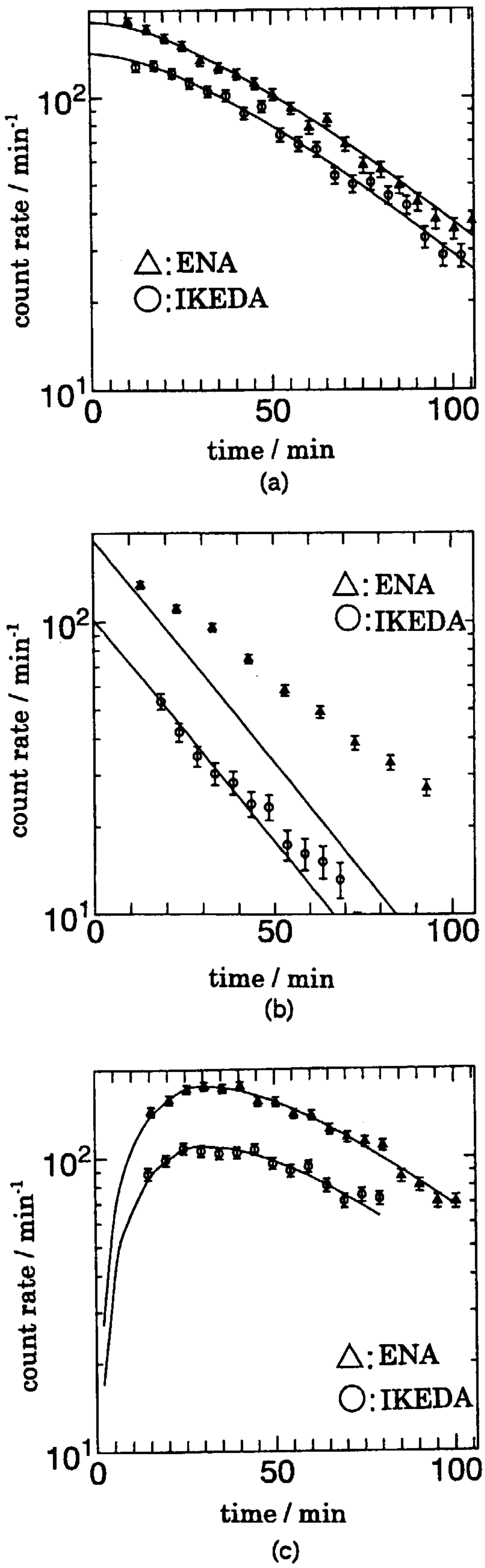


Fig.6 Typical results of (a)Experiment 1 (b)Experiment 2 (c)Experiment 3

The theoretical values calculated from eqs(1-3) are presented in solid lines in Fig.6, where the value of N_{10} or N_{20} was determined arbitrarily.

Through Experiment 1 to 3, measured values is considered to be coincident with calculated ones within statistical error in case of Ikeda spring water. In case of Ena spring water, there exists a wide difference between measured values and calculated ones in Experiment 2. The half-life derived from the measured values was close to half life of ^{214}Pb (27min) rather than half life of ^{214}Bi (19.9min). This means precipitates of Experiment 2 was contaminated with ^{214}Pb from unknown reason.

When measured values in Fig6 (a) were extraporated to t=0, counting rates at t=0 were $182min^{-1}=3.03s^{-1}$ and $143min^{-1}=2.38s^{-1}$ for Ena spring water and Ikeda spring water, respectively. By dividing these values with 0.029, counting efficiency of the GM counter, the radioactivity (Bq) of ^{214}Bi can be calculated as 3.03/0.029=104Bq in case of Ena spring water and 2.38/0.029=82Bq in case of Ikeda spring water. Since the ^{214}Bi in 80mL of Ena spring water and that of Ikeda spring water were turned out to be 192Bq and 129Bq 2.21days after sampling based on the gamma spectroscopic analysis, yield of the Experiment 1 is 0.54 and 0.64,respectively.

4.Conclusion

It was made clear that safe and inexpensive experiment was possible using hot spring water of Ena and Ikeda. The results obtained are quantitative enough for educational purposes, nevertheless no special facility nor special technique were necessary. By using natural radioactivity, learners are expected to recognize that radioactivity/radiation is not something special isolated from their daily lives.

Although there exists strict regulation against the usage of radioactive materials in Japan, it should be noted here that these educational experiment mentioned above are free from any regulation because the amount of the radioactivity is extremely small.

Acknowledgement

Special appreciation is presented here to kind cooperation of every staff in Ikeda spring and Ena spring (Rousoku Onsen) spas.

This work was partly supported by the Grand-in-aid for Developmental Scientific Research from the Ministry of Education, Science and Culture (No. 10558077) in 1998-2000.

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3.9 EDUCATIONAL EXPERIMENT FOR STUDENTS USING NATURAL RADIOACTIVITY. II

(Practical Example of Radiochemical Experiment Conducted at Tottori University)

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Abstract

This paper presents a practical example of educational experiment conducted at Tottori University, whose theme is to separate $^{214}Bi(+^{214}Pb)$ from superphosphate of lime or the soil sampled at Ningyo-Touge mountain pass. The results of this experiment are quantitative enough for educational purpose, although the amount of radioactivity is so small that it is free from any regulation in Japan.

1.Introduction

Although the words "radiation" and "radioactivity" are often used in our daily lives, what we learn about these subjects in our school education of science is limited and only very basic part of them is taken up in physics of senior high school in Japan. When it comes to practical work or educational experiment for students to use radiation or radioactivity, the case that they are conducted is very rare even in science courses of a university. The primary reason for this situation is that the regulation against the usage of radiation and radioactivity is very tight and that the measuring apparatus is very expensive in Japan. In order to change this situation, we have developed several kinds of safe and inexpensive experiments using natural radioactivity and a small GM counter(1,2,3).

This paper reports the practical work of radiochemistry that has been conducted at Tottori University since 4 years ago.

2. Practical work of radiochemistry in Tottori University

2.1 Background of the practical work

The practical work of radiochemistry has been conducted for 3rd year students belonging to

Department of Materials Science, Faculty of Engineering in Tottori University. Although they learn many fields of chemistry such as inorganic chemistry, physical chemistry and analytical chemistry through lectures and practical works, they had met almost no chance to learn about radiation/radioactivity before this radiochemical experiment was introduced in their practical work "Experiment for Materials Science II (EMS II)" 4 years ago. The subjects of EMS II are presented in Table 1.

Table 1 Content of EMS II

1.Electrode Potential and Electrode Reaction
2.Radiochemical Analysis
3.Distillation under the Reduced Pressure
4.Catalysis in Decomposition of Hydrogen Peroxide
5.Synthesis of 4,6-di-*tert*-Butylresorcinol
6.Synthesis of 2-nitoro-p-Toluidine
7.Preparation of Triphenylcarbinol

The number of 3rd year students in this department is 80 to 90. They are divided into 6 groups of 14 or 15 students and are engaged in the practical work of radiochemistry group by group. Since the practical work is conducted once or twice in a week, it takes more than 3 weeks to finish all of them. This means that mineral spring water containing ^{222}Rn such as Misasa spring water in Tottori prefecture is not appropriate for a experimental material because the half life of ^{222}Rn is less than 4 days and fresh material has to be prepared every time.

As a substitute for the Misasa spring water, superphosphate of lime as garden fertilizer or the soil sampled at Ningyo-Touge mountain pass in Tottori prefecture has been used, both of which contain radioactive species belonging to uranium decay series. Since superphosphate of lime is produced from rock phosphate which contains uranium, the product contains ^{228}Ra, one of the daughter species of ^{238}U and radioactive equilibrium is considered to be established between ^{226}Ra and ^{214}Po (cf. Fig.1).

	Half-life	Decay
^{238}U ↓	4.47×10^{9}y	α
^{234}Th ↓	24.1d	β
^{234}Pa ↓	1.17m	β
^{234}U ↓	2.45×10^{5}y	α
^{230}Th ↓	7.54×10^{4}y	α
^{226}Ra ↓	1.6×10^{3}y	α
^{222}Rn ↓	3.82d	α
^{218}Po ↓	3.11m	α
^{214}Pb ↓	27m	β
^{214}Bi ↓	19.9m	β
^{214}Po	164μs	α

Fig.1 Uranium decay series

2.2 Method of the experiment

The theme of the experiment is to separate ^{214}Bi(+^{214}Pb) from superphosphate of lime or the solid sample, radiochemically and to measure the decay of ^{214}Bi(+^{214}Pb) using a GM counter or a handy type beta survey meter "HAKARU-KUN II", which Science and Technology Agency lends to schools for free. Their appearances are presented in photo 1 and 2, respectively.

Since superphosphate of lime as garden fertilizer and the soil sample contain many kinds of compounds as impurities, it is not easy to separate very small amount of one particular

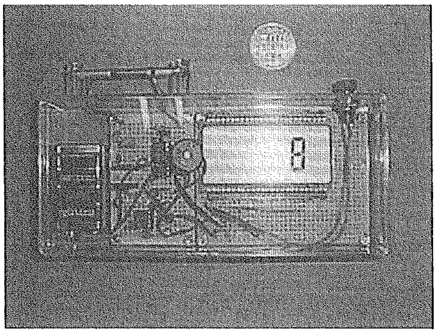


Photo 1

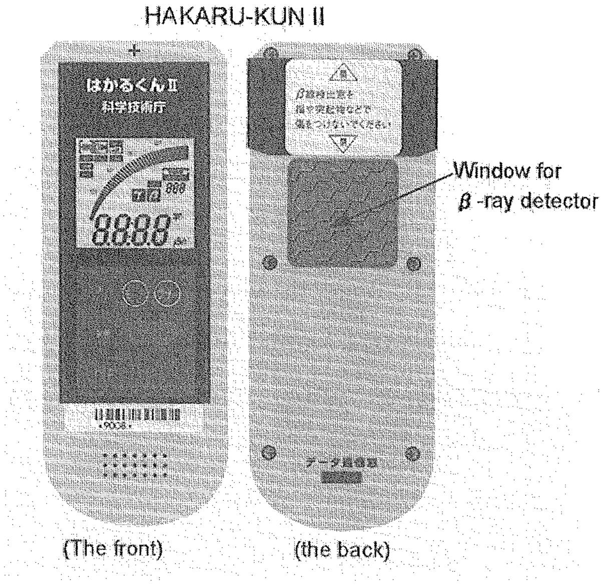


Photo 2

radioactive species, such as ^{214}Bi, chemically from it. In this work, we made use of the fact that only ^{222}Rn is gaseous in uranium decay series as illustrated in Fig.1, and is easily adsorbed onto charcoal activated. This means, if a few grams of charcoal activated is enclosed in a desiccator with 1 or 2 kilograms of superphosphate or the soil sample for one week as shown in Fig.2, ^{222}Rn and its daughter species, such as ^{214}Pb and ^{214}Bi, are accumulated on the charcoal activated. After this charcoal activated is washed in a HNO_3 aqueous solution and these radiochemical species are moved to the liquid phase, it is easy to settle out ^{214}Bi with ^{214}Pb as precipitate of $Bi(OH)_3$. A flow chart of the radiochemical procedure is presented in Fig.3.

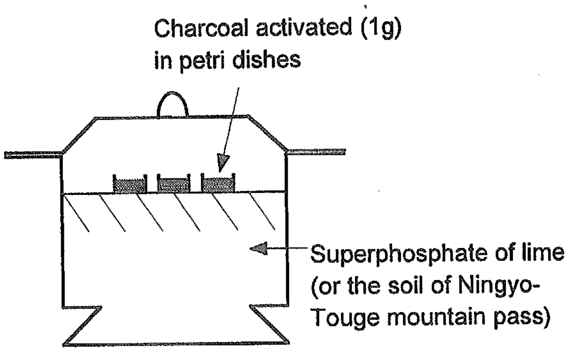


Fig.2 Separation of ^{222}Rn and the daughters from Uranium decay series

Dissolve Bismuth(III) nitrate *($Bi(NO_3)_3 \cdot 5H_2O$, 100mg)* in Nitric acid solution *(HNO_3, 10ml + H_2O, 30ml)*

↓

Add Charcoal activated *(1g)* on which ^{222}Rn is adsorbed and stir for five minutes *(with magnetic stirrer)*

↓

Remove Charcoal activated with a wide-mouthed buchner funnel

↓

Add 25% Ammonia solution until pH exceeds over 10 and precipitate bismuth hydroxide

↓

Gather bismuth hydroxide on Kiriyama filter paper *(21mm in diameter)*

↓

Wrap the filter paper with polyethylene foil and put it around GM counter or under HAKARU-KUN II to measure the β-ray from $^{214}Bi(+^{214}Pb)$

Fig.3 The sequence of the experiment

2.3 Practical Example

A time table of the practical work is illustrated in Fig.4. At the beginning of the practical work, a brief instruction on the experiment is given to the students and they (14～15 students) are divided into smaller groups of two or three. Then as training and as a measurement of background radiation, the students rehearse the experiment using charcoal activated on which no radioactive species are adsorbed. After this rehearsal, or cold run, the actual experiment is carried out. Since the half-life of ^{214}Pb is 27min, swiftness is required. When they finish the chemical procedure, they put the precipitate containing $^{214}Pb+^{214}Bi$ around a GM counter tube or under a window of HAKARU-KUN II. In case of the GM, the counters are put under an OHC (Over Head Camera) and counts displayed on the scalers are recorded into a video tape. During this measuring time of 70～80minutes, the students clean up the apparatus they used and a small lecture is given to them on radiation and radioactivity. Although some of the students has learned about the basic of this subject in senior high school, most students have not learned (or remembered) it. After the lecture is over, the video tape is played back every 10minutes and they record the counts on their own notebook. They are required to submit their report within a week.

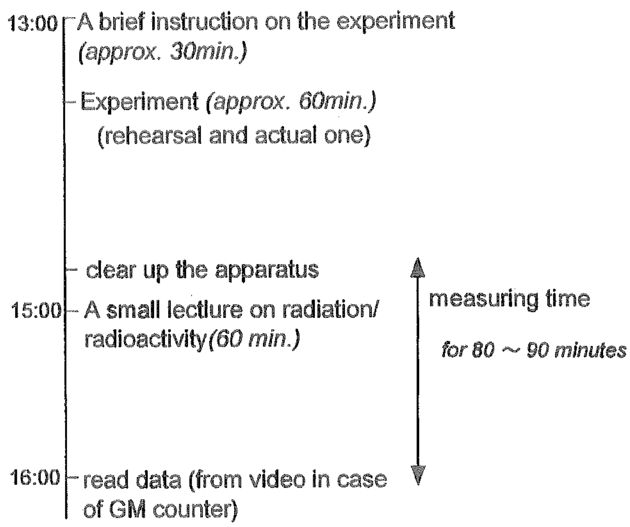
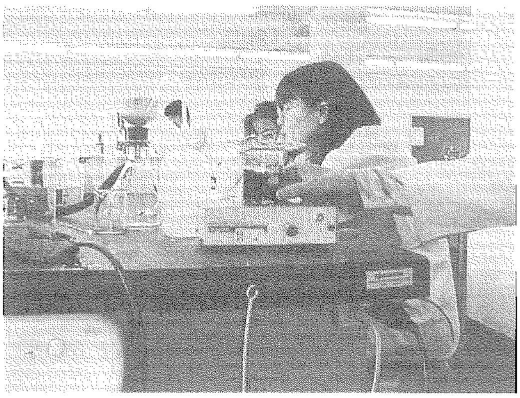
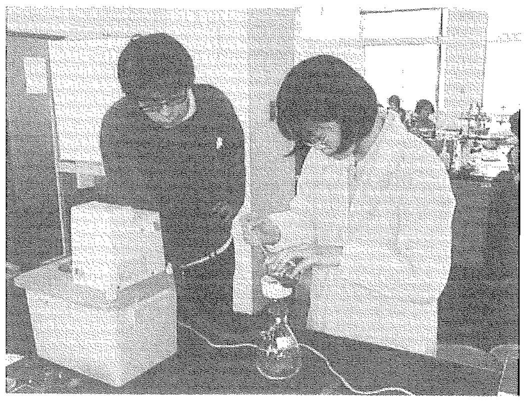


Fig.4 Time table of the practical work

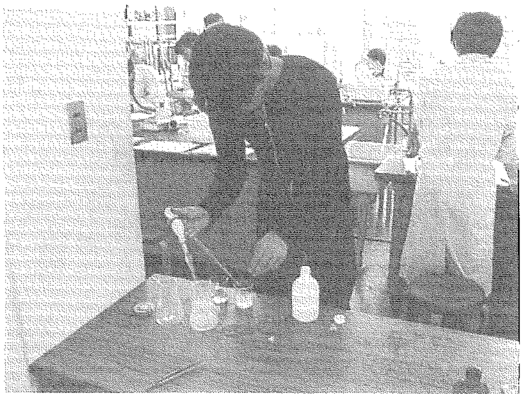
The scenes of this practical work are presented in photo 3.



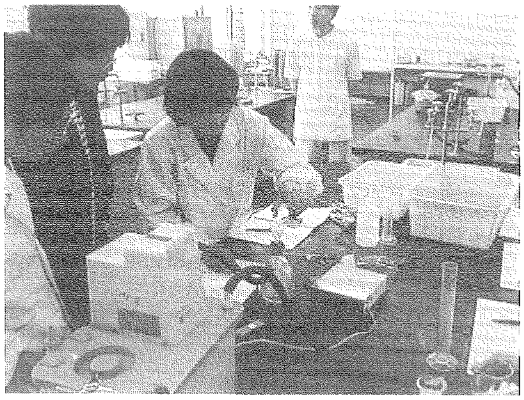
Stir charcoal activated in HNO_3 aq. for five miniutes



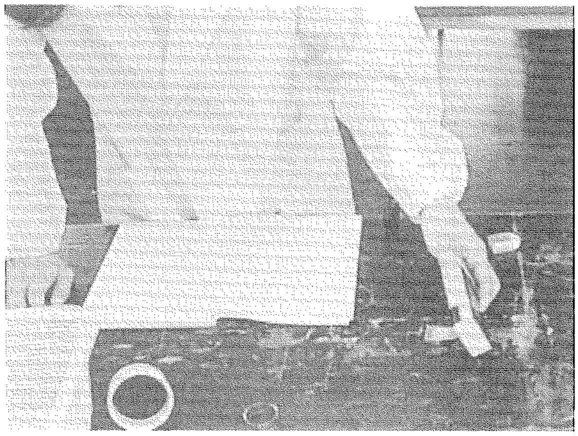
Remove charcoal activated



Add 25% ammonia solution

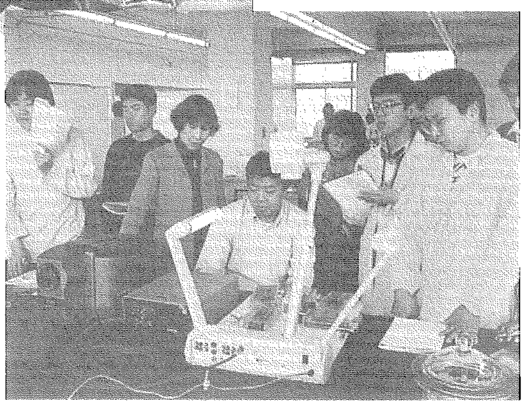


Gather bismuth hydroxide



Measure with HAKARU-KUN II

Fix the Kiriyama filter paper around GM counter



Read recorded data with video

Photo 3 Scenes of the EMS II

4. Experimental results

A typical example of the results obtained using a GM counter is presented in Fig.5. Although only high energy beta ray emitted from ^{214}Bi is detected by the GM counter tube (HAMAMATSU D3372), the slope of decay curve is close to the half life of ^{214}Pb (27min) and this means that ^{214}Pb is also included in the precipitate of $Bi(OH)_3$ with ^{214}Bi, Therefore, the theoretical line in Fig.5 was calculated using

$$N_2=\{\lambda_1/(\lambda_2-\lambda_1)\}N_{10}\{\exp(-\lambda_1 t)-\exp(-\lambda_2 t)\}+(\lambda_1/\lambda_2)N_{10}\exp(-\lambda_2 t) \quad (1)$$

derived from

$$dN_1/dt=\lambda_1 N_1 \quad (2)$$

$$dN_2/dt=\lambda_1 N_1-\lambda_2 N_2 \quad (3)$$

under the initial condition

$$N_1=N_{10},$$

$$\lambda_1 N_1=\lambda_2 N_2 \quad \text{at } t=0 \quad (4),$$

where λ_1 and λ_2 denote decay constants (s^{-1}) of ^{214}Pb and ^{214}Bi, respectively.

The result obtained using "HAKARU-KUN II" is presented in Fig.6. Since this detector is sensible to beta ray with lower energy<0.5MeV or that emitted from ^{214}Pb, the theoretical value is approximately proportional to $\lambda_1 N_1+\lambda_2 N_2$. Thus, the theoretical line in Fig.6 was calculate with eq.1 and

$$N_1=N_{10}\exp(-\lambda_1 t) \quad (5).$$

It should be noted here that the sensitivity of HAKARU-KUN II is far better than a GM tube (HAMAMATSU D3372) and has a function to store every one minute data for 10 hours, which makes the preparation of the practical work much easier.

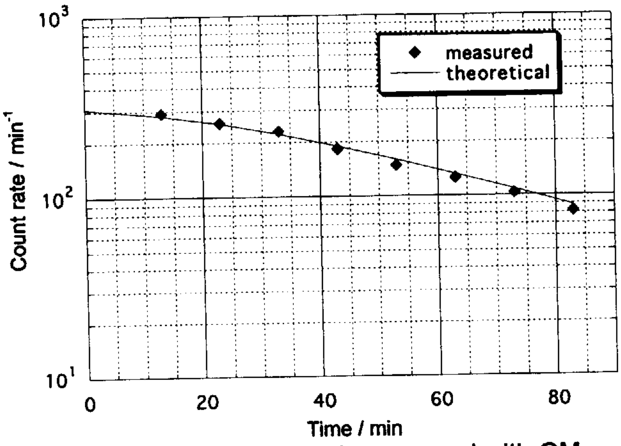


Fig.5 An typical result measured with GM

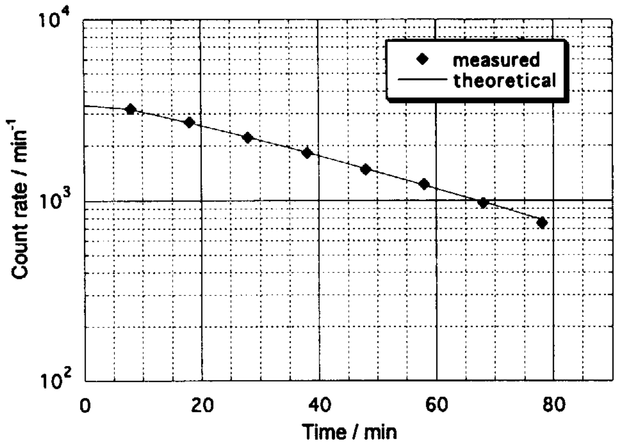


Fig.6 A typical result measured with HAKARU-KUN II

7.Conclusion

Since most students did not have enough knowledge on radiation/radioactivity for this practical work, its educational effect must be considered to be limited. However, it can be expected that students has got a valuable chance to study radiation/radioactivity based on their own experience and they may change their too negative attitude toward radiation/radioactivity usage.

Since neither special apparatus nor special technique is needed in this experiment, this experiment is suited for high school students as a theme of their club activity.

Acknowledgement

This work was partly supported by the Grand-in-aid for Developmental Scientific Research from the Ministry of Education, Science and Culture (No.10558077) in 1998-2000.

Reference

1. M.Kamata, M.Nakamura and T. Esaka, "Radiochemical Experiment with Natural Radioisotope(I) Radiochemical Analysis of ^{214}Bi in Mineral Spring Water", Chemistry and Education (in Japanese), **42**, 286-291(1994).
2. M.Kamata and T. Esaka, "Radiochemical Experiment with Natural Radioisotope(IV) Radiochemical Analysis of ^{222}Rn Released from Calcium Superphosphate for Gardening and its Daughters(I)", Chemistry and Education (in Japanese), **43**, 588-591(1995).
3. M.Kamata, M.Nakamura and T.Esaka, "Educational Experiment for Students Using Natural Radioactivity.I (Radiochemcal Analysis of ^{214}Bi in ENA and IKEDA Mineral Spring Water)", Proceeding of International Symposium on Radiation on Education (ISRE 98) to be published.

3.10 岐阜県東濃地域の環境放射線測定を通しての放射線教育

RADIATION EDUCATION BY MEANS OF THE MEASUREMENT OF NATURAL ENVIRONMENTAL RADIATION IN TONO REGION, GIFU PREFECTURE

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Abstract

The Tono region is placed in the south-east of Gifu prefecture. In this region, there is a plan of construction of the Research and Education Park. As the center facility of the park, the National Institute for Fusion Science (NIFS) has started their research activities.

The Plasma Research Committee of Toki-city has been organized by the board of education of Toki-city for about 20 years. The committee is mainly composed of science teachers of elementary school, junior high school and high school in the area.

The committee has measured continuously the natural environmental background radiations in cooperation with NIFS. Its activities were started before constructing the NIFS laboratory buildings. Now, the new measuring points in Tajimi-city and Mizunami-city are added to the points in Toki-city area, therefore, some teachers join as the new members of the committee.

In this conference, we present as follows.

(1) Plasma Research Committee of Toki-city; its history, organization and activities.
(2) Obtained data of the natural environmental radiation in Toki-city.
(3) Example lecture taken in natural radiation, its results and the farther issues.

1 はじめに

岐阜県東濃地域は県の東南部に位置して，その丘陵地帯には研究学園都市建設構想があり，その中核としての核融合科学研究所はすでに完成し研究活動を開始している。土岐市教育委員会を世話役として，地域の小,中,高の理科の先生を中心に土岐市プラズマ研究委員会を組織し，この核融合研究所の建設が始まる前から研究所と共同で，20 年ほど地域の環境放射線の測定を継続的に行ってきた。現在は,多治見市,瑞浪市なども測定エリアに入れ関係の先生と核融合研究所との共同研究を深めている。

今回の発表では

(1) これまでの経緯，実施項目，研究会の組織
(2) 環境放射線測定データの紹介（土岐市周辺の測定結果の紹介）
(3) 教育への採り入れ事例とそこでの成果と今後の方向などを紹介する。

2. 土岐地区環境放射線測定研究の歩み

(1980～1998)

1980 土岐市プラズマ研究委員会
名古屋大学プラズマ研究所　共同研究「土岐地区の環境放射能の測定」開始
1981 ・ＧＭ計数器の試作とそれによる測定
・報告書　Ｉ（資料とＧＭ計数管による測定）IPPJ-DT-89 (1981)
1982 土岐市プラズマ研究委員会
・NaIを用いた車上測定（土岐市内）　　・土壌試料のNaIスペクトル分析
・各種可搬型測定器(Ar電離箱、NaI-DBM、GM計数管、TLD)による同時比較測定（市内巡回）
1983 ・報告書　II（各種測定器による比較測定）IPPJ-DT-105 (1983)
・ＴＬＤによる定点測定（土岐市プラズマ研究委員会側で運営）
・環境トリチウムの測定用試料採取（河川、雨水、井戸、水道、等）（液シン法）
・土壌採取（Ge測定器用試料）　　・環境でのガンマ線成分の測定 (U, Th, K-40, Csその他)
・高校理科教育カリキュラムに反映（土岐北高校）
1984 土岐市プラズマ研究委員会
・Ge測定器による現地測定（空間線量）および採取試料測定
1985 ・土岐市がＴＬＤ測定用機器(UD-512P)購入
・報告書　III（昭和58年度の活動）IPPJ-DT-116 (1985)
1986 土岐市プラズマ研究委員会
・チェルノブイリ事故による環境放射能変化の点検
・報告書　IV（昭和59～60年度の活動）IPPJ-DT-130 (1986)
文部省科学研究費を受領（土岐北高校）
1987 ・ＴＬＤの継続的定点観測（3ヶ月値）
・環境トリチウムの継続的測定
1988 土岐市プラズマ研究委員会
・土岐地区環境放射能の分析（プラズマ研究所測定分との比較）
1989 ・報告書　V（昭和61～62年度の活動）IPPJ-DT-146 (1989)
・報告書　VI（昭和63年度の活動）IPPJ-DT-147 (1989)
名古屋大学プラズマ研究所廃止に伴い共同研究中断（測定中断）
核融合科学研究所発足
1990 土岐市プラズマ研究委員会
核融合科学研究所　共同研究「土岐地区の環境放射線の測定」開始
・ＴＬＤ継続測定再開（15点）
1991 ・ＴＬＤ未回収期間を含めてデータ整理・測定点の整備
変化の要因（読み取り機器の調整、設置場所近傍の改変、自然変動、等）
1992 土岐市プラズマ研究委員会
・ＴＬＤ校正測定の重視
・動燃主催による土岐市周辺カーボーン測定に協力（可搬型機器測定）
1993 土岐市プラズマ研究委員会
・Rn測定（カップ法）準備
1994 ・ＧＭ計数管キットによる試作と測定
・核融合研究所放射線モニターシステム
1995 土岐市プラズマ研究委員会
・1991～94の測定値の検討
・ＴＬＤ読み取り機器の不調----修理調整、校正の徹底
・可搬型測定器（Ar電離箱、Ge、NaIとＴＬＤ）による巡回測定（ＴＬＤ測定点6点を巡回）
1996 ・ＴＬＤ測定点の追加（多治見を含む）
・ガラス線量計とＴＬＤとの比較
・Rn測定（カップ法）の開始
1997 土岐市プラズマ研究委員会
・野外巡回測定　測定器「はかるくん」を用いるルート測定と他の可搬型機器による測定
1998

3 環境放射線測定研究の意義と目的

核融合科学研究所およびその前身である名古屋大学プラズマ研究所：

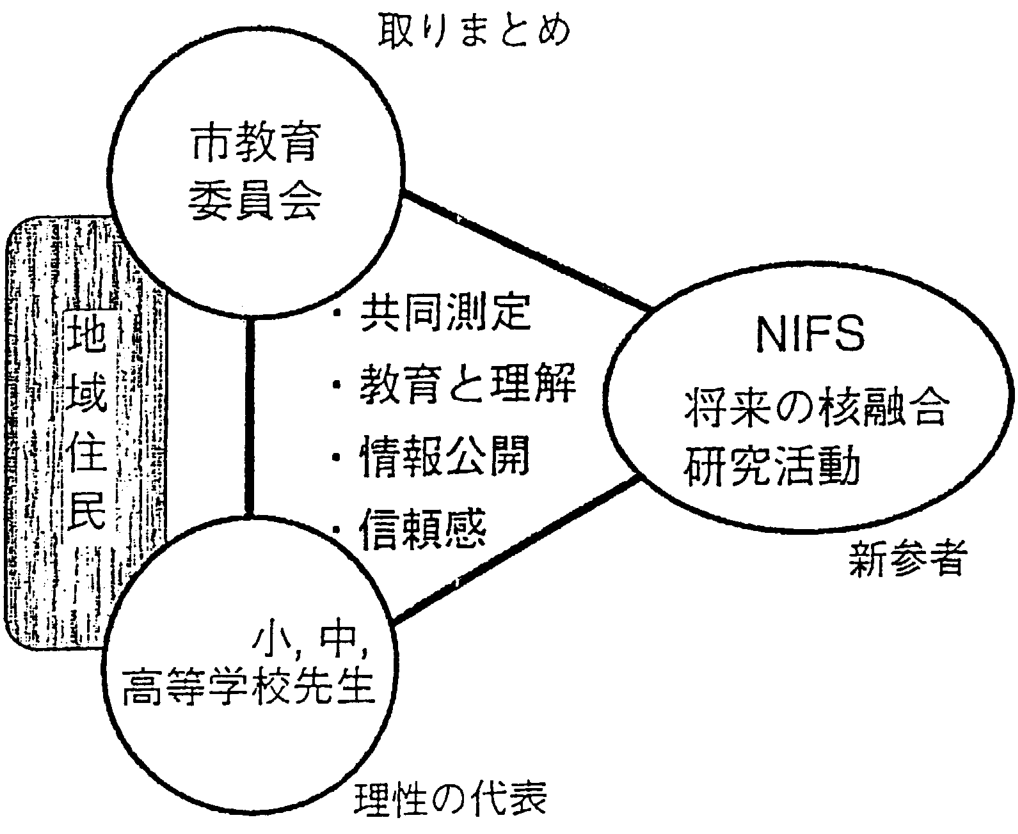
プラズマ核融合の新しい研究施設を建設、運用していく上で
常に念頭に置かれている点：

- 先進的な研究を行う開かれた研究所
- 地域および自然の環境と調和した研究活動
- 共同研究・国際協力・教育効果の重視
- 社会・住民の理解・協力と信頼の確保
- 安全性の十分な確認とそのための管理

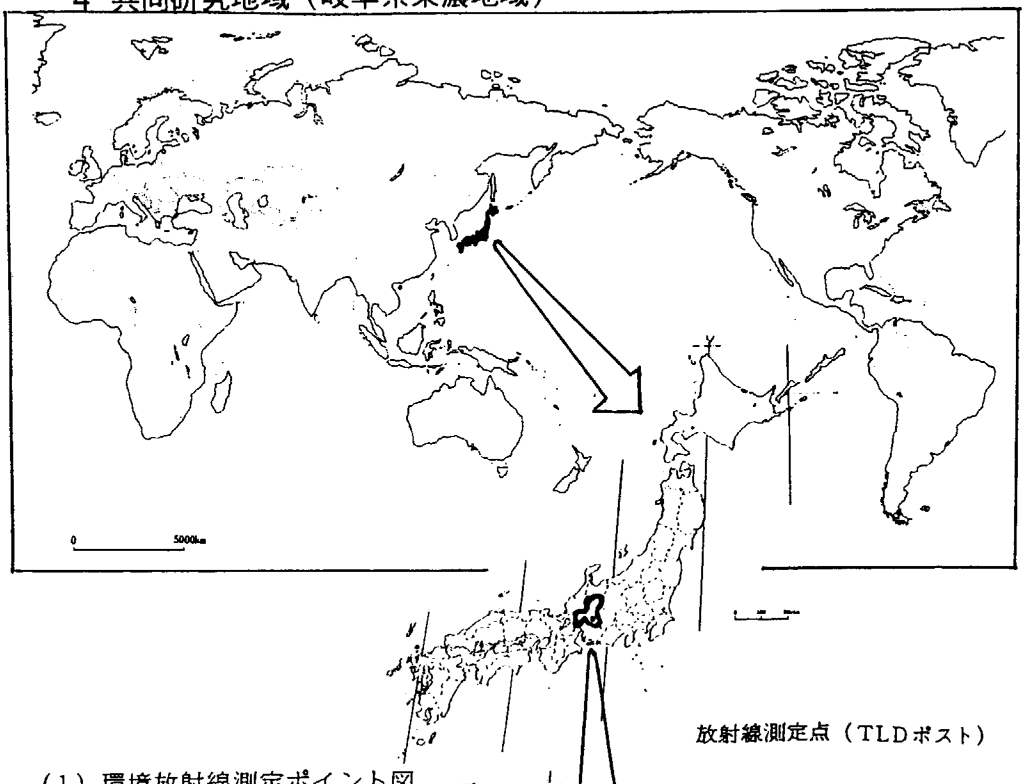
プラズマ核融合装置の大型化に伴う発生放射線の問題：

- 装置運転時の発生放射線が周辺の環境に影響を及ぼさない
- 具体的目標として、敷地境界で年間　50μSv を越えないこと
- 地域の自然放射線の特性の把握が必要
- 監視・評価・確認の手法の確立
- 放射線について住民との共通理解が不可欠

土岐市の側で、核融合プラズマ放射線問題に対応していく組織として
土岐市教育委員会を世話担当とし、高、中、小学校の、理科の先生を中心に
　　土岐市プラズマ研究委員会
が設置された。

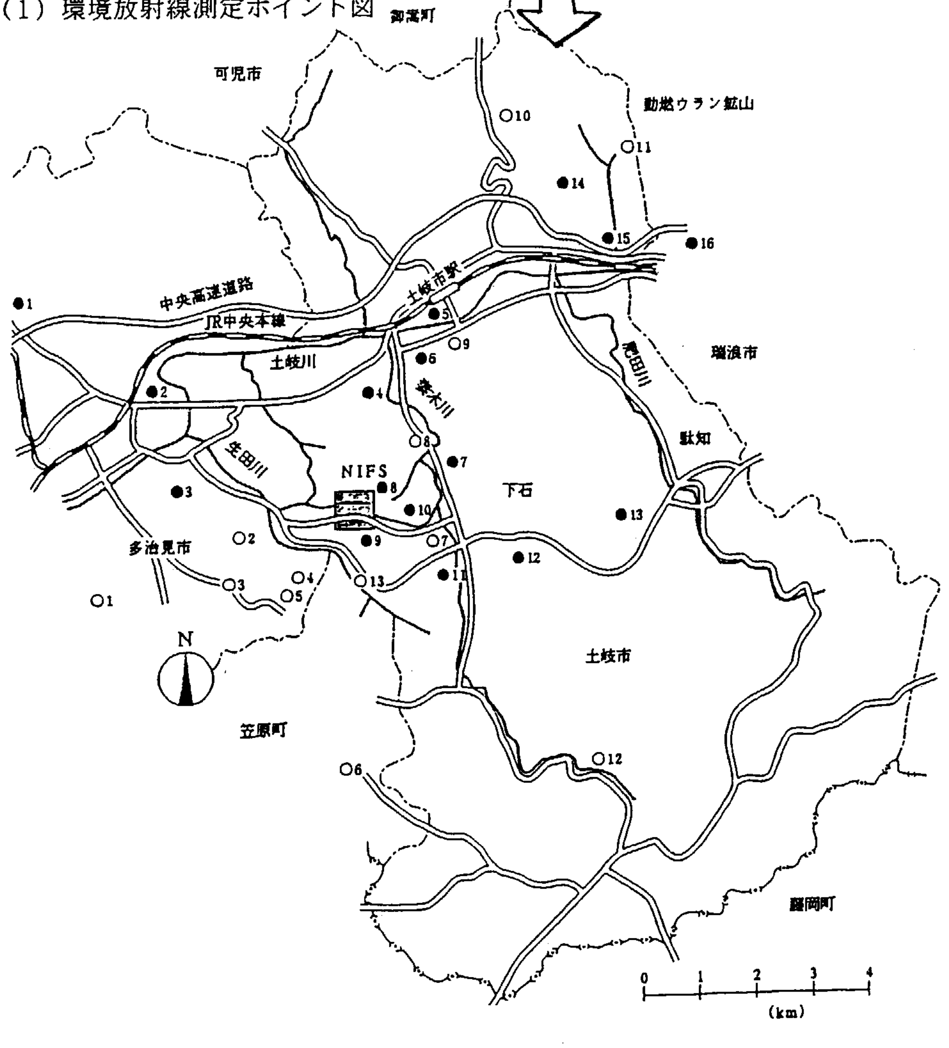


4 共同研究地域（岐阜県東濃地域）



放射線測定点（TLDポスト）

（1）環境放射線測定ポイント図



5 土岐地区環境放射線測定結果

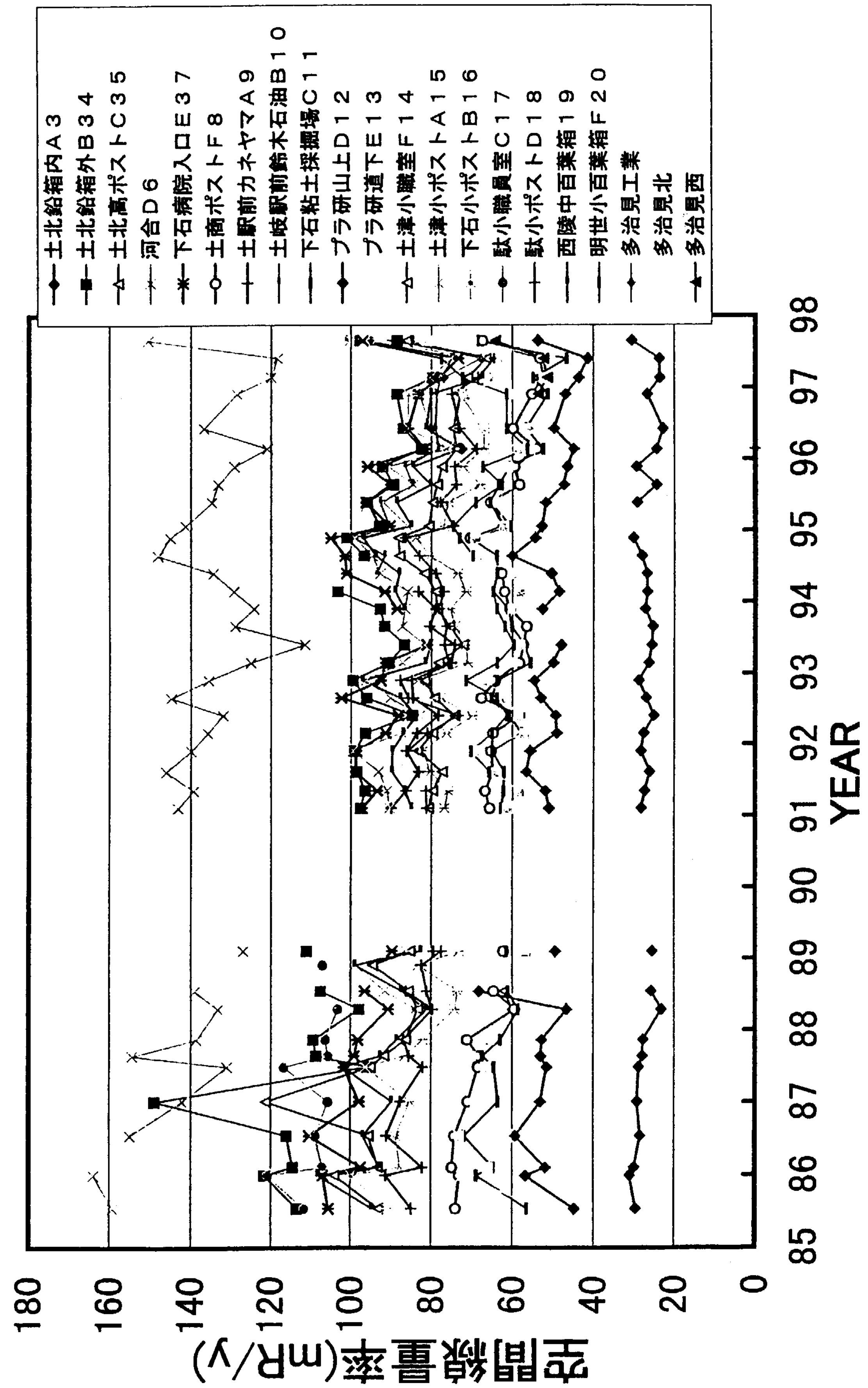
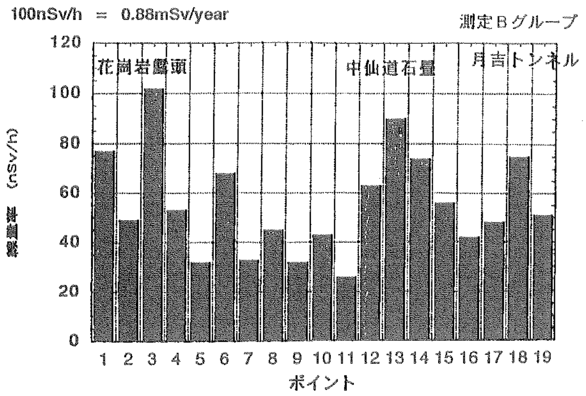


図1 土岐地区環境放射線測定結果　補正なし

6 可搬型測定器(Ar電離箱, Ge, NaIとTLD)による巡回測定
簡易線量計「はかるくん」による移動測定



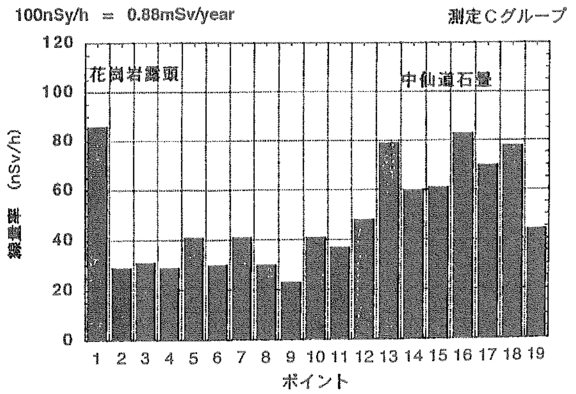
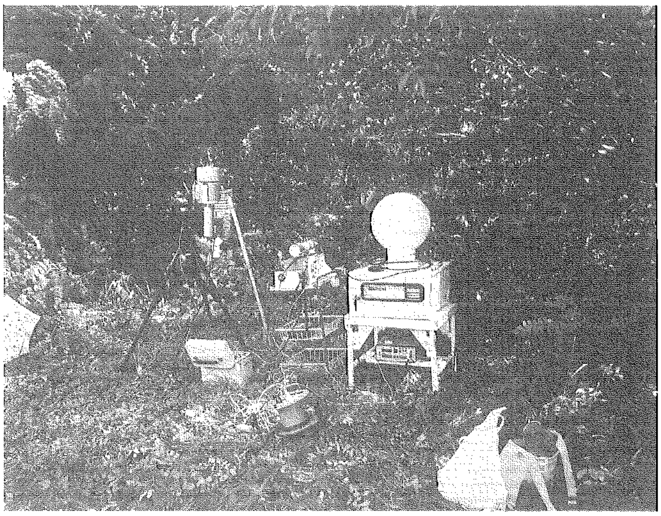
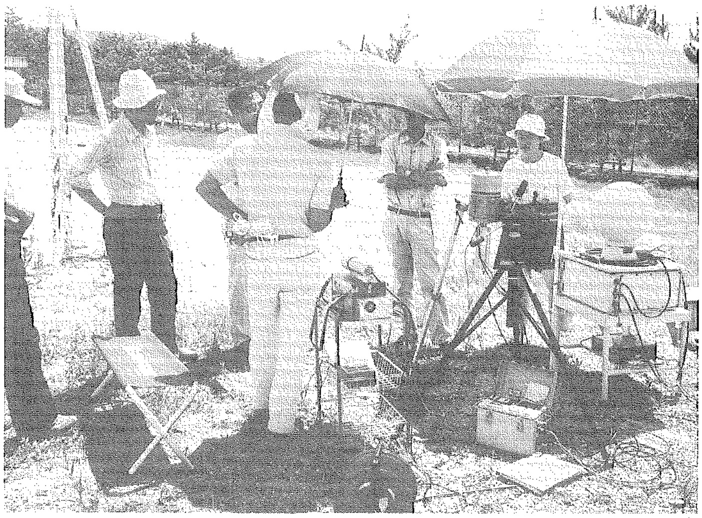
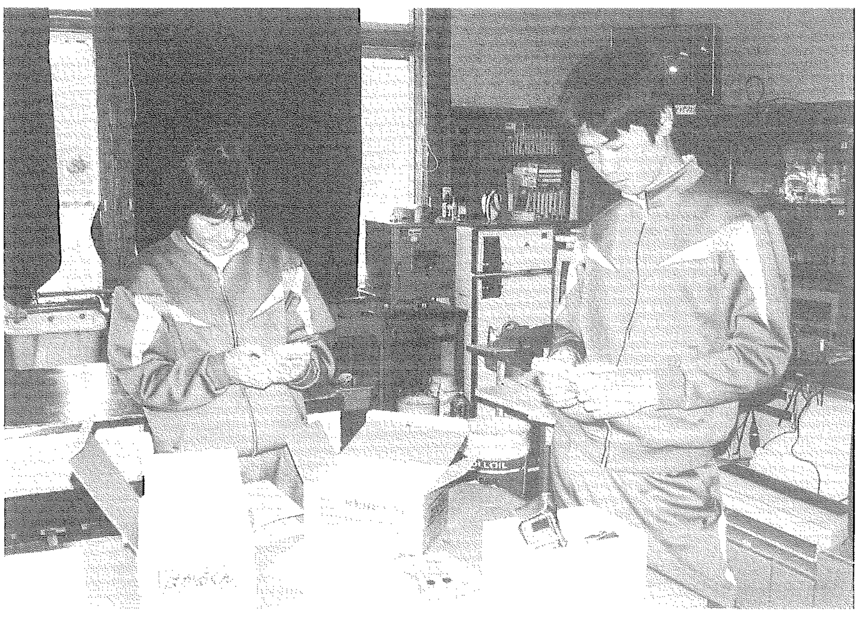


図2 簡易線量計「はかるくん」による移動測定結果





↑
【写真】可搬型測定器による巡回測定



【写真】「はかるくん」による移動測定

7 環境教育活動実践（中学校における実践）

（１）指導計画の概要（ねらい，タイムスケジュールなど）

	タイムスケジュール・活動項目	ねらいと活動内容
４月	○平成９年度活動計画の企画 ○理科環境研究グループの結成	・本年度の環境教育に関する活動計画と環境研究グループ゜を結成する。
５月	○ＪＣﾘﾊﾞｰﾈｯﾄﾜｰｸ(水生生物・水質調査に参加) ○選択理科の環境調査計画	・地域の環境活動として，積極的に参加する。選択理科をｸﾞﾙｰﾌﾟに加える。
６月	○環境研究の研究内容検討 ○ＪＣﾘﾊﾞｰﾈｯﾄﾜｰｸ環境サミットに参加	・環境研究の情報を収集する。 ・身近な環境問題を考える。
７月	○環境テーマ研究の計画と実施 ○環境テーマ研究の資料収集	・環境研究の具体的準備をはじめる。 ・環境研究に実際に取り組む。
８月	○環境テーマ研究の実施 ○実験・観察・調査・ファイルまとめ	・環境テーマ研究を通して，環境問題を考えたり，対応する力をつける。
９月	○インターネットホームページの開設 ○郡上郡科学作品展に出品	・学校のホームﾍﾟｰｼﾞを開設する。 ・郡科学作品展出品準備をする。
10月	○後期の活動計画　○鍾乳洞見学 ○全国小学校中学校環境教育賞参加	・鍾乳洞見学で，自然の大切さを学ぶ。 ・環境研究ｸﾞﾙｰﾌﾟの研究を応募する。
11月	○地域環境調査(酸性雨測定，気温，気圧など) ○ｲﾝﾀｰﾈｯﾄﾎｰﾑﾍﾟｰｼﾞに環境教育のページ開設	・秋から冬の環境調査し，季節の違いと環境について考える。
12月	○冬の環境調査（降雪，夏と冬との違いなど） ○環境に関する研究の情報発信，情報収集	・環境に関する研究をｲﾝﾀｰﾈｯﾄ上に載せ情報発信する。
１月	○降雪調査（雪の結晶，気温，積雪量，pHなど） ○ｲﾝﾀｰﾈｯﾄﾎｰﾑﾍﾟｰｼﾞの作成と活用	・冬の気候，雪に関する調査により，環境問題を考え，研究につなぐ。
２月	○理科環境研究冊子づくり ○環境調査・観察・実験のまとめ	・１年間のまとめとして，環境研究冊子の作成にとりかかる。
３月	○環境調査研究グループ１年間の総合まとめ ○環境研究冊子の完成と来年度の計画	・環境研究のまとめを作成する中で，研究を積み上げ来年度につなぐ。

（２）生徒の取り上げた，研究テーマとそのポイント

学年	研究テーマ	環境の視点	備考
1年生	合成洗剤が環境におよぼす影響	各種洗剤・小松菜・イースト菌・めだか	☆☆☆
1年生	私の鬼谷川の環境調査：水中の生物から	水生生物による川の環境調査	☆☆
1年生	デンプンの謎	デンプンの分解・体・環境との関連	☆☆
1年生	アリの生態と住みやすい環境	アリは，どんな環境で生活しているか	☆
1年生	はずみところがりに関する研究	運動エネルギー・エネルギーと環境	☆
2年生	身の回りの水の環境	西和良地区４ヵ所・名古屋ｐＨ・ＣＯＤの調査	☆
3年生	太陽エネルギーの利用	熱と光についてパソコン分析・クリーンな環境	☆☆☆
3年生	地中の保水性・吸水性の追究	水のモデル実験・森林環境問題への提言	☆☆
3年生	西和良の酸性雨	酸性雨の測定・自動車排気ガスへの実験分析	☆☆
3年生	木と水と自然について	木の役割・水の大切さ・環境を守る方法	☆☆
3年生	土の中の小動物	小動物の環境問題・どこにどんな生物がいるか	
3年生	西和良の天気	気象環境調査・標高さ（３００ｍ・温度変化）	

1年生	身の回りの水質調査	飲料水，川，生活に関わる水のpH，CODなどの調査	☆☆
1年生	川の生きものと住みやすい環境	地域の鬼谷川の水生生物を通して，環境を調べる	☆
1年生	光の進み方の不思議	光についての基礎実験を実施し，光の利用につなぐ	☆☆
1年生	自作プロペラの研究	さまざまな自作プロペラを作り，風力発電をめざす	☆☆☆☆
1年生	水の性質を探ろう	水の実験を通し，水の大切さについてまとめる	☆
1年生	色と太陽の光の関係を調べよう	様々な色と太陽熱の関係（温度上昇，燃え方など）	☆☆
2年生	生活排水が環境におよぼす影響	生活排水のおよぼす影響を調べ，浄化装置の開発	☆☆☆
2年生	熱エネルギーの利用	省エネルギーはどうあるべきか，実験でさぐる	☆☆☆☆
2年生	水質汚染と生物の関わり	水質汚濁を考え，浄化装置の開発と提言	☆☆☆
2年生	本当に消化は進んでいるのか	人体の環境：消化の原理と，消化の度合いの検討	☆☆☆
3年生	酸性雨が自然に与える影響	西和良に酸性雨が降っていることを測定実験で検証	☆☆
3年生	音の性質を調べ，騒音問題を考える	音をパソコンで実験，調査・騒音問題に対して提言	☆☆☆

学年	研究テーマ	環境の視点	備考
1年生	ゴミをよりよい環境で処理しよう	ゴミ（ゴミの分別，処理，自然の戻す）の処理の仕方	☆☆
1年生	生活排水をよりよい環境にしよう	生活排水や水の性質，雨の性質を調べる。よりよい環境	☆
1年生	鍾乳洞と環境	地域の鍾乳洞を観察，調査と環境(気温，水，大気の状態)	☆
1年生	生活用品の処理の仕方	生活用品をどう処理したらよいか，大気汚染と環境	☆
2年生	つりと川の環境	自然な川と人間の手の入った川を比較し，つりとの関係	☆
2年生	自然エネルギーの活用	自然のエネルギー太陽光発電と風力発電について	☆☆☆
2年生	水を汚さずにどれだけ生活できるか	よごれがとれ方，洗剤，洗剤なし，アクリルたわしの効果	☆☆
3年生	廃棄物処理の環境におよぼす影響	廃棄物を燃やした時，人体や植物におよぼす影響	☆☆
3年生	人間はどれだけ省エネができるか	生活エネルギー節約(ｴﾈﾙｷﾞｰﾀﾞｲｴｯﾄ，CO2ﾀﾞｲｴｯﾄ)と省エネ	☆☆☆
3年生	生活排水の浄化とよりよい環境を求めて	自作浄化装置の効果，水質汚濁と生物との関わり	☆☆☆☆
3年生	人間の五感と人間生活の環境	五感(視覚，聴覚，味覚，嗅覚，皮膚感覚)について	☆☆

備考：作品展→ ☆☆☆☆最優秀賞（中日賞）(県出品)　☆☆☆優秀賞（中日賞）　☆☆優良賞　☆努力賞

（３）環境教育に関する具体的実践

①選択理科における環境教育

《気象観測調査，酸性雨調査》

○理科実験を環境問題と結び付けながら活動する。

○パソコンを活用した，実験・観測などの方法を取得する。

ｲﾝﾀｰﾈｯﾄによる観測に参加

②サンパークランド美山鍾乳洞の見学（３年生：理科授業）

○地域（八幡町美山）にある，郡上八幡サンパークランド美山鍾乳洞の見学を，理科環境学習として実施した。(関連単元：大地の変化)

③ＪＣリバーネットワーク水生生物・水質調査，環境サミットに積極的参加（２０名）

○ＪＣリバーネットワークの意味を理解させ，自発的に参加できるようにした。

○水生生物調査を環境学習，理科環境研究につなぐように助言した

④簡易線量計「はかるくん」による放射線の測定

○「はかるくん」を利用して,学校を中心に地域の放射線を調べた。

⑤リサイクル用品の作製（２年生：技術，選択技術）→郡上郡創意工夫展に出品

○「手軽にできるリサイクル用品」を，ペットボトルや牛乳パックを利用して作製した。

・環境にやさしい。費用￥０。実用的。

（４）地域・他機関と連携した実践の場合は連携の仕方

○水生生物・水質調査，環境サミット（郡上青年会議所主催の事業に参加）

○鍾乳洞見学（校区内：サンパークランド美山鍾乳洞との連携参加）

（５）現在までの成果

○理科環境テーマ研究の実施と郡上郡科学作品展に出品参加

・科学作品展（環境と結び付けたテーマ研究をまとめる。継続研究）

○郡上八幡ｻﾝﾊﾟｰｸﾗﾝﾄﾞ美山鍾乳洞の見学・観察と感想文の交流

○JCﾘﾊﾞｰﾈｯﾄﾜｰｸ水生生物調査，環境サミットに参加，環境テーマ研究との連携

○インターネットホームﾍﾟｰｼﾞ開設，環境教育のページの作成

○選択理科における酸性雨測定

（６）今後の課題

○実地資料やデーターに基づく，地域の自然・環境調査地図の作成を検討していく。

○環境学習を盛り込んだ授業のあり方について検討し，授業実践を深めていく。

○放射線測定や酸性雨の測定など，環境調査研究を年間通して継続していく必要がある。

○　インターネットなどで情報収集や情報発信，メール交換などを押し進める。

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JAERI-Conf 99-011

3.11 大気吸入式正負イオン密度測定器について

薩谷　泰資（イオン情報研究所・神戸電波株式会社）
戸谷　佳武（神戸電波株式会社）

1. はじめに

現在放射線、放射能関係の測定器による測定データーは、それらの強度により環境大気中に生成されるイオン密度（正イオン、負イオン）が正確に測定されていない。

今回は放射線強度に対する小イオン（電気移動度、0.4cm^2／V・sec以上）の正イオン密度、負イオン密度の変化を測定したので報告する。

2. 測定方法

放射線を測定する測定器としては（財）放射線計測協会が貸し出している「はかるくん」を使用した。

その強度変化に対する小イオン密度は開発商品化されている大気吸入式のKST－900型で測定した。

放射線強度を変化させる試料としては放射線を放出する直径約10mm程度のセラミックボールを使用。

測定場所は鉄筋5階建の3階の室内（温度約22℃、湿度約43％）である。

3. 測定結果

a). 室内における放射線強度と正負イオン密度の測定

b). セラミックボール1個の放射線強度と正負イオン密度の測定

c). セラミックボール3個の放射線強度と正負イオン密度の測定

d). セラミックボール7個の放射線強度と正負イオン密度の測定

以上の事例について測定したので、それらの結果の平均値を表1に示す。

表1. 放射線強度と生成正負イオン密度

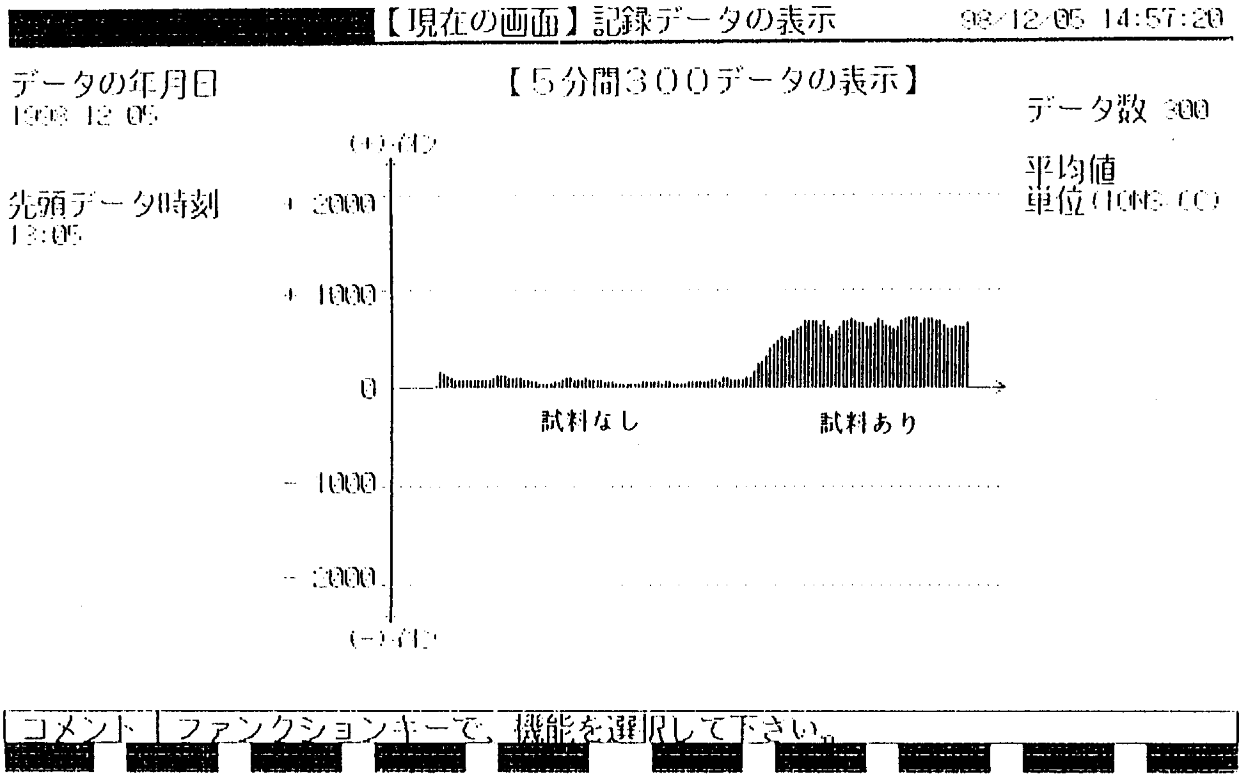
	放射線強度 (μ Sv／h)	小イオン密度 (コ／ml)		イオン比
		正	負	正／負
室内 a)	0.054	123	77	1.59
ボール1個 b)	0.300	415	361	1.14
ボール3個 c)	0.581	661	628	1.05
ボール7個 d)	0.924	1070	1045	1.02

図1は事例C). の正負イオン密度等の実測データ。表2, 表3はそれらの1秒毎のイオン密度である。

放射線強度に対する生成イオン密度は正負イオン密度共に増加するが、負イオン密度の方が多い。すなわちイオン比が1.59から1.02に変化している。一方放射線強度の増加割合よりも生成イオン密度増加は小さい。

4. おわりに

放射線強度変化による環境大気中に生成される小イオンにおける正イオン密度、負イオン密度変化を測定した。このようなイオン密度変化が「低線量放射線の健康への影響」の研究に役立ば幸いである。



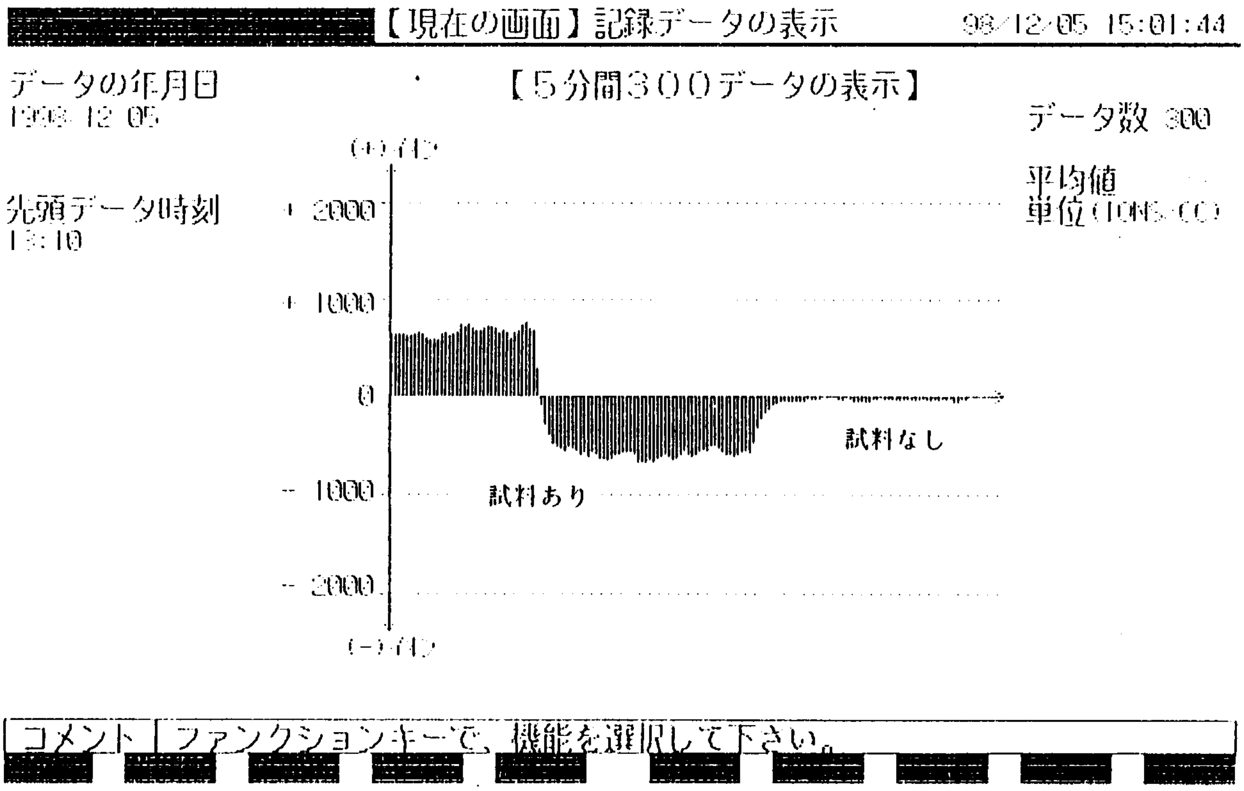


図 1.　事例C). の正負イオン密度等の実測データ

表2. 事例C). の1秒毎の正イオン密度等

イオンデータ（単位 IONS/CC)
1998/12/05 13:05

(+) - 1	(+) - 1	(+) - 1	(+) - 1	(+) + 0	(+) - 1
(+) - 1	(+) + 1	(+) - 1	(+) - 1	(+) - 1	(+) + 0
(+) + 0	(+) + 0	(+) + 1	(+) + 0	(+) + 0	(+) + 0
(+) - 1	(+) + 0	(+) - 1	(+) + 1	(+) + 20	(+) + 141
(+) + 167	(+) + 158	(+) + 147	(+) + 138	(+) + 136	(+) + 127
(+) + 116	(+) + 104	(+) + 98	(+) + 96	(+) + 91	(+) + 87
(+) + 84	(+) + 86	(+) + 83	(+) + 83	(+) + 81	(+) + 83
(+) + 92	(+) + 95	(+) + 97	(+) + 93	(+) + 87	(+) + 86
(+) + 89	(+) + 96	(+) + 96	(+) + 98	(+) + 102	(+) + 106
(+) + 123	(+) + 142	(+) + 136	(+) + 123	(+) + 120	(+) + 123
(+) + 118	(+) + 108	(+) + 106	(+) + 105	(+) + 107	(+) + 107
(+) + 110	(+) + 102	(+) + 93	(+) + 91	(+) + 81	(+) + 80
(+) + 78	(+) + 72	(+) + 67	(+) + 62	(+) + 59	(+) + 50
(+) + 54	(+) + 52	(+) + 54	(+) + 50	(+) + 58	(+) + 68
(+) + 71	(+) + 74	(+) + 76	(+) + 76	(+) + 86	(+) + 96
(+) + 109	(+) + 108	(+) + 102	(+) + 99	(+) + 92	(+) + 87
(+) + 87	(+) + 93	(+) + 98	(+) + 102	(+) + 101	(+) + 96
(+) + 87	(+) + 87	(+) + 86	(+) + 84	(+) + 82	(+) + 81
(+) + 80	(+) + 73	(+) + 76	(+) + 73	(+) + 70	(+) + 67
(+) + 63	(+) + 59	(+) + 54	(+) + 52	(+) + 52	(+) + 44
(+) + 44	(+) + 44	(+) + 44	(+) + 44	(+) + 48	(+) + 40
(+) + 40	(+) + 48	(+) + 50	(+) + 58	(+) + 62	(+) + 65
(+) + 68	(+) + 74	(+) + 68	(+) + 65	(+) + 63	(+) + 63
(+) + 60	(+) + 56	(+) + 54	(+) + 56	(+) + 60	(+) + 60
(+) + 61	(+) + 64	(+) + 58	(+) + 54	(+) + 54	(+) + 52
(+) + 52	(+) + 50	(+) + 56	(+) + 59	(+) + 66	(+) + 68
(+) + 71	(+) + 75	(+) + 72	(+) + 68	(+) + 64	(+) + 64
(+) + 63	(+) + 67	(+) + 72	(+) + 86	(+) + 88	(+) + 86
(+) + 84	(+) + 80	(+) + 79	(+) + 100	(+) + 110	(+) + 104
(+) + 103	(+) + 97	(+) + 89	(+) + 87	(+) + 87	(+) + 88
(+) + 92	(+) + 92	(+) + 97	(+) + 103	(+) + 106	(+) + 102
(+) + 109	(+) + 123	(+) + 172	(+) + 223	(+) + 247	(+) + 262
(+) + 277	(+) + 297	(+) + 327	(+) + 367	(+) + 408	(+) + 436
(+) + 444	(+) + 458	(+) + 497	(+) + 529	(+) + 536	(+) + 518
(+) + 505	(+) + 516	(+) + 533	(+) + 553	(+) + 582	(+) + 607
(+) + 606	(+) + 605	(+) + 622	(+) + 658	(+) + 696	(+) + 701
(+) + 683	(+) + 691	(+) + 699	(+) + 698	(+) + 696	(+) + 677
(+) + 658	(+) + 682	(+) + 688	(+) + 659	(+) + 627	(+) + 577
(+) + 549	(+) + 573	(+) + 587	(+) + 598	(+) + 630	(+) + 657
(+) + 686	(+) + 680	(+) + 693	(+) + 719	(+) + 703	(+) + 708
(+) + 691	(+) + 669	(+) + 673	(+) + 667	(+) + 665	(+) + 653
(+) + 622	(+) + 601	(+) + 632	(+) + 651	(+) + 666	(+) + 701
(+) + 714	(+) + 706	(+) + 690	(+) + 679	(+) + 656	(+) + 630
(+) + 623	(+) + 624	(+) + 618	(+) + 610	(+) + 636	(+) + 656
(+) + 686	(+) + 718	(+) + 712	(+) + 728	(+) + 733	(+) + 718
(+) + 739	(+) + 747	(+) + 739	(+) + 708	(+) + 677	(+) + 690
(+) + 708	(+) + 719	(+) + 717	(+) + 708	(+) + 701	(+) + 696
(+) + 694	(+) + 690	(+) + 682	(+) + 663	(+) + 646	(+) + 624
(+) + 607	(+) + 601	(+) + 607	(+) + 630	(+) + 635	(+) + 657
(+) + 634	(+) + 623	(+) + 623	(+) + 648	(+) + 670	(+) + 647

時間 ———→

表3. 事例C). の1秒毎の正負イオン密度等

イオンデータ（単位 IONS/CC)
1998/12/05 13:10

(+) +	653	(+) +	657	(+) +	651	(+) +	641	(+) +	643	(+) +	651
(+) +	653	(+) +	644	(+) +	630	(+) +	609	(+) +	624	(+) +	634
(+) +	640	(+) +	637	(+) +	666	(+) +	658	(+) +	646	(+) +	631
(+) +	609	(+) +	598	(+) +	599	(+) +	600	(+) +	596	(+) +	599
(+) +	596	(+) +	592	(+) +	642	(+) +	663	(+) +	667	(+) +	643
(+) +	630	(+) +	644	(+) +	659	(+) +	651	(+) +	669	(+) +	711
(+) +	746	(+) +	730	(+) +	731	(+) +	733	(+) +	748	(+) +	732
(+) +	708	(+) +	694	(+) +	687	(+) +	693	(+) +	694	(+) +	698
(+) +	716	(+) +	727	(+) +	727	(+) +	732	(+) +	726	(+) +	717
(+) +	703	(+) +	692	(+) +	678	(+) +	687	(+) +	689	(+) +	673
(+) +	666	(+) +	632	(+) +	608	(+) +	640	(+) +	667	(+) +	690
(+) +	686	(+) +	711	(+) +	750	(+) +	777	(+) +	761	(+) +	738
(+) +	718	(+) +	713	(+) +	698	(+) +	686	(-) +	292	(-) +	53
(-) -	108	(-) -	218	(-) -	300	(-) -	362	(-) -	411	(-) -	461
(-) -	504	(-) -	522	(-) -	530	(-) -	529	(-) -	541	(-) -	558
(-) -	565	(-) -	545	(-) -	534	(-) -	533	(-) -	548	(-) -	542
(-) -	565	(-) -	593	(-) -	600	(-) -	601	(-) -	599	(-) -	621
(-) -	629	(-) -	616	(-) -	581	(-) -	571	(-) -	601	(-) -	631
(-) -	652	(-) -	670	(-) -	654	(-) -	647	(-) -	669	(-) -	659
(-) -	649	(-) -	629	(-) -	612	(-) -	608	(-) -	609	(-) -	595
(-) -	595	(-) -	590	(-) -	590	(-) -	595	(-) -	585	(-) -	587
(-) -	609	(-) -	654	(-) -	683	(-) -	681	(-) -	686	(-) -	695
(-) -	695	(-) -	687	(-) -	679	(-) -	674	(-) -	683	(-) -	684
(-) -	659	(-) -	644	(-) -	631	(-) -	621	(-) -	608	(-) -	605
(-) -	635	(-) -	652	(-) -	660	(-) -	658	(-) -	654	(-) -	622
(-) -	604	(-) -	585	(-) -	570	(-) -	587	(-) -	614	(-) -	633
(-) -	630	(-) -	606	(-) -	602	(-) -	596	(-) -	587	(-) -	570
(-) -	564	(-) -	574	(-) -	564	(-) -	534	(-) -	537	(-) -	536
(-) -	529	(-) -	528	(-) -	548	(-) -	581	(-) -	598	(-) -	600
(-) -	606	(-) -	603	(-) -	600	(-) -	610	(-) -	628	(-) -	621
(-) -	611	(-) -	603	(-) -	586	(-) -	571	(-) -	563	(-) -	587
(-) -	596	(-) -	569	(-) -	494	(-) -	423	(-) -	355	(-) -	296
(-) -	251	(-) -	214	(-) -	188	(-) -	170	(-) -	148	(-) -	127
(-) -	113	(-) -	104	(-) -	93	(-) -	85	(-) -	79	(-) -	74
(-) -	70	(-) -	65	(-) -	62	(-) -	61	(-) -	65	(-) -	67
(-) -	66	(-) -	68	(-) -	61	(-) -	64	(-) -	61	(-) -	61
(-) -	54	(-) -	50	(-) -	54	(-) -	58	(-) -	54	(-) -	48
(-) -	42	(-) -	38	(-) -	38	(-) -	38	(-) -	36	(-) -	36
(-) -	38	(-) -	36	(-) -	35	(-) -	33	(-) -	42	(-) -	48
(-) -	46	(-) -	40	(-) -	36	(-) -	38	(-) -	46	(-) -	54
(-) -	62	(-) -	61	(-) -	62	(-) -	65	(-) -	70	(-) -	69
(-) -	66	(-) -	64	(-) -	62	(-) -	61	(-) -	56	(-) -	52
(-) -	46	(-) -	42	(-) -	38	(-) -	40	(-) -	42	(-) -	50
(-) -	46	(-) -	48	(-) -	54	(-) -	60	(-) -	50	(-) -	46
(-) -	54	(-) -	52	(-) -	50	(-) -	48	(-) -	48	(-) -	48
(-) -	46	(-) -	42	(-) -	46	(-) -	46	(-) -	48	(-) -	50
(-) -	54	(-) -	60	(-) -	59	(-) -	56	(-) -	52	(-) -	52
(-) -	50	(-) -	42	(-) -	44	(-) -	46	(-) -	42	(-) -	44
(-) -	44	(-) -	48	(-) -	50	(-) -	62	(-) -	64	(-) -	64
(-) -	69	(-) -	65	(-) -	58	(-) -	50	(-) -	42	(-) -	38

時間 ——————▷

3.12 高校現場における放射線教育の実験事例と実情の報告

宮澤　弘二

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要趣

現行の高校教育課程の中で、今後、国民的なレベルで必要とされる放射線教育が現場の理科教育で実践する状況にはほとんどない。高校生の物理の履修率が20%にも届かない現状にあって、物理離れとともに理科離れが進んでいる。本校では1996年より選択履修で文系に大学進学する生徒にとっても、より理解しやすく、また、実験中心に進める講座として自然科学実験講座という名称で物理、化学、生物、地学を含めた総合講座の形式で開講した。1998年には高校２年と高校３年にそれぞれ２講座ずつ設けられている。この講座のカリキュラムの中に放射線教育を取り入れて実践した内容を紹介します。

1．はじめに

私たち身の回りには沢山の放射線がある。放射線というと生徒に危険な物というイメージが強い。わが国は原子爆弾の世界最初の被爆国である。生徒にとって放射線教育はいろいろな問題を含んでいる。しかし、昔から自然の放射線は存在していたのである。自然に存在する放射線のことをバックグラウンド放射線と呼び、次の２つに大別している。１つは、宇宙線と言われ空から降り注いでくる。その発生源は太陽であったり、宇宙に存在する他の天体からのものであろうと推定されてる。もう１つは、地球に存在しているもので、地面の中にあるウランやトリウム、ラドンなどをごくわずかに含む鉱物から出る放射線、植物や建物にある放射性物質から出る自然の放射線などがある。

このような自然の放射線に対して人工的な放射線がある。それは１９世紀の終り頃、ドイツの科学者レントンゲンによって発見されたＸ線や、原子炉などで作られる各種の放射線同位元素（ラジオアイソトープ）、原子爆弾や水素爆弾による各種の放射性物質など、人間が作り出したものである。こうした人工的に作り出された放射線は、身体にとって危険性が多いので取扱いには十分な注意が必要である。しかし、これらの人口放射線も科学的に安全に取り扱えば私たちの日常生活の中で有効に活用されるものもある。例えば医療用に使用したり、新しい製品開発のためにβ線などが使用されている。もちろん、発電にも原子力発電が使用されており、様々な課題を含みながらも原子力発電に依存しなければならない現状である。

こうした身近な放射線について、科学的に正しく理解することが重要であり、下記に示すような実践事例を紹介する。

2．授業活動のねらい

自然放射線の科学的な理解を深め、放射線そのものが身の回りに存在することを認識させる。高校理科教育の自然科学実験の授業のねらいとして下記のような放射線教育の目標を立てた。

①私たちの身の回りにある自然放射線を簡易放射線探知機や、簡易型霧箱を用いて、α線、β線、γ線などを観察し、その違いについて観察する。自然放射線にはいろいろな種類があることを理解する。

②放射線探知機と電子線計測器とを組み合わせて、自然の放射線の定量測定をすることにより、日常的に放射線が飛来していることを認識する。

③放射能、放射線、放射線量などの用語を正確に理解する。

④放射性元素がα崩壊、β崩壊を繰り返して一定の周期で質量が半減されていく現象を模擬実験で検証する。

⑤人工放射線の実験例として、ソフテックス（軟X線装置）用いて生徒の持ち物などをX線撮影する。X線の透過力の強いことの危険性について認識し、放射線の実験で被爆した研究者の写真や、広島、長崎などに原子爆弾が投下された写真などを観察し、人口放射線のに対する認識を科学的に正確に理解させる。

以上の実験や観察を実施することにより、放射線の科学的な理解と認識を深めるとともに原子力利用の実情などを紹介する。放射線は危険なものであり、しかし、扱い方によっては安全であり、人類にとって今後、研究し、開発していかなければならない大きな課題であることを認識する。

3．実験方法と事例

(1).私たちの身の回りにある自然放射能探知機と実験用簡易放射線源セットを用いて、放射線を観測する。市販されている実験用簡易放射線源セットは、次のようなものがある。

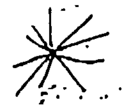
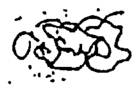
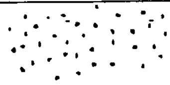
ポロニウム（Ｐｏ－210）α線、0.1 μＣｉ、半減期138 日、ストロンチュウム（Ｓｒ－90）β線、0.1 μＣｉ、半減期28.6年、コバルト（Ｃｏ－60）γ線、0.1 μＣｉ、半減期5.27年などがありプラスチックケース入りで取扱い免許の必要はないとされている。

①．簡易放射線探知機を使用して自然放射線を測定し、下記の表に記入する。ただし、飛行機などの測定は、その様な機会があった時に測定する。

＜バックグラウンド放射線の測定結果＞

測定場所	μＳv／10min（放射線カウント数）					
	1回	2回	3回	4回	5回	平均
屋　内						
ｺﾝｸﾘｰﾄ建物						
木造建築						
トンネル内						
池、湖、海						
飛行機						

また、簡易型霧箱を用いて、α線、β線、γ線などを観察し、その違いについて観察する。自然放射線にはいろいろな種類があることを理解する。その違いは、下記の図のように霧箱の中で観察することができる。

放射線の種類	霧箱の飛跡の様子	飛跡の図	イオン化能力	透過能力
α線	たこ糸のように太く短い		大	小
β線	蜘蛛の糸のようで細く曲がっている		中	中
γ線	点状に広がる		小	大

②放射線探知機と電子線計測器とを組み合わせて、自然の放射線の定量測定をすることにより、日常的に放射線が飛来していることを認識する。

地学標本の岩石の中にウランの鉱石が数種類ある。これらを用いて測定する。ほかに上記に示した市販されている実験用簡易放射線源セットなどを用いて、放射線源を定量的にカウントする。単位時間当たりどれだけのカウントされたかをそれぞれについて表にまとめて考察をする。また、自然放射線の飛来してくるものをカウントしてその比較をする。

③放射能、放射線、放射線量などの用語を正確に理解する。下図のような絵をえがき、黒板用磁石で固定し、上記の用語を正確に理解する。

放射能、放射線、放射線量の違いと単位

左図のように放射能、放射線を光に例えると、放射線は光で、放射能は光を出す能力である。放射能をもつ物質が放射性物質で、光源に相当する。

〈放射線の単位〉

1．放射能（崩壊の強さ）：ベクレル（Bq）

1ベクレルは1秒間に1個の原子核が崩壊する放射能の強さ

1 Bq＝1 崩壊／秒　1 Ci＝3.7×10^{10}Bq

2．吸収線量（D）：グレイ（Gy）

物質 1 kgに、放射線によって与えられるエネルギーが1ジュールになる放射線の量

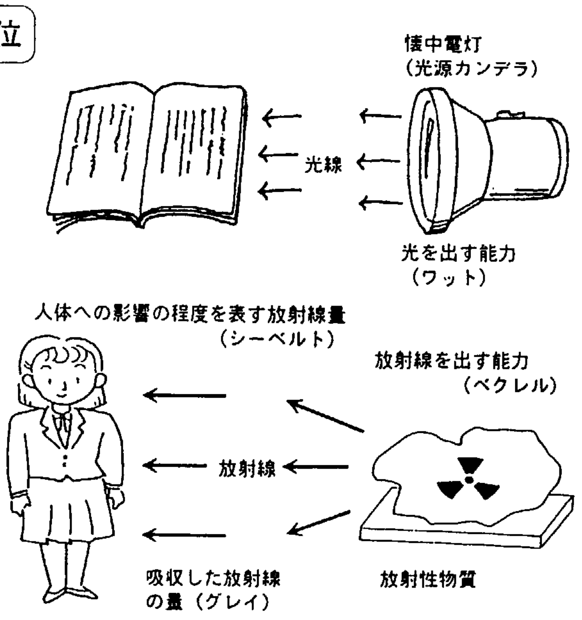
1 Gy＝1 J／kg＝100rad（ラド）

3．線量当量（H）：シーベルト（Sv）

放射線の吸収量に、人体に対する影響の現れ方を補正した線量

H＝D×Q　1 Sv＝100rem（レム）

Q：線質係数



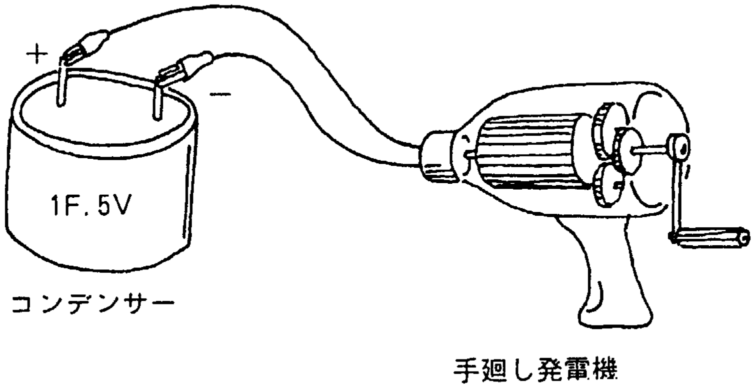
④放射性元素がα崩壊、β崩壊を繰り返して一定の周期で質量が半減されていく現象を模擬実験で検証する。

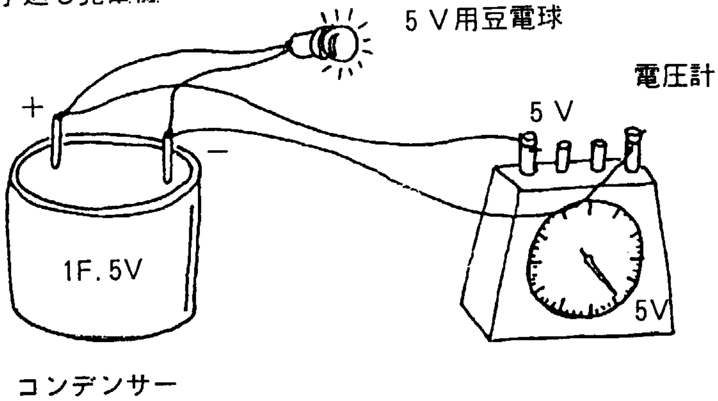
（ア）コンデンサー（容量、耐電圧それぞれ１Ｆ、５Ｖ）に、手巻き発電機を用いて、電圧、５Ｖまで充電する。

（イ）充電したコンデンサーに５Ｖ用豆電球を接続し、放電時間を１０秒間ずつとりこの時の降下電圧を測定してグラフにする。

（ウ）下図のようなグラフが描くことができる。これは放射性物質の質量の半減期の様子に似ていることから半減期の公式を検証することができる。

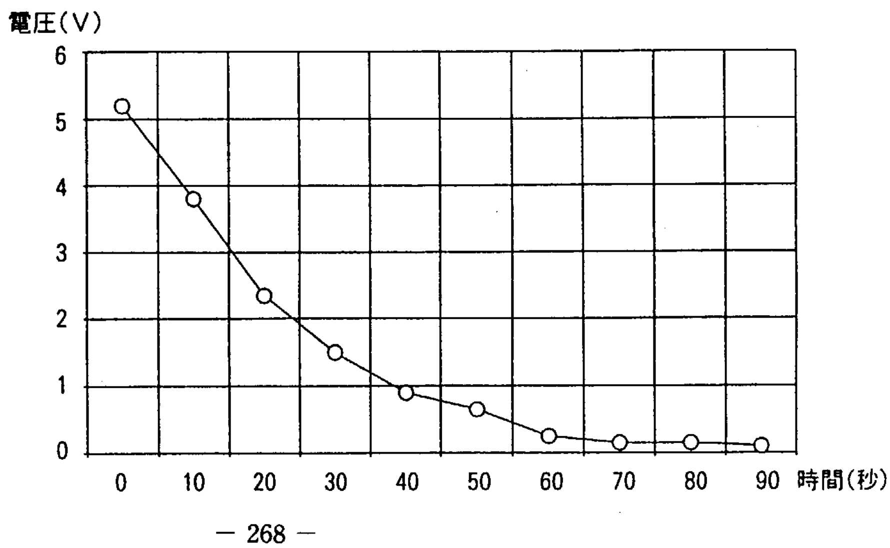
手廻し発電機による充電





コンデンサーに豆電球を接続した放電現象

放射性物質の半減期減少をコンデンサーの放電によって表わすグラフ



⑤人工放射線の実験例として、ソフテックス（軟X線装置）用いて生徒の持ち物などをX線撮影する。

（ア）ソフテックスX線照射口の下5㎝のところに、大きさ3㎝×4㎝の歯科用のデンタルフィルムを不透明なビニール袋に封入されたまま、白い面を上に向けて置く。

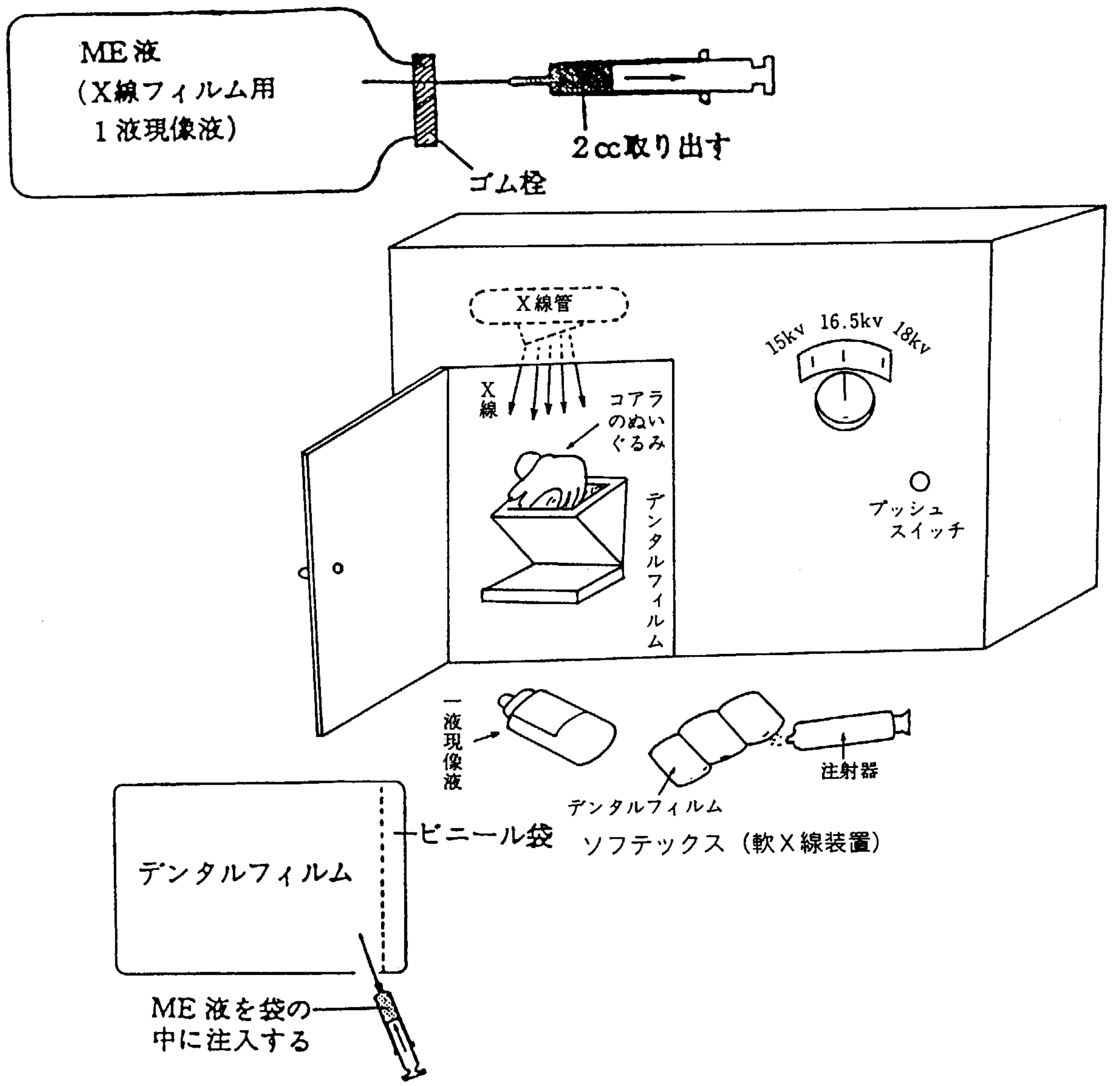
（イ）そのフィルムの上に、例えば生徒の持ち物のコアラの人形など載せ、取りだし口を閉める。これでX線を照射しても漏れることはない。

（ウ）プッシュスイッチを押してX線を5秒間照射し、照射後フィルムの入ったままのビニール袋を外に出す。

（エ）X線フィルム用1液を（ME液）の入ったポリ容器のゴム栓の中に注射器の針を差し込みME液を2ccほど取り出す。

（オ）X線を照射したデンタルフィルムのビニール袋の中に注射器の針を差し込み、2ccのME液を注入する。現像時間、1分後、はさみでビニールの端を切り取って、開封し、中のフィルムを取り出して水洗いする。

（カ）数分間水洗い後、風通しのよい所でフィルムを乾燥する。完成である。



４．実情報告

①．本校の場合、自然科学実験法という講座が選択科目で履修できるカリキュラムになっている。ここで放射線教育を６時間から８時間の時間帯で学習できる。

②．この実験・実習をとおして生徒は自然放射線の実態を体験することから、安全性について理解することができた。

３．将来、生徒たちにとって放射線に関する学問や実践の場で活動することに危険なイメージを拭うことができた。

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JP0050097

3 . 13 Natural Radioactivity Distribution Images and Their Educational Uses

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Distribution images of natural radioactivities in vegetables, meat and porcelain works were obtained by use of Imaging Plate with very high sensitivity to radiations. A brochure titled "Natural Radiations through Naked Eyes" was published in both Japanese and English which included the images mentioned above. In this paper, the method to obtain the distribution images of extremely low level natural radioactivity, the content of the brochure and the effect of it to the public are described.

1. Introduction

Potassium is always contained in living cells and it contains 0.0119% of radioactive potassium K-40 which emits beta-rays with the maximum energy of 1.33MeV. Although the radioactivity in food or meat is only 0.02-1Bq/g, if we use Imaging Plate (IP) [1] which was developed by Fuji Photo Film Co. Ltd. and has very high sensitivity of more than 100 times compared with conventional X-ray films it might be possible to obtain the images of the natural radioactivity distribution. If so, we thought that such images would be effective to let the public understand through their eyes that radioactivity and radiations are naturally present even in food or in our own bodies. This was the beginning of this work.

Rough estimation revealed that almost one month would be necessary to obtain the distribution images of natural radiations from vegetables, meat etc. in a shielding box for the reduction of background radiations. We finally obtained some new images [2,3,4] of vegetables, meat, porcelain wares, glass wares etc.

Then we published a brochure titled "Natural Radiations through Naked Eyes" including the new images and have distributed them in public meetings.

2. Reduction of natural background radiations

Since the radioactivity contents in vegetables and meat are almost same or sometimes smaller than those in environmental natural materials, it is necessary to reduce background radiation intensity to obtain the images. Figure 1 shows the background radiation intensity as a function of a thickness of the wall of a shielding box measured with IP by exposing it for 10 hours in the box. A lead box or iron box whose inner side was lined with Cd 1mm, Cu 1mm, and acrylic resin 1cm, so to speak a graded shielding box, showed a reduction of background radiations to about 1/30 [5].

3. Specimen exposure, image reading and radioactivity determination

The exposure time of vegetables and meat on IP in the shielding box is very long over about one month. We had to antisepticize such specimens to prevent from rotting. The specimens were

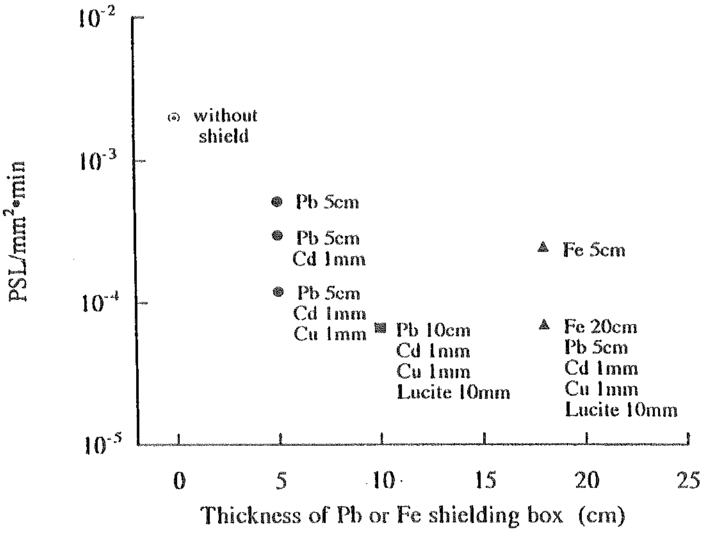

Fig.1 Reduction of background radiations with shielding box

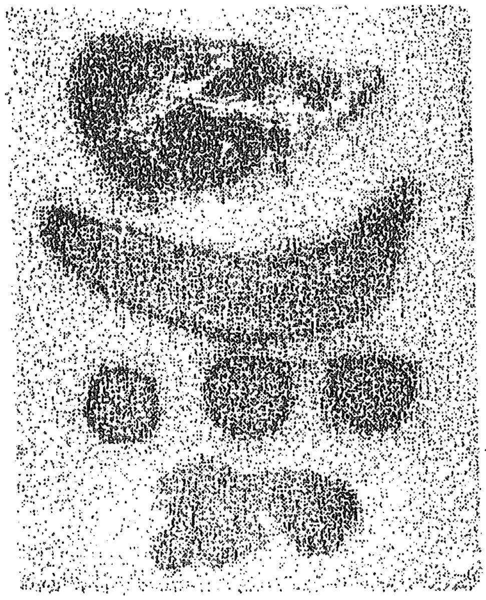

Fig.2 Radioactivity distribution images of pork, banana and ginger

wrapped up with a thin polythene film. After the exposure, the IP must be quickly read out, otherwise the accumulation of background radiations deteriorates the image clarity.

Figure 2 shows the natural radioactivity images of pork, banana and ginger. It can be seen that the part of fat in pork does not show radiation intensity. In the case of vegetables and meat, the contribution of radionuclide to making images is K-40 and the contribution of other nuclides such as C-14 and H-3 is less than 1% because of their low energy beta-rays and low concentration.

Figure 3 shows natural radioactivity distribution images of three pairs of glasses. The radiation intensity largely depends on the difference of glass material. The intensity from the glasses shown at the bottom in the figure was estimated by calculation that they will bring radiation exposure dose to the eyes wearing them about 2-3mSv/y, which is very small and included in the difference of background radiation intensities depending on the district.

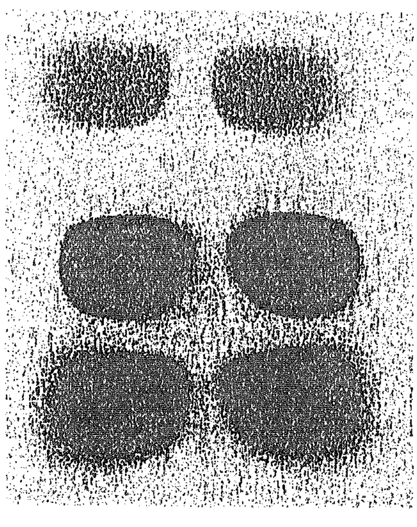

Fig.3 Radioactivity distribution images of glasses

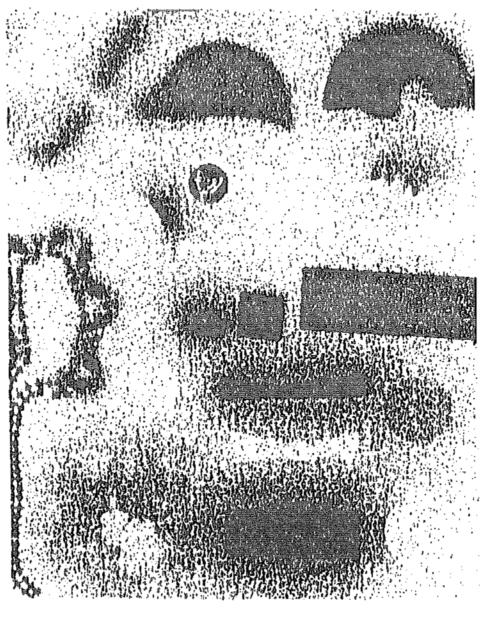

Fig.4 Radioactivity distribution images of personal ornaments made of glass and ceramics

Figure 4 shows some images of personal ornaments. Some brooches made of porcelain and some others including necklace made of glass contain some amount of radioactivity of mainly K-40 and of small amount of other nuclides in uranium and thorium series.

A known weight of KCl was dissolved in distilled water. The amount of K-40 was determined from the natural abundance (0.0119%) of K-40. The solution was poured into a vessel and put on a high purity Ge detector in a graded shielding box. The gamma-ray energy spectrum was obtained. Vegetables was then ground and the same amount of it to the KCl solution was put into the vessel. The intensity of gamma-rays (1.46MeV) from K-40 in the vegetable was compared with that of KCl and K-40 radioactivities were determined as shown in Fig.5 which coincides with published data [6].

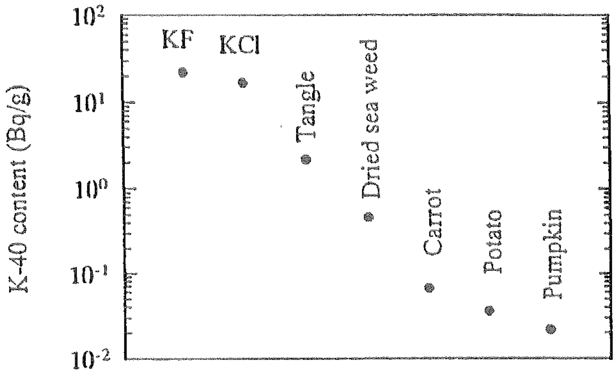

Fig.5 Radioactivities contained in some specimens measured with HP Ge detector

3. Publication of brochures

Since we obtained some new images of natural radioisotope distributions, we considered that they might be helpful to visually inform the figure of the nature as it is to the public. We prepared a brochure [7] as shown in Fig. 6 which includes various natural radiation images: natural radioactivity images of vegetables as shown in the cover paper, Prof. Roentgen's X-ray images although X-rays are not natural ones, Prof. Becqerel's gamma- and beta-ray image from uranium ore, polar light caused by cosmic radiations, Sun's flare caused by nuclear fusion, traces of radiations in stones, paths of radiations in cloud chamber, Cerencov radiation, natural radioactivity distribution images of porcelain paint, etc. Both Japanese and English versions were published. They have been used for three years in public meetings and sometimes in radiation education classes for high school students and even in university students. English version was distributed in foreign countries, Canada, Australia, USA, Korea and other countries.

Fig.6 Cover page of the brochure showing lotus root, sweet potato, potato, ginger and pumpkin. The title of English version is "Natural Radiations through Naked Eyes"

Another brochure titled "Environmental radiations through figures" was published in Japanese, which also has been widely distributed. When we use these brochures with explanation on the content, we sometimes make inquiries about the effect of the brochures. Most of the audience reply that they had rather strong impression on the images of natural radioactivity in food and consequently in their own bodies.

4. Conclusion

The images of the distribution of natural radioactivity in vegetables, meat etc. were first obtained in the world by using Imaging Plate. Brochures including them were published and widely distributed in public meetings or school classes. Fairly large proportion of the public people first understood that natural radioactivity was included in food and even their own bodies.

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JP0050098

3.14 40KVナロービームX線の吸収線量

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要旨

最近ナロウビームXγ線が放射線治療と診断に利用されている。そして、治療用には4MV以上の高エネルギーX線と^{60}Coγ線を使用し、診断用には150KV以下の低エネルギーX線が用いられている。しかし自由空気電離箱を線量標準とした平行ビーム光子の校正場の概念で構成されている照射線量体系ではナロービームの吸収線量測定は不能である。

われわれは、X線エネルギーを40KVに限定して、PMMA(PMMAはポリメチルメタクリレートの略号) 厚板ファントムを媒質に用いた零外挿式電離箱の一次元空洞の比電離電荷 q_n/dx とその分布特性から吸収線量の評価を試みた。

その結果、3mmφと300x300mmのコリメータを通過したナロービームとブロードビームのX線を比較すると、ナロービームの吸収線量はブロードビームに対してて0.336倍の値を示した。またこれらのX線ビームの分布特性は、いずれも正規分布に近似して比較することができた。また衝突阻止能との関係から一次元空洞:dx(cm)・S(cm^2)の吸収線量は特定した電子の飛程数:T_nとdE/dXρ^{-1}の積で表す事ができた。

1. はじめに

要旨でも述べた PMMA 厚板ファントムを媒質に指定したγ線用の零外挿式電離箱が開発[1]されている。基本的にβ線の吸収線量測定器と同じであるが、β線用の測定器は人体胴部を想定したファントム効果が小さくγ線吸収線量の評価には不適当と考えられている。一般に用いられている軸長:Lと直径:D_Cで電離容積:V_Cが決まる円筒形電離箱の電離電荷量はV_Pに比例するが、二次電子の放射体としての壁:W_Cの面積とは比例関係をもたない。これが単位容積(V_P/cm^3)当たりの電離電荷量:q_Eにのみ注目する照射線量:Xの概念である。

吸収線量:D_d は光子の相互作用で生成する壁:W_Pの転換電子e_Kと散乱電子e_Sとの電離:e_{KS}の単位質量当たりのエネルギー量:J_d/gに注目するから、e_{KS}の電離電荷:q_n はW_Pの面積Sと電離容積:V_P に比例関係係を持つ平面空洞が必要になる。

比電離電荷:q_n/dxを求める零外挿式電離箱は入射媒質に正対する集電極面積:S(cm^2)までの長さ:dx(cm)を変数として電離容積:V(cm^3)が決まる(1)式の1項が示す一元空洞:dx・Sである。図1.参照

いま入射媒質から集電極に向って通過するe_{KS}が一様な分布で放出されていれば、一次元空洞の電離電荷:q_nは平坦分布を示す。このエネルギー吸収量は(1)式の2項からJ_d(erg/g)で表される。

$$J_d = \frac{q_n(C)}{dx(cm)\cdot S(cm^2)} \times \frac{33.97(eV)\times 1.59\cdot 10^{-12}(erg/eV)}{1.293\cdot 10^{-3}(g\cdot cm^{-3})\times 1.602\cdot 10^{-19}(C)} \text{------}(1)$$

入射媒質の厚さ:dを指定した吸収線量:D_d(Gy)は$J_d\cdot 10^4$を媒質:PMMAの阻止能比:$_GS_M$で補正すれば決まる。最近、^{137}Csと$^{60}Co\gamma$線のe_Kの阻止能分布が零外挿式電離箱で測定[2)]された。この結果からq_n/dxを転換電子:e_Cの減速過程の電離:e_K と電離ポテンシャル:$\underline{I}$を越えるが飛程の短い散乱電子の電離:e_Sとの混在電離:e_{KS}の比電離電荷q_{KS}/dxと表せば電離の仕組みを更に詳述できる。

一次元空洞の電離電荷:q_Pが正規分布近似[3)]を示す照射断面積:A/S<Aのナロービーム X線では、J_dの検出に長さ:dxと集電極面積:Sを変数に必要とするが S が固定されているからJ_dが成立しない。そこでS の面積内に収まるq_Pの分布特性からエネルギー吸収量:J_Pを検出する方法を試みた。

2. 零外挿式電離箱とX線装置

X線装置と零外挿式電離箱の実験配置を図1. に示してある。ここでナロービームX線は3mmφX100mmのPbコリメータを通過して照射される。またブロードビームX線は300X300(mm)の照射野は可変絞りで決められている。Z軸の照射距離はX線装置の上下の移動によつて変えられる。このX線の出力条件は管電圧、管電流、照射時間の各々を40KV, 320mA, 100mSとした。

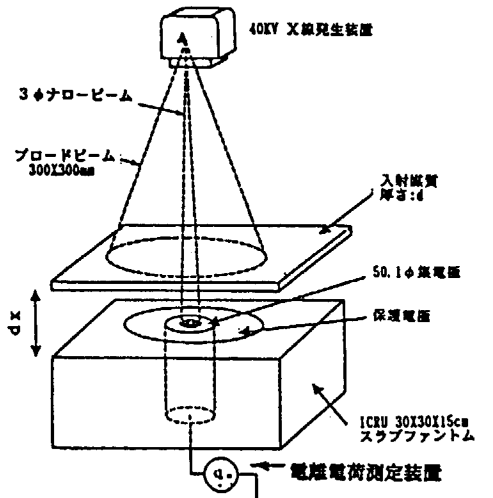

図1. 実験配置概要図

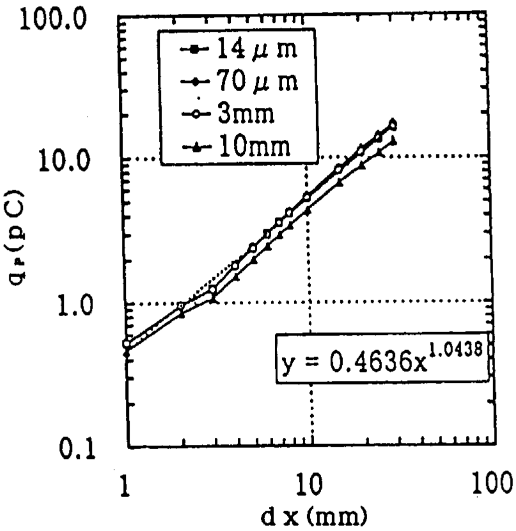

図2. ナロービーム電離電荷特性$q_P\cdot$dx

図1. に描かれた零外挿式電離箱は国際放射線単位・測定委員会(ICRU)が推奨する30X30X15(cm)のPMMA厚板ファントムで作られている。このファンムに支柱を介してグラファイトで導電化した最も薄い入射媒質(14μm厚さのPMMA)が正対して、厚板ファントム中央の50.5mmφ集電極と一次元空洞を構成している。そして目的とする媒質の厚さ:dはこの入射媒質の上に重ねて置かれる。また一次元空洞のdxは支柱の長さを変更して求める。この零外挿式電離箱は電離電荷:q_Pの分布特性を測定するためX線ビームの中心に位置するX-X'、Y-Y'の2 軸水平移動架台に据えられている。

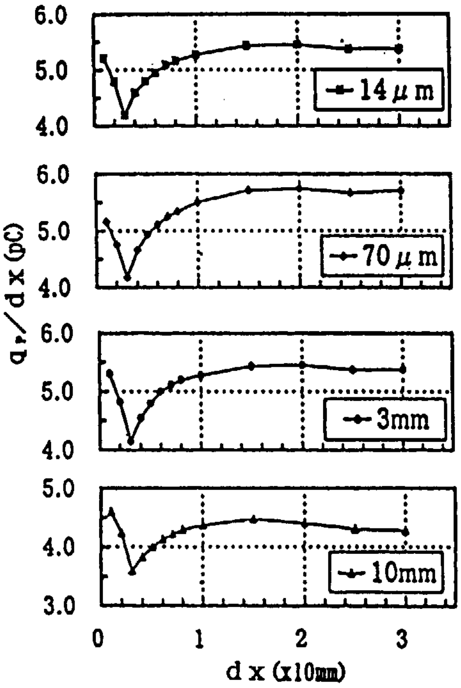

図3. 比電離電荷特性:Kqi

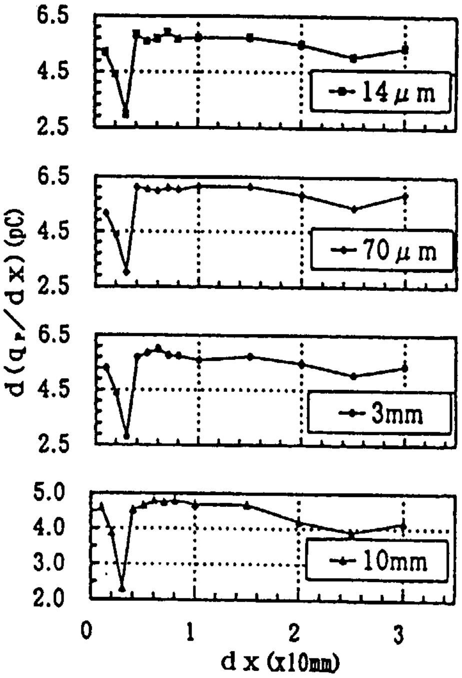

図4. 微分比電離電荷特性:Kqd

3. 比電離電荷測定

入射媒質の厚さ:d(厚さは各々14μm, 70μm, 3mm, 1cm)をパラメータに採り、dxを1mmから30mmまで変えて測定したナロービームの電離電荷特性:q_P・dxを図2. に示す。図3. にq_P/dxの比電離電荷特性:Kqiが示してある。このKq_iはdに拘らずdxが3mmで最小値を示すが、これは入射媒質が放出するe_{KS}のエネルギーが低くて、飛程の短いことに起因する。従ってq_P/dxの最大:q_iはdxの零外挿から求めるが、統計誤差の大きさが問題になる。dxが3mm以上になるとX線の光子が空気と相互作用を起こしている。ここでは信頼性の高いq_iが得られる。しかしKq_iの最小値を含む平均値であるから、$q_P+\Delta q_P$とq_P の差分の最大として $q_d=d(q_P/dx)$ を採る微分比電離電荷特性:Kq_dで修正すれば$q_i=q_d$の関係から信頼性は向上する。

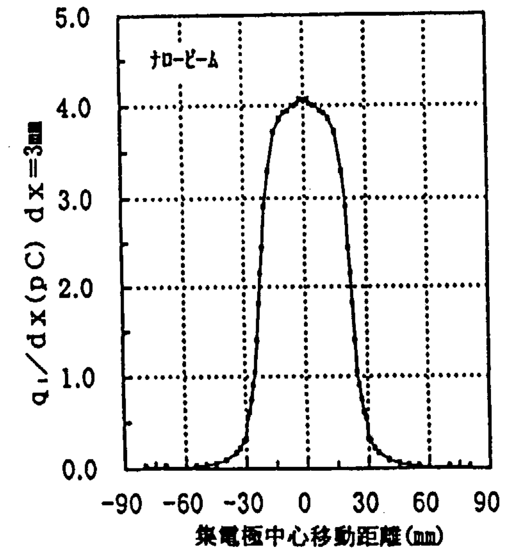

図5. ナロービーム距離移動分布：q_i

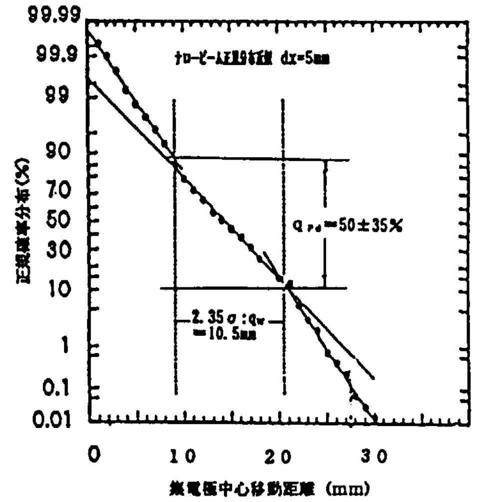

図6. ナロービームの正規分布近似 d x =5mm

4. 正規分布近似

X線装置から60cm離れた直径:Dが50.5mmの集電極中心:0に向けて入射媒質d:70μmを通過するナロービームX線は、一次元空洞にKq_dで修正した q_i=6.18 pC を生成した。この中心0をX方向に移動した 図5. の q_i の移動距離分布:q_0 を微分すれば電離電荷分布:q_{pd}が求まるが、微分法は統計変動を増幅するので大きな誤差を与える。正規分布近似は図6. の正規確率紙にq_0の百分率を点描して、q_{pd}の高さ 50±37.5% に対する 幅2.35σ:q_W を規格する手法で q_Wは移動距離から、また分布乖離度は百分率直線性から直読できる。しかし、一次元空洞のe_{ks} が半径方向に起こす散乱のため、dxの次数でq_W の値が異なるから入射媒質内の電離分布:e_Pはdxを変数とした零外挿値:$q_W=q_P/dx\to0$ になる。表1. に一次元空洞の $q_P/dx\to0$=6.4mm と、X線フイルムで求めた相対黒化度分布:F_P のX-X' 面分布:F_Xの2.35σ:$W_{1/2}$=5.6mm が示してある。図7. に示してあるF_Pの信頼性は確立しているからフイルム組成が入射媒質に等しいとすれば、$e_P=F_P$

ナロービーム　入射媒質厚さ70μm		
dx mm	q_W mm	$q_i \fallingdotseq q_d=d(q_p/dx)$ pC
30	17.2	5.82
20	15.4	6.18
10	13.5	6.18
5	10.1	6.02
2	7.8	6.1
$q_P/dx\to0$	6.4	6.18
フイルム$W_{1/2}$	5.6mm	

表1. 一次元空洞と写真黒化度の2.35σ巾(mm)

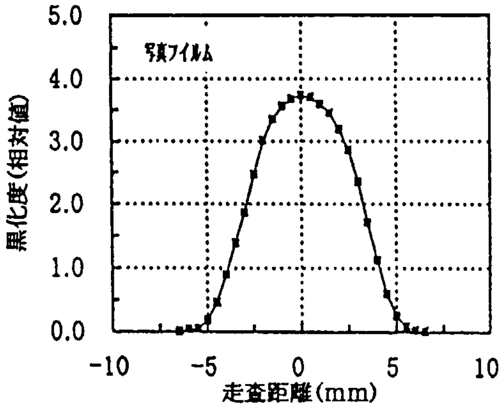

図7. 写真フイルムX-X' 軸の黒化度分布

になる。このF_Xにq_i:6.18pCを0.5mm巾で按分して、頂点:m_Xを中心とした0.5mm巾の分布スライスに占めるq_X=0.43pC を求めた。さらに分布スライスの Y-Y' 面の分布:F_Yの半値巾:$W_{1/2}$ を5.6mmとして0.5mm幅で0.43pCの按分をすれば、F_Yの頂点:m_Yとm_Xが交差する面積:$S_d=2.5\cdot10^{-3}cm^2$の電離電荷:q_{XY}=0.03pC が求まる。F_XとF_Yの分布の概念を図8. に示してある。ナロービームに対するこのq_{xy}/S_d の照射立体角:σ_nは(3)式

$$\sigma_n=2.35\sigma\cdot S_d^{0.5}/5.6(W_{1/2})$$
$$=0.21\sigma \text{ ---------------- (3)}$$

である。このσ_nの収斂係数:$K\sigma$は正規分布表から1.022を求めた。$K\sigma\cdot q_{xy}/dx\cdot S_d$ は 平坦分布電離電荷:q_nに等価であるから $q_{xy}/S_d=12.26\cdot10^{-12}C/cm^3$ を(1)式の1項に代入した(4)式

$$J_p=12.26\cdot10^{-12}C/cm^3 X 2.598\cdot10^{11}erg/g\cdot cm^{-3}$$
$$=3.186erg/g \text{ ------------------------ (4)}$$

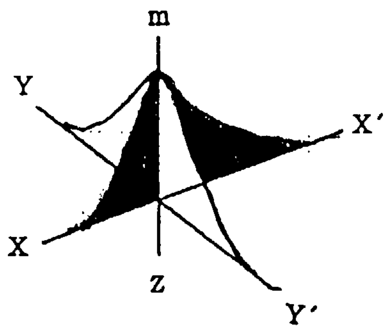

図8. 分布スライスの概念図
面積:S_dはmからzを見たX−X'、Y−Y'の重なり部分で、概念図とは異なり各々のmはオフセットしている。

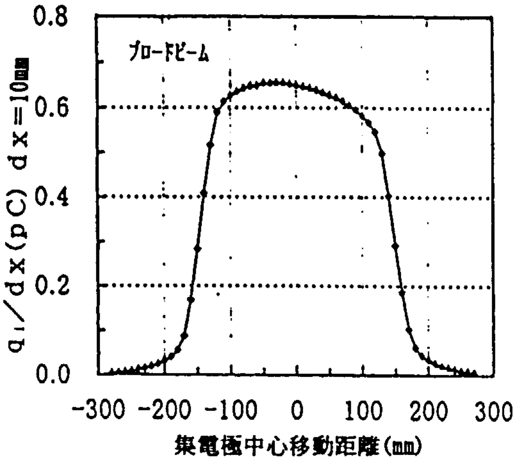

図9. ブロードビームの距離移動分布:q_e

で近似される。

一様な照射野を目的とするブロードビームX線はd:70μmを通過して集電極中心:0にq_iとして653.5pC/dx_{1cm} を生成した。図9. に示す距離移動分布:q_eから求めた q_wは208mmになる。また直径:Dが50.1mmの集電極の照射野立体角σ_bを(5)式に示す。

$$\sigma_b = 2.35\sigma \cdot D/q_w$$
$$= 0.566\sigma \text{ ------(5)}$$

このσ_bの収斂係数:$K\sigma$は1.121になる。そして$K\sigma \cdot q_i$は一次元空洞の平坦分布電離電荷:q_nに相当するから平面に対するJ_dが成立する。直径50.5mmの面に与えるJ_dは $K\sigma \cdot q_i/dx \cdot S = 32.63 \cdot 10^{-12}$C/cm^3 を(1)式1項に代入した結果の(6)式

$$J_d = 9.502\text{erg/g-----(6)}$$

で近似できる。

測定共通条件 照射距離:60cm 入射媒質厚さ:70μm		
X線共通条件 管電圧:40KV 管電流:320mA 出力時間:100mS		
ビームモード	ナロー	ブロード
コリメータ(cm)	0.3φ	30X30
検出面積(cm^2)	$2.5 \cdot 10^{-3}$	20.03
σ_a	0.21*1	0.556*2
$K\sigma$	1.022	1.121
q_n(pC/cm)	0.0307*3	732.6*4
erg/g·cm^{-3}	3.186	9.502
Gy*5	$3.162 \cdot 10^{-4}$	$9.419 \cdot 10^{-4}$

表2. 吸収線量線のビームモード比較

表2.にナローとブロードの40KVX線の測定結果を示し、内容の補足説明を下記に述べてある。

*1：照射断面積:Aと集電極面積:Sの関係がA/S<Sであるから図5.で中心 0 から(+)の領域の100分率が図6.の正規分布近似に相当する。

*2：ここでは、A/S>S であるから(−)から(+)の全領域の積分値の100分率が図6.の正規分布近似に相当している。$d(q_P/dx)$の修正はない。

*3：Kσの補正で検出面積に対して平坦な電離電荷分布：q_nを適用する。

*4：*3に同じ。

*5：${}_G S_M$=1.13を使って入射媒質のGyに換算した。

5.むすび

周辺が空気壁で構成された一次元空洞:dx·S の比電離電荷:q_n/dx が一様分布である場合が J_d/g の成立条件として40KVのナロービームX線とブロードビームX線のPMMA厚板ファントム吸収線量：D_dを測定した。その結果ナロー、ブロードの両ビームとも 一次元空洞の転換電子:e_Kと散乱電子:e_Sとの合成電子:e_{KS}が垂直方向と直角方向に特定分布を示すため一様分布に相当する修正を必要とした。垂直方向では空気飛程が3mm以下のe_{KS}の比電離電荷:q_{KS}/dxがJ_dに寄与するからdx→ 0の零外挿を必要とした。しかし零外挿のq_iは大きな統計誤差を含むからX線光子と空気の相互作用のe_{KS}による微分電離電荷:q_dで補償することを述べた。光子エネルギーが高くなると空気の相互作用が減少するのでq_d によるq_iの補償は不能であるから、これに替わる統計誤差の補償法が課題となっている。

直角方向はdxの零外挿と更に照射野立体角σ_n、σ_bの補正を必要とした。とくにブロードビームのσ_bがKσ=1.121を示した。この補正値の精度を実験的に確かめるため集電極直径が10.5mmの零外挿式電離箱のD_dと比較する準備を整えている。そして正規分布近似の方法としての信頼性は異なるKσで補正された両方のD_dが一致する事で確立するであろう。

光子の質量エネルギー吸収係数から吸収線量の説明がなされているが、電

表3.Coleの空気とコロジオンに対する飛程とエネルギー損失の測定と計算の結果

電子エネルギー KeV	飛程(測定値) μm(単位密度)	飛程(計算値) μm(単位密度)	dE/dR(測定値) KeV/μm(単位密度)	dE/dX(計算値) KeV/μm(単位密度)	W値 KeV
0.02	0.00096		11		70.08
0.04	0.0026		14		67.82
0.06	0.0038		26		59.43
0.1	0.0054	0.0035	26	29.7	52.14
0.2	0.0094	0.0073	23	24.6	48.19
0.4	0.019	0.017	17	17.9	45.50
0.6	0.032	0.029	14.5	14.5	43.89
1.0	0.061	0.062	10.6	10.6	39.89
2.06	0.192	0.186	6.5	6.6	37.63
4.0	0.63	0.59	3.9	3.9	35.96
6.0	1.25	1.20	2.9	2.9	34.39
10.0	3.1	2.9	2.0	1.97	33.47
20.0	10.0	9.8	1.20	1.16	33.47
40	33.0	33.3	0.71	0.68	33.47
60	65.0	67.5	0.53	0.51	33.47
100		163		0.36	

子飛程の問題を扱わないので電離空洞でのエネルギー吸収の仕組みが解明しなかつた。この問題について電子衝突阻止能:S_{col} MeV cm^{2}g^{-1} と一次元空洞のq_n/dxの仕組みを下記で考察した。

表3.にCole[1.]が減圧電離箱と20eVから50KeVの単色電子エネルギービームを用いた空気とコロジオンに対する電子の飛程と損失の測定結果と、対応する計算値が示されている。ここには、電子エネルギー(E)KeVに対して飛程(R)をμm(単位密度)、dEをKeV、電子が通過した吸収体の厚さdRをμm当りで表した測定値と、dE/dXの計算値が記してあるが、dEはdRまたはdXで起きるエネルギー損失の平均値である。また、グラフ形式で報告した平均のW値を数値化して記載した。そして測定結果に対して、下記に示すEとRに関係する経験式は20eVから100KeVまでの範囲が概ね10%程度で一致したと報告されている。

$$E=5.9(R+0.007)^{0.565}-0.367$$
$$R=0.0431(E+0.367)^{1.77}-0.007$$
$$dE/dX=10.05(E+0.367)^{-0.771}$$

更にこの測定結果は他の理論計算[2.]とも比較されている。

電子衝突阻止能と一次元空洞:dE/dx・Sの比電離電荷:q_n/dxとの関係の考察をするため、図3.のd:70μmのK_{qi}をq_n/dxに仮定する。またdE(KeV)/dR(μm:単位密度)をdE(KeV)/dX(cm) ρ^{-1}(1.293・10^{-3}gcm^3)=S_{col}MeV cm^{2}g^{-1}の空気等価に表示換算しておけば、最小dx=1mmは飛程1.293μmに相当するから表3.の電子エネルギーを6KeV、dE/dR は2.9KeV/μmまたはこのdE/dXρ^{-1} は29 MeV cm^{2}g^{-1} に近似できる。このq_P/dx が5.4pC/cm で零外挿値が6.18pC/cm であれば

$$29\text{MeV cm}^2\text{g}^{-1}\times 5.4\text{pC/cm}\div 6.18\text{pC/cm}=33.19\text{MeV cm}^2\text{g}^{-1}$$

になるからこの値に対応する電子エネルギーとしては表3.の4KeV、3.9KeV/μmの近傍値 5.2KeV、1μmに近似する。またW値を35.33eVに近似した6.18pC/cmの電子エネルギー損失は 5.49・10^{4}MeV g^{-1}であるから一次元空洞の単位面積当たりの電子飛程数:T_n

$$T_n=5.06\cdot 10^4\text{MeV g}^{-1}\div 33.19\text{ MeV cm}^2\text{g}^{-1}$$
$$=1.525\cdot 10^3\text{cm}^{-2}$$

で表せる。従って一次元空洞:dx/S の吸収線量D_dはdx を変数とした電子の平均エネルギー dE/dXρ^{-1}と電子飛程数:T_nとの積が最大になる J_d/gである。しかしこの dE/dXρ^{-1}・T_n は10KeV以下のW値の信頼性を今後の課題としている。

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3 .15 APPLICATION OF RESEARCH REACTORS FOR RADIATION EDUCATION

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ABSTRACT

Nuclear research Reactors are, as well as being necessary for research purposes, indispensable educational tools for a country whose electric power resources are strongly dependent on nuclear energy. Both large and small research reactors are available, but small ones are highly useful from the viewpoint of radiation education. This paper offers a brief review of how small research reactors can, and must, be used for radiation education for high school students, college and graduate students, as well as for the public.

1. EDUCATIONAL RESEARCH REACTORS

Research reactors belonging to universities and colleges have been introduced for education as well as various research purposes. In the United States about 80 educational research reactors were built during the most prosperous period of the atomic energy development. This number has now decreased to less than half, mainly due to the weakening of government support. The beginning of atomic energy development in Japan was delayed about 10 years compared to the leading nations. Furthermore, as the nation that suffered the first atomic bombing, people felt ambivalent toward atomic energy development and the introduction of educational research reactors. Thus the number of the educational research reactors in Japan was limited from the beginning. Nowadays management is confronted with such inner difficulties as aging of facilities and of personnel.

The controversial use of educational research reactors, as is more or less the case in

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many countries, is seriously questioned by people concerned with college education. Particularly in Japan, which must depend on a substantial fraction of electricity generated by nuclear power, educational research reactors are indispensable for education and for the development of advanced nuclear power technologies. The functions of educational research reactors can be summarized as follows:

1. Cultivation of professional nuclear engineers through college education
2. Education of college students outside nuclear engineering into neutron and nuclear physics, nuclear sciences, radio- and radiation sciences
3. Training and re-education of professional nuclear engineers
4. Education of the public for the understanding of reactors, radioactivity and radiation
5. Study of reactor design and reactor performance
6. Study and development of radioactivity measurements and neutron physics
7. Study of neutron reactions, including production of radioisotopes
8. Various utilization of neutrons for research and practical applications

In all these functions, the importance of the educational research of nuclear reactors lies in its ability to provide opportunities to experience real phenomena, or even accidental occurrences, which cannot be obtained from textbooks, simulators or firmly guarded, non-research orientated nuclear plants.

Watt class reactors are useful for education in nuclear physics, neutron measurements, and the training of reactor operation. 100kW class reactors usually have irradiation facilities, which are useful for radioisotope production. Direct educational use of reactors larger than 1MW is limited but, nevertheless, they are effectively used through research activities of post-graduate students.

2. RADIATION EDUCATION FOR COLLEGE STUDENTS AND TEACHERS USING RESEARCH REACTORS

Normally students enter college without much knowledge of radiation, or with a misguided understanding of the danger of nuclear energy. Students must be encouraged to explore this vital area open-mindedly.

1) Students in nuclear science and technology;

Needless to say, the knowledge of radiation is a professional necessity for this group of students. Commonly detailed educational courses on radiation are programmed both by lectures and by laboratory experiments. But normally little opportunity is given to students to spend time in a research reactor facility. On the average, these students spend less than 1 week at such a facility during their undergraduate years. It is necessary to give them more opportunity to work with research reactors.

2) Non-nuclear, science and engineering students

All the students of science and engineering should be educated to deal with radiation and radioisotopes properly. This appears to be completely ignored in Japanese colleges. It is not easy to establish programs in every faculty or department. A practical solution would be to make use of nearly research reactors. These students should be required to do an internship, several days in duration, at least one once during their undergraduate years.

3) Students in human sciences

Students in human sciences should also be given a reasonable education in the field of radiation. The invaluable experience of visiting a research reactor should be incorporated into their education requirements.

4) Professors

Many professors lack competency in the field of radiation and nuclear sciences. Any trial to educate students would not be very fruitful if educating professors is ignored. A countermeasure for this would be to plan a projective program for college professors. Junior and secondary high-school teachers may also be included in this plan.

5) Post-graduate students

Many post-graduate students in science and engineering are given frequent chances to visit nuclear or radiation facilities, nuclear reactors, accelerators, photon factories and so on, as a part of their research activities. Since the users are obligated to attend a special guidance course in radiation protection in many radiation facilities, radiation safety is firmly insured. But proper understanding of radiation treatment is not sufficient. For example, at many radiation facilities, both post-graduate students and the teachers think that radiation is dangerous entity that should be strictly avoided. Since such misconceptions cause inefficiency and unnecessary care and cost, a stronger effort should be made to reassure people of the safety of the safety of radiation research and useful recognition about radiation. It would be advisable to create professional course on radiation for this group of students.

3. RADIATION EDUCATION FOR HIGH SCHOOL STUDENTS

Students in junior and senior high schools are taught about “matter” through their study of physics and chemistry. It should not be difficult to make them understand that radiation or radioactivity is a particular activated state of a substance. For this purpose research reactors provide various, but most simple, nuclear reactions: degradation of neutron energy, nuclear reactions induced by neutrons, neutron absorption, nuclear fission, nuclear transformations and the production of radioisotopes. High school students need not understand the details of all these processes, but it would suffice for them to see these amazing natural phenomena during a half-day visit of a research reactor.

4. EDUCATIONAL ITEMS OF SMALL SCALE RESEARCH REACTORS IN CONJUNCTION WITH RADIATION

The characteristics of small research reactors (below ca 300 kW) in conjunction with radiation education are as follows:

(1) The reactor core can be observed during operation.

(2) Radioisotopes of various half-lives can be produced without the danger of excessive activity.

(3) Neutron beam is used easily and can be applied to neutron measurements and radiography.

Considering the above characteristics, the following educational subjects can be programmed.

1) For elementary school pupils

a) Cerenkov radiation

Cerenkov radiation is the light that is emitted when a charged particle, which in the case of reactors is the electron ejected by gamma-ray bombardment of water, passes through a substance with a velocity larger than that of photons in it. This light, being different from normal light emission in origin and mystically blue in color, is of intriguing scientific interest.

b) Radiation Level

There are various radiation levels around the reactor. Measurements and analysis of these radiation levels are useful for understanding the nature of radiation. It is also valuable to know the radiation level is not at a dangerous level in the reactor room even when the reactor in operation. Pupils must be given the chance to manipulate radiation detectors to experience radiation by themselves. It would be useful to compare the radiation level around the reactor site with that, for example, near their homes.

c) Radioactivity

Any material put into a reactor is activated normally. The activity can be measured immediately after irradiation, and on-site experience of how fast the activity decays and how a part of the activity remains a long time may be given. This must be presented together with a demonstration that the activity is not very dangerous when it is dealt with properly and carefully.

2) For high school students

The items described above should be included in the educational program of high school students, too. In addition, a more familiar and quantitative experience with radiation and activated substances must be given. Brief qualitative understanding of activity (dps), count rate (cps), fluence and exposure, absorption dose (Gy), and effective dose (Sv) may be given. The concept of "exposure" may also be taken up in conjunction with time, distance, and shielding. For this purpose demonstrational experiments of activation using reactors are highly educational.

3) For college students

The understandings expected for high school students as described above must be elevated to a more quantitative level. College students of science and engineering course must be able to calculate quantities related to radioactivity and radiation. College students of nuclear science must be able to calculate the stopping power of a substance toward ionizing radiation, attenuation, absorption doses, and shielding effects. This may well be done through designing their own experimental set-ups and/or conditions.

4) For the public

Education of the public is highly important at this time since radiation education for adults has been largely ignored. Because free access to reactor sites is usually forbidden to the general public at the present time, reactor facilities must be made more available to the public. A well conceived short course for teachers, from elementary school teachers to high school teachers, will also be important.

5. CONCLUSION

Although research reactors are highly useful for radiation education of people of various generations, they are not used to their full effectiveness. Many research reactors from time to time open their facilities for the public to visit, often with some exhibitions. This, however, is usually done on a voluntarily and irregular basis. Since research reactors are the educational property of society , they should be given proper support for their educational and research potential.

Recently, problems regarding the existing research reactors in Japan have become the focus of the attention. Some associations have started an urgent examination of management and operation of research reactors, aimed at promoting more extensive use of them. It is not without reason that the social movement for research reactors is in accordance with that of the radiation education.

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3.16 科学館における放射線関連の展示

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要旨

放射線教育における博物館の有効利用及びその推進を目的とし、関東・東北地方を中心に50館の博物館（PR館を含む）における放射線の展示を1996年4月から1998年11月にかけて調査した。調査内容は、放射線の展示（例えば、宇宙線の展示やX線の展示など）の有無と、その展示背景についてである。調査対象のうち、放射線についての展示がある館は30館、原子力についての展示がある館は25館、いずれかについての展示がある館は39館あった。私立の館については、電力会社関係の館が多かったため、ほとんどの館に放射線及び原子力に関する展示が存在した。スパークチェンバーは12館、霧箱は4館に存在し、両方とも存在する館は2館である。X線を実際に使用した展示は4館にあった。

放射線の展示の種類は決して十分とは言えず、内容にも大きな偏りが見られ、多くの館にあるものは「環境に少量の放射線と放射能が常に存在すること」についての展示であり、他の展示は少ない。全体的に放射線の展示は印象が薄くなりがちなハンズオフであったり、仕組みや原理がブラックボックス的であったりすることが多い。現在の博物館において、放射線教育の効果を考えた場合、展示が十分でないことから、成果が確認できない可能性が高い。博物館で放射線教育の効果を狙うためには、科学史的な観点から展示している館に対しては寄贈のシステムを整える、サイエンスセンター型の館に対してはハンズオンの展示の開発するなどの対策が考えられる。ハンズオンの展示として実際の測定の他、数種類の展示があるが、現在展示されていない放射線の他の面についても分かりやすくするための展示の工夫が必要である。

1. はじめに

放射線やラジオアイソトープは、理化学の研究の他、医療や工業・農業など広い分野で利用されている。また、原子力も総発電量の約35%を占めるにいたっている。これに対し、一般的な知識・教養として放射線は認識されておらず、そのうえ不正確な知識による誤解も多い。

現在、放射線・放射能教育について様々な教育普及活動を行っている団体は、学校における放射線教育が中心としているところが多いが、学校の範囲を超えた活動も不可欠であると考えられる。その理由の一つとして、仮に2000年に高校生への放射線教育を必修とした場合でも、この教育を受けた人が有権者として過半数を超えるためには30年以上かかるということがある（図１）。もう一

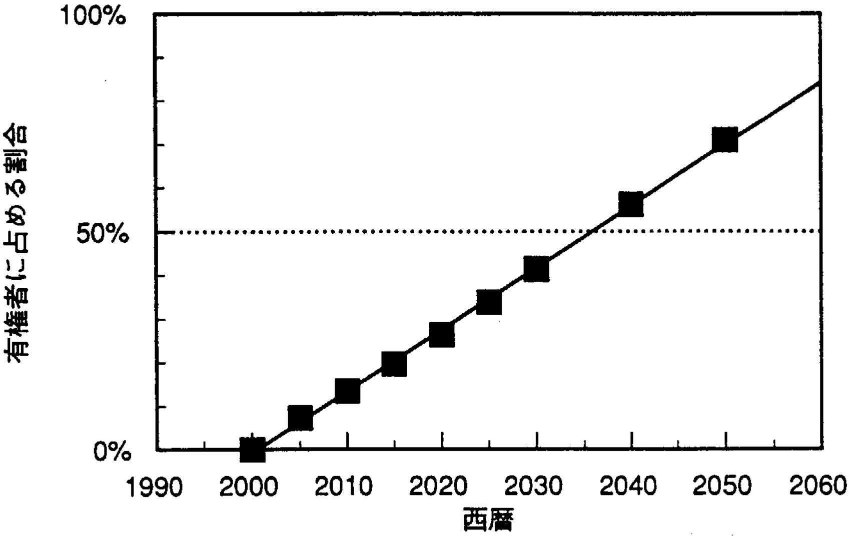

図１：全有権者に対する放射線教育を受けた人の割合
（2000年から放射線教育を義務づけた場合）
（高校進学率を100%、死亡率は変化しないと仮定し日本の統計[1)] をもとに計算した）

つの理由としては、学校で獲得した知識は必ずしもそのまま保持されるわけではないため、卒業後に記憶の保持に対する何らかの補佐を行う必要があるということがある。

渡辺ら[2)] の報告によれば、生徒が調査や自習を行う場合、博物館・展示館を利用すると答えた生徒はほぼ半数になる。卒業してもその傾向は続くと考えられ、博物館は教育の一端を担うと考えられる。成人は博物館で見た事実や知識をほとんど記憶していないということがいわれているが、想起法で自由に述べさせるといくつかの展示については覚えており、それは事前の知識と事後の経験により影響されるとされている[3)]。そのため、博物館だけによる知識の普及は難しいものの、他のメディアや学校教育との供用により、博物館が放射線の新しい知識を提供することや、既に獲得した知識の保持の一端を担うこと、放射線に興味を持たせること（動機づけ）は可能である。

しかし、放射線に関して、博物館・展示館で何をどのように展示され、来館者にどのように利用されているのか分かっていないことが多い。

本調査では、放射線教育における博物館の有効利用及びその推進を目的として、東日本を中心に博物館における放射線の展示を調査した。

調査内容は松浦[4)] の「最低限度必要な基本知識」を基準としたが、放射線についての知識は放射線そのものの知識のほかに利用についての知識もあることや、放射線への理解には、放射線の基本的な知識が必要であるが、その動機づ

けには「どのように利用されているか」ということの理解も必要であると考えられることからも、放射線の利用についても展示の調査を行った。

2. 調査内容及び方法

2.1. 調査対象

東日本を中心に、理工系の展示を持つ館及びPR館の中から50館選び、調査対象とした。調査は、1996年4月から1998年11月にかけて行った（表1）。

表1　今回見学を行った博物館・展示館の数

	国公立			法人	私立	合計
	国立	都道府県立	市町村立		企業	
館数	3	3	28	6	10	50

2.2. 調査方法

実際に見学を行い、実物展示を中心に展示内容の記録を取った。

その結果を元に、松浦[4]の「最低限度必要な基本知識」を基準に展示されている情報の有無をまとめた。また、放射線の利用等その他の知識についても傾向ごとにまとめた。尚、最低限度必要な基本知識（松浦[2]による）とは

1. 環境に少量の放射線と放射能が常に存在すること
2. 近くに放射線を放出する放射性物質が存在してもそれから安全に身を守ることができる3つの基本的方法（線源から距離を取って遠ざかる、線源と身体との間に遮蔽体を置く、線源から近い距離にいる時間を短くする）
3. すべての放射性物質が固有の半減期に従ってひとりでに消滅していく
4. 放射性物質が体内に入ったとき「生物学的半減期」により体内から排出される

である。

3 調査結果及び考察

今回調査を行った館のうち、放射線についての展示がある館は30館、原子力についての展示がある館は25館、いずれかについての展示がある館は39館あった。私立の館については、電力会社関係の館が多かったため、ほとんどの館に

表2-調査結果（抜粋）

	内容		展示物	国公立	法人	私立
基本的事項	環境に少量の放射線と放射能が常に存在すること		スパークチェンバー	8	2	2
			サンプル等の放射線の測定	0	3	3
			霧箱	1	2	1
	近くに放射線を放出する放射性物質が存在してもそれから安全に身を守ることができる3つの基本的方法	線源から距離を取って遠ざかる	アトムカー[a]	0	0	1
		線源と身体との間に遮蔽体を置く	アトムカー[a]	0	0	1
			放射線防護服[b]	1	0	1
			放射線の特徴[c]	0	2	0
		線源から近い距離にいる時間を短くする	無し（1館のみパネルで存在）	0	0 (1)	0
	全ての放射性物質が固有の半減期に従ってひとりでに消滅していく		無し（1館のみパネルで存在）	0	0 (1)	0
	放射性物質が体内に入った時「生物学的半減期」により体内から排出される。		無し	0	0	0
放射線の利用に関する展示	医学利用		X線によるレントゲン(hands onのみ)	3	1	0
			アトム号[d]	0	1	0
			器具の滅菌	0	1	0
			X線CT	0	0	1
	理工学的利用		コッククロフト・ウォルトン型加速器	1	0	0
			加速器の原理-コロガリトロン[e]	0	1	0
			蛍光X線分析装置、及びその実演[f]	1	0	0
			装飾品の着色／架橋・分解	0	1	1
			空港での荷物検査に用いられるX線	0	1	0

a)アトムカー（電車）を走らせて、駅に止めるというゲームであるが、アトムカーのジオラマの下にある検出器の放射線量をその検出器とそばにある放射線の線源の模型の距離をハンドルで調整したり、遮蔽体を置くことにより変化させ、それとともに速度を調整することができるようになっている。

b)放射線防護服-厚さ5cm分の鉛程度の防御ができると説明されているが、単なる衣服の機能を説明する例として取り上げているため、「何故この服は、放射線防護の機能を持つのか」ということに関して詳しい説明がない。

c) α、β、γ の線源と検出器の間に紙や、アクリル板、鉛等をおいて、どの程度遮蔽されるかを示す展示

d)映像に合わせて客席も揺れるようになっている装置。内容は「放医研のHIMAC」に関したものであり、自分が重粒子とともに行動し、ガン細胞を叩くという話になっている

e)レールの上の金属球を粒子に見立て、加速させるゲーム。レールには2個所の枠があり、枠の中を通過するタイミングに合わせてボタンを押すと電流が通り、加速できるようになっている。

f)蛍光X線分析装置-実物が存在し、原理をパネルや映像で説明するほかに、来館者が持ってきたものを実際に測定することができる（一日2回）

放射線及び原子力に関する展示が存在した。結果の一部を表2に示す。

3.1. 放射線に関する基本的な知識について

「環境に少量の放射線と放射能が常に存在すること」に関する展示の中で一番多いのはスパークチェンバーの展示である。私立の館の場合、原子力の展示とともに置かれている例が多いが、公立の館では宇宙線を「宇宙や自然を理解するための道具」として扱い宇宙や環境に関するコーナーに置かれていることが多い（表3）。また、オブジェとして出入り口近くに置いている館もあった。来館者はパネルをあまり読まないことや、物理的なコンテキストで展示物を理解することを考慮すると公立の館の配置で環境放射線が存在することを理解させることは、難しいと考えられる。

表3　実物展示の所在（展示物毎に）

展示物	展示場所	館数		
		公立	法人	私立
スパークチェンバー	宇宙	4	-	-
	原子力	-	1	4
	光	1	-	-
	環境	1	-	-
	（オブジェとして）	2	-	-
X線	光	3	-	-
	原子力・放射線	-	2	-

但し、「天文、宇宙、地球の科学」に対しては学習関心調査報告[5]から潜在的関心が他の科学分野よりも高いことから、「放射線についての知識があれば宇宙や天文への理解がより深まること」を示唆できればスパークチェンバーは放射線への理解のきっかけとして使うことができる。

また、宇宙の展示は入り口に近い所に置かれていることが多い（4館中3館）。このため、身体的にも疲労が少なく、心的飽和状態（展示物を見ることに飽きてくる状態）になっていないことから比較的じっくりと見てもらえる可能性が高い。さらに2館では展示会場が暗くなっており、解説が読みづらいという難はあるものの、光を放つスパークチェンバーは人の光指向から考えても注目度

が高いと考えられる。

しかし、今後の展示の傾向を考えると、ハンズオフの展示は好まれない傾向があるため、ほとんどがハンズオフの展示であるスパークチェンバーは、展示が敬遠される可能性もある。公立の館の中には、スパークチェンバーの一部に空間をつくり、その中に手を入れることにより宇宙線が体を透過することを理解させるという工夫をし、ハンズオンに近い展示を行っている館もある。また、スパークチェンバーの持つ芸術性を高めるため、鏡やスライドを組み合わせて独特の雰囲気を作っている館もある。

自然の中にある物質を実際に検出器を用いて測定させるという展示は電力関係のPR館に多く公立の館ではあまり見られなかった。測定させるものとして「コンブ」「湯の花」「肥料」「土」等が一般的に用いられており、館による変化があまり見られない。この展示は、ハンズオンであるが、変化に乏しいため注目を高めさせるための工夫も必要である。また、検出器はある意味でBlack Boxであるため、この仕組みでなぜ放射線が測定できるのか理解させる展示も今後開発する必要がでてくるであろう。

自然史の科学館では放射線を出す鉱石として検出器を近付けて音の変化を見せている館もある。この場合は、「そんな性質をもつ石がある」というのを見せているだけなので放射線に関する教育効果は期待できない。

「線源から距離を取って遠ざかる」には線源と検出器の距離を離させることにより、線量が次第に低下していくのを確認させているものがある。「線源と身体との間に遮蔽体を置く」では、「遮蔽体について展示」や「放射線防護服」の展示がある。遮蔽体については線源と検出器との間に遮蔽体を挿入させ、計測器のメーターが下がるのを確認させる展示が多い。実際に遮るものとしては紙、アルミ、ガラス、鉛、コンクリート等から幾つかが選ばれている。放射線防護服を展示するのは、放射線防護の理由を認識しづらいが防護服が普段見ることができない変わったものであるため関心を引きやすいと考えられる。

それらに対し「線源から近い距離にいる時間を短くする」に関しては展示がほとんど無かった。同様に、「半減期」、「内部照射」についての展示もほとんど無かった。視覚化し、なおかつ来館者の興味を引くようにすることは難しいためであると考えられる。

以上のことから、放射線についての展示はあるものの、松浦の「必要な知識」から考察すると、内容に大きな偏りがあるといえる。また、全体を通してみても、放射線は実際に見ることができないこともあり、展示物の仕組みや原理が

ブラックボックス的なものが多い。現在の博物館において、放射線教育の効果を考えた場合、展示が十分でないことから、成果が確認できない可能性が高い。

3.2. 放射線の利用

「博物館」は本来ものを収集し、研究し、展示し、保管するということを目的としている。この目的に沿った館では、収集や展示を行いやすい利用についての知識のほうが展示されやすいと考えられる。

X線は検診などのようにかなり身近なものとして利用されているが、X線についての展示は私立の電力関係の館ではほとんど見られなかった（表3）。公立の館の中にはX線の医学利用を豊富な写真を用いて、有益性を紹介しているところもある。

X線の展示は実際に持参したものを透過させて見ることができるハンズオンの展示として良く使われている。レントゲン撮影をはじめとして割合と身近でよく知られているものの解説のため、どの館でも興味を持って接している子供が良く見られた。

今後、ガン治療をはじめとする医学での放射線利用はますます増えると考えられるうえ、インフォームド・コンセントが重視される中、放射線の医学利用の知識の提供は必要になると考えられる。また、X線の他に加速器や、蛍光X線装置（化学分析の一例として）を展示している館もある。これらの展示には放射線の性質そのものよりもどのような原理で行われるのかや、どのような成果を挙げられるかについてパネルなどで説明されている。

現在のバイオテクノロジーの基礎となる部分は、トレーサー利用により解明された部分も多く、また、X線によるタンパク質や核酸の結晶解析も様々な役割を果たしているが、生物学への応用に関する展示は少ない。また、厚さ計、着色等のように工業的な利用例も、多いとは言えない。科学技術の発展に対する放射線の貢献についての展示は功績に比べて少なすぎるといえる。

3.3. 博物館に放射線の展示を受け入れてもらうためには

現在のところ放射線を展示するということは科学館に必ずしも要求とされているわけではない。そのため、科学館が受け入れやすいような体制を作っていく必要がある。

新規に建設される館や展示替えをしている館では良い展示方法があれば受け入れられやすい。例えばエクスプロラトリアムの展示方法はハンズ・オンの展

示があるほとんどの館で、「調和水槽」等も、環境に関する展示を最近開始した所では必ずといっていいほど置かれている。また、サイエンスセンター型[6]の科学館が増えることにより、ハンズ・オフの展示より、ハンズ・オンの展示が増加が考えられる。このようなことを考慮すると、放射線の新しい展示方法（できうるかぎり五感を使う参加型、またはオブジェとしての使用に堪えられるような芸術性の高いもの）を開発する必要もあると思われる。

館の数は少ないが、科学史の展示も行っている館もある。このような館では、収集資料の質や量が展示の質も決めてしまうため、大学や研究所で放射線に関する実験器具で不要になったものを寄贈しやすいようにする等の体制を整える必要がある。

なお本調査は私的に実施したものである。

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3.17 "RADIATION FAIR" FOR 15 YEARS IN OSAKA, JAPAN, AND SURVEY OF THE PARTICIPANTS' ATTITUDE TOWARD RADIATION

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ABSTRACT

We have been successfully operating "Radiation Fair -- The relationship between daily life and radiation --" during summer vacation season in August every year for 15 years in Osaka, the largest city of western Japan. The purpose of this event is radiation education of public including school kids through efficient information transfer of radiation and radiation-related technology. Currently we set up the space of it on a floor of Kintetsu Department Store, one of the major department stores in downtown Osaka and display various irradiated products available in our daily life together with explanatory panels. We have been devising various attractions as efficient information transfer media so that even elementary-school kids understand the basic knowledge of radiation and irradiation technologies. The number of participants has increased year by year until more than 20,000 in recent years. We distributed questionnaires to the visitors for recent 3 years to inquire their status toward radiation and irradiated products as well as impression toward the displays. The survey results suggest that school education may contribute to establish the public image toward "radiation" as well as mass media.

1. INTRODUCTION

Although radiations, which always exist in our environment, are utilized in various fields of our daily life, it is hard to say that they are well understood. In order to find a way out of such a situation, information transfer activities have become more important. In case of food irradiation, for example, test marketing has been successful in gaining efficient information transfer to those who have little knowledge specialized for radiation and radiation-related technology. As a result, in a large survey of over 1,000 people in the United States, the Gallop organization determined that 73% have heard something about food irradiation; and 24% have some knowledge of the food irradiation process. 54% stated that they would be likely to purchase irradiated foods over non-irradiated foods when they learned of the benefits and organizations that endorse the process[1]. We have been held "RADIATION FAIR, -- The relationship between daily life and radiation --" for 15 years in Osaka, the largest city of western Japan, for the purpose of public education and information transfer of radiation, radioisotopes, and radiation-related technology to citizens including school kids. We have also been conducting a questionnaire study toward the visitor of the Fair for 3 years to inquire public knowledge and feeling toward radiation and irradiation technology as well as the impression of this event. knowledge of them

In this paper, we introduce the outline of our activity and the survey results of the feeling toward radiation and the route of cognition of the word, "radiation".

2. OUTLINE OF "RADIATION FAIR"

We organize the Executive Committee for "relationship between radiation and our daily life" with other associations supporting and promoting the use of radioisotopes, irradiation technologies, and atomic energies in Osaka area. They are Osaka Nuclear Sciences Association, Inc., Japan Radioisotope Association, Inc., Japan Atomic Industrial Forum, Inc., Association of Radiation Engineers in Osaka Prefecture, Inc., Atomic Energy Society of Japan, Inc., Electron Sciences Research Institute, Japan Atomic Energy Relations Organization, Japan Atomic Energy Research Institute, and us. We have been holding "RADIATION FAIR, the exhibition of radiations related with our daily life" annually in summer vacation season for 15 years. The scale of the exhibition expanded year by year until 1990. Since then, we have been set up the space on a floor of Kintetsu Department Store, one of the major department stores in downtown Osaka (*see* Photo).

Various "irradiation-treated" products available in our daily life have been displayed, including irradiated potatoes, EB-treated Styrofoam products, tires, golf balls, etc. together with explanatory panels. We have been devising efficient information transfer media, such as games, quizzes, street performances, and handicrafts as well as explanatory panels so that even elementary-school kids can understand the basic knowledge of radiation and irradiation technologies. We invite professional actors and street performers playing characters of famous historic radiation scientist providing science quizzes related to radiation sciences and games and acrobatics using irradiated products. We have also provided "Experience corner" where the participants could experience the existence of the radiation through observation of cosmic rays by a cloud chamber and radiation measurement of soils and stones. Free medical clinic and bone densitometry service has provided for adult visitors (*see* Photo). The number of participants has increased year by year until more than 20,000 in recent years (*see* Fig. 1).

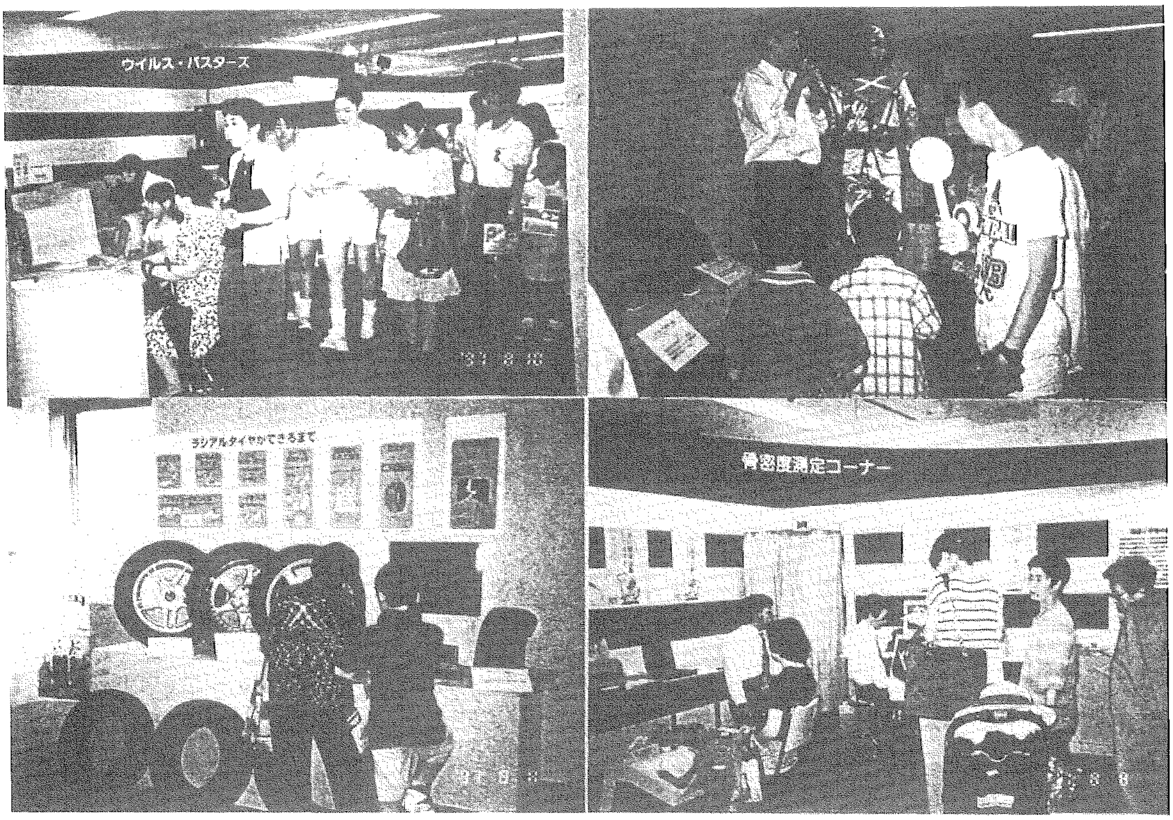

Photo: Various events at "Radiation Fair" on the floor of Kintetsu Department Store in Downtown Osaka.

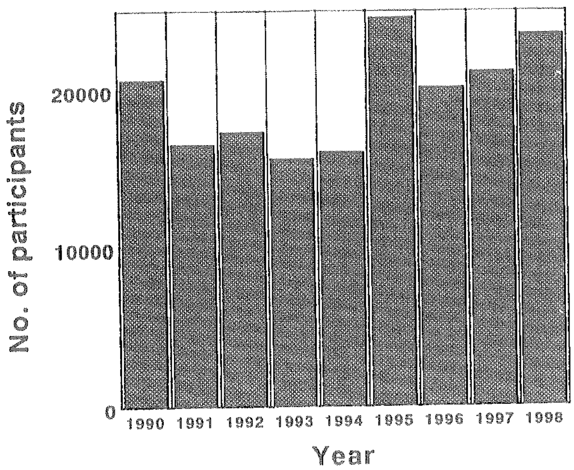

Fig. 1. The increase of participants in the "Radiation Fair".

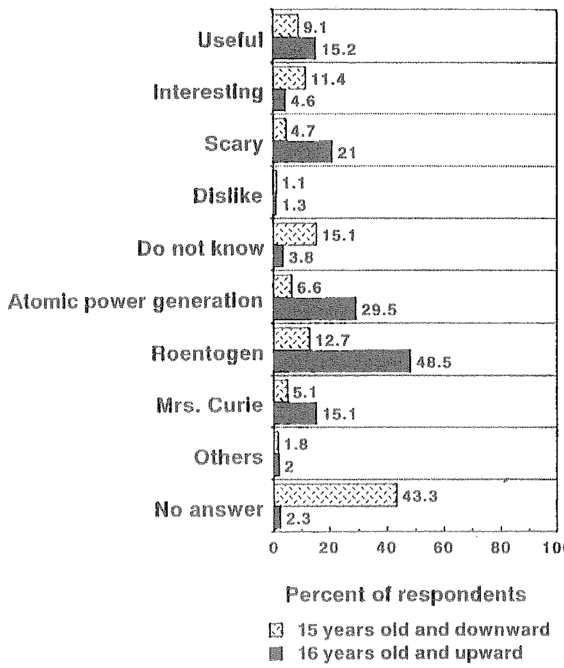

Fig. 2. Closest Images associated with "radiation".

3. QUESTIONNAIRE PROCEDURES

We designed two questionnaires for kids (under 16 years old) and grown-ups (16 years and upward), separately. The both ones contain questions about the knowledge of radiations and the impression toward the various activities of our event. as well as the demographic questions, such as sex, age, companions, and information source of the Fair. We added detail questions about the time and place of recognition of the word "radiation" together with knowledge of natural radiations and irradiated products including irradiated potatoes and other food safety issues to the questionnaire intended for the grown-ups. We distributed the questionnaire sheets to the visitors at the entrance and collected the answered sheets at the "Questionnaire collecting corner" beside the exit.

4. QUESTIONNAIRE RESULTS

We obtained 3568, 2136, and 2320 answers in 1996, 1997, and 1998 surveys, respectively. Most kid visitors were accompanied by their mothers. More than 50% of the visitors occasionally recognized this event when they stopped at the department store . Each survey revealed that the ratio of visitors who had heard something about radiation increased with increasing age and reached over 90% at junior high school ages (13-15 years old).

In 1996 survey, “Roentgen” standing for X-ray radiography in Japan, and “atomic power generation” were the closest words associated with “radiation” chosen by grown-up participants. In contrast, more than 40% of kid participants chose “no answer”. Interestingly, the ratio of “scary” chosen by grown-ups as the closest word with “radiation is approximately 4 times higher than kids (*see* Fig. 2). Fifty six point nine percent and 37.7% of the grown-up participants indicated “rather bad” image of “radiation” in 1997 and 1998 surveys, respectively, when they heard of the word (*see* Fig. 4). These ratios were the largest among the 5 choices including “very good”, “rather good”, “average”, “rather bad, and “very bad” in each survey. The ratio (59.6%) of the answers, either “rather bad”, ”bad”, or ”very bad” from the grown-up participants for the image of the 1st encounter of the word “radiation” became approximately 4 times as much as those from kid participants. Fortunately half of the participants answered that the image became better after their first encounter with “radiaiton”. More than 70% of the kid participant answered that they understand the “radiation” after browsing the Fair. The same ratio of the grown-up participants also noted that their visit of “Radiation Fair” was a good chance of improvement of their image toward radiation, indicating that our event is effective for public acceptance of radiations and radiation-related technology.

1996 survey for grown-up visitors also revealed that 59.1% of participants recognized the word of “radiation” when they were at elementary school and the most significant sources of this information were school lessons and mass media (*see* Fig. 3). 1997 and 1998 surveys also indicated similar results.

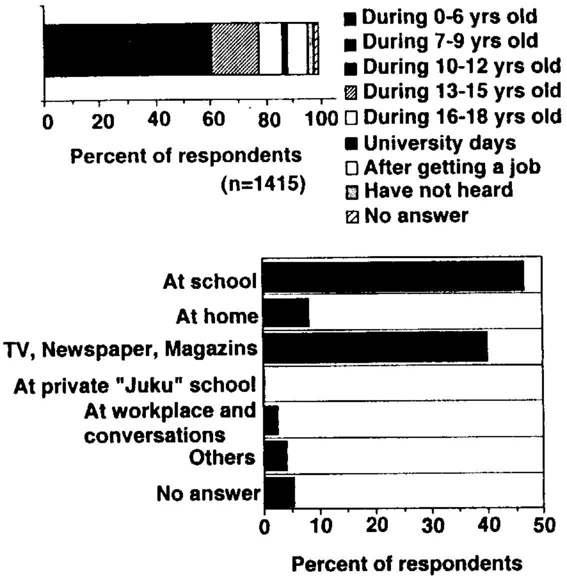

Fig. 3. Distribution of the recognition time (Top) and sources (Bottom) of "radiation"by 16-year old and upward participants.

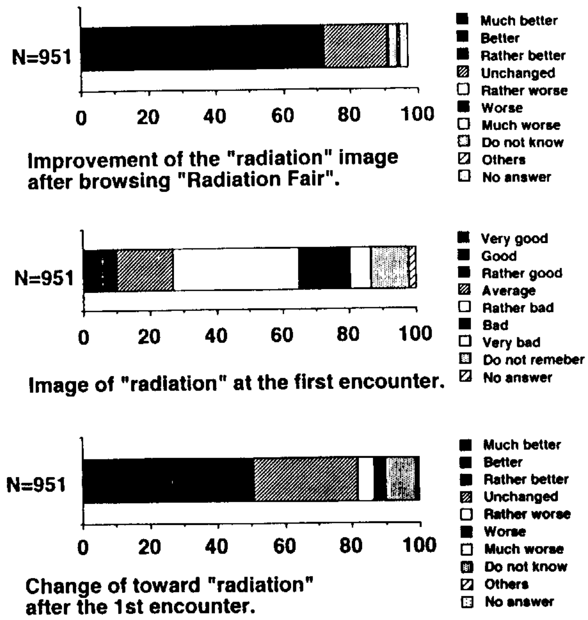

Fig. 4. Difference of the image toward "radiation" before and after the visit of the "Radiation Fair"

5. DISCUSSIONS

These survey results indicated that worse images toward radiation would be formed after junior high school days while the word, "radiation" is initially recognized during elementary school days according to Figs 2 and 4. "Radiation fair" was shown to be very helpful not only as an introduction of radiation science and radiation-related technology to elementary school kids but also as an media to improve the image of radiation and atomic power-related technology toward older people. From these viewpoints, if we transfer the correct information about radiation sciences and technology at the right stage of education, we could improve consumer's image toward radiation.

The survey results also showed that school education is an important recognition route of the word, "radiation" as well as the mass media. Therefore, we should watch the school curriculum. Although several radiation- and atomic power-related topics are appeared in authorized textbooks including science and social studies for school education in Japan, many mistakes have been pointed out in the context of the description of each topic by several radiation scientists groups. Thus we should check the current teaching materials and plans in order to make radiation-related information transfer in school more effective. To do this, we are planning more detailed survey to reveal actual status of "radiation education" at school and food irradiation among consumers.

ACKNOWLEDGMENT

We thank the members of the specialized subcommittee of "Relationship between radiation and our daily life" Executive Committee for valuable discussions to develop the questionnaire. We also thank I &S Inc. for technical assistance.

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3.18 IONIZING RADIATION – ONE OF THE MOST IMPORTANT LINK OF THE ENERGETIC CHAIN IN BIOLOGICAL CELL

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ABSTRACT

High (large) and low (small) doses of ionizing radiation consistently induce opposite physiologic effects in biological systems. The effects of low doses cannot be inferred by interpolation between the result from groups exposed to high doses and controls irradiated only by Natural Background Radiation. Stimulation („bio-positive") effects by low-level doses of ionizing radiation are called radiation hormesis. It is still controversial idea, however it was found that some biological objects (yeast, seeds, animals) after gamma irradiation by low-level doses (10-50 times more NBR) can increase their development.

The result of present researches demonstrate that the excitation of living system by gamma quanta (high energy) initiates prolonged secondary emission that influences biota and activates many important processes in biological systems. According to the excitation theory of bio-molecules the author suggests that gamma irradiation in low-level doses excites such molecules as DNA and proteins, and this being followed by a long-termed secondary coherent radiation. The spectral analysis of this secondary emission confirmed the contribution of the UV component to the total emission.

The data obtaining by using SPC method (single photon counting) make possible a partial understanding of the radiation hormesis phenomenon and suggest closer relationship to UV emission from biological systems during mitotic processes.

The experiments with humic acid (high doses) and glycine (low doses) confirm the author hypothesis that gamma-irradiated organic compounds are capable to emit secondary radiation This secondary radiation probably plays very significant role in the intercellular communication inside the living systems.

In conclusion the author proposed de-excitation processes in bio-molecules as a common denominator of UV and ionizing radiation interacting with living cells.

Finally he refers to the Cerenkov radiation which is created inside the biological cells. Because the Cerenkov radiation is totally absorbed, consequently these photons must be play very important part in energetic balance in living organism. The author expects that Cerenkov radiation may converse - like ionizing radiation - into UV photons and effects as a "bio-positive" factor (Cerenkov Hormesis).

1.INTRODUCTION

A great deal of scientific researches confirmed that high and low doses of IR consistently induce opposite physiologic effects in biological systems. Stimulation (bio-positive effect) by low-level doses of any agent is called **hormesis**. Luckey[1,2] in his works transferred this notation to IR and defined radiation hormesis (RH) as a bio-positive effect of low-level doses of IR. What does it mean low-level dose of IR? This dose is defined as a value from of more than ten times of Natural Background Radiation (NBR) to 1/100 LD (lethal dose); i.e.40-50 mGy.

The data show increased or accelerated respiration, germination, growth, development and maturation, reproduction, resistance to disease and sub-sequent irradiation and average longevity. Under the irradiation of gamma rays the increasing of mitosis index is observed.

Hormesis evokes increased vigor and strength in individuals subjected to sub-optimum conditions[1,2,3].

The hormetic dose varies with subject, conditions, physiologic function measured, dose rate and total exposure. The type of radiation seems to be less important than the rate at which it is administrated. Next, the dose rate is probably more significant than the total dose in radiation damages. The same total dose irradiated in long or short time effects differently in living organisms.

RH following whole-body irradiation was established in animals for growth and development, fecundity, immune competence, decrease mortality rates from infection and average life span. RH is regularly noted in independent microbes such as bacteria, yeast and algae. RH is found in plants and both vertebrate and invertebrate animals[3].

Whole-body human exposure to low-level doses of IR consistently results in decreased cancer death rates[1,2].

Man appears to be one of the most radiosensitive species. The magnitude of LD_{50}^{30} for man equals to about 2.6 Sv and this value is at least one order of magnitude smaller than the corresponding value for other living organisms Tab.1. We can realistically estimated total dose, which a man is exposed to equals about 1 mGy/y. But there are some regions of the Earth, where the NBR is much higher than so-called normal level. For example: in Brazil, beaches of Guarapari - 263 mGy/y, Guapara 10-18 mGy/y and Apaxi 35 mGy/y; Iran, Ramasari 7-480 mGy/y; India - Kerela coast - 4-23 mGy/y; several thousand people in Espirito Santos - 30 mGy/y; Caucasus and Himalayan mountaineers - 35 mGy/y – Tab.2[2].

Subject	Sv
Man	2.5-3.0
Dog	2.6
Monkey	5.0
Rat	8.0
Fish	8.5
Chicken	10
Bat	150
Snail	200
Snake	800
Wasp	1000
Ameba	1000
virus	5000

Tab.1.

Place	[mGy/y]
United States	2.6
Nile Delta	3.5
Exposed workers	3.6
Jet air flyers	5.0
Kerala, India	4-23
Guapara, Brazil	10-18
Apaxi, Brazil	35
Optimum	100
Ramasari, Iran	243
Guarapari, Brazil	263
Maximum safe level	10000
Proposed person allowance	5.0

Tab.2.

People from Nagasaki or Hiroshima who during A-bomb explosion received doses of 60 to 700 mGy appear to live longer than those who received either higher dose or none[1,2].

Till 1990 the information about RH in scientific literature had only little meaning however a great deal of data shown that high and low-level doses induced opposite results in microbes, plants, a variety of invertebrates and many mammals, including humans. The effects of low-level doses cannot be inferred by interpolation between the result from samples exposed to high doses and controls irradiated only by NBR.

The development of A-bombs and political situation in the World ("cold war", existing of two opposite political and military systems) led to extensive researches only on the damaging effects of high-level doses and forced the concept that all doses of IR are harmful. Harm dominated the last half-century of radiobiological research. Even today RH hypothesis is still controversial.

2.IR AND SECONDARY UV - TWO LINKS OF THE SAME ENERGETIC CHAIN

In my opinion there is close relationship between IR and secondary UV emission from the cell. I postulate the above hypothesis based on the principal biological fact - the process of cell division (mitosis) is conditioned by two factors, namely: by metabolic processes which lead cells to dividing stand-by, and by "impulse" (stimulant) which starts division, proliferation and mitosis processes[4,5].

I suggest that the IR can create this so-called „starting impulse". Even low intensity of short electromagnetic waves (180-220 nm) or a few quanta can start mitosis. On the other hand under the irradiation of gamma rays the increasing of mitosis index is observed[6,7].

2.a. PROBABLE SOURCE OF PHOTON EMISSION FROM THE CELL

Konev[8,9] has carried out the pioneering work on photon emission and cell cycle. He was the first to employ the UV sensitive photomultiplier tube to detect UV photon emission from living organisms, using synchronized cultures of *Candida utilis*. Spectral analysis indicated that the wavelength range was 250-380 nm. The most extensive investigations on photon emission in the cell have been performed in meiosis during pollen grain formation in the anther of *Larix europea*[10] and in mitosis of yeast *Saccharomyces cerevisiae*[11].

First a biochemical reaction has been looked for that is based on a physiological process of general nature. Mainly Russian[12] investigators have been successful in finding some distinct correlation between low level luminescence and radical reactivity, originating essentially from lipoxygenaese reaction.

Guided by the photon storage hypothesis, Popp[13] suggested that only DNA can work as the coherent biological photon store. In order to examine whether DNA really works as a photon store[15] performed a basic experiment by using ethidium bromide as a probe. At least Van Wijk[15] experiments have confirmed that a considerable part of biological photon emission originates from DNA.

Li and Popp[16] have proposed a physical explanation of photon storage of DNA on a molecular level, but only a very general approach to the mechanism has been suggested. They postulated that exciplex (exciton-) states of the DNA base pairs are responsible for this effect.

In the latter experiments, photon emission was measured as a function of the cell-division cycle. The research has shown that photon emission - for instance - in yeast follows a characteristic pattern in the course of the cell-division cycle, increasing in the late S phase to the G2 phase[11,17]. The estimated photon spectrum is continuous, with maximum in the UV and blue region.

The source from which the emission from yeast originates is not known. It has been suggested that the UV component arise from excited tryptophan[18,19] . I have tried irradiated this compound but till now with repulse. Exciting tryptophan by ionizing radiation is difficult.

2.b. CERENKOV RADIATION – CERENKOV HORMESIS CH

It is well known that all living systems contain some natural radioisotopes and all are under the constant cosmic ray irradiation. Any charged particle that moves at a velocity higher than the phase velocity of light in a medium produces Cerenkov radiation. Quickenden[20] reported that the exposure of pure water to cosmic or NBR (for example -^{14}C,^{32}P,^{40}K) leads to the excitation of UV and visible emission in addition to Cerenkov radiation. The excitation of bacterial and yeast suspensions by the Cerenkov rays from ^{32}P results in fluorescence with a spectral distribution similar to that of MR. Barenboim and Domanski[21,22] have studied such important molecules as tryptophan, lysozyme, DNA and RNA and have found that these compounds are similarly excited by ^{32}P and ^{40}K to produce their characteristic fluorescence. Because Cerenkov radiation is totally absorbed inside cells, consequently these photons must play very important part in energetic balance in living organism.

3.EXPERIMENTS AND RESULTS

As we know from radiation chemistry the formation of H_2 and H_2O_2 are equally possible in aqueous solutions irradiated by ionizing radiation. The primary ionization of the water molecule is followed by the recombination and fast dissociation: $H_2O \rightarrow H_2O^+ + e^- \rightarrow H_2O^\bullet$. Part of the excited water molecules dissociates into radicals: $H_2O^\bullet \rightarrow H^\bullet + OH^\bullet$. Molecular products form through the recombination radicals: $H^\bullet + H^\bullet \rightarrow H_2$ and $HO^\bullet + OH^\bullet \rightarrow H_2O_2$. The above combination processes take place at the beginning of the life the clouds when the local radical concentrations are still high.

Therefore, when the water solution was irradiated, as the product of radiolisis some concentration of hydrogen peroxide has been received. This chemically aggressive compound effects on another bio-important compounds.

3.a. EXPERIMENTS WITH GLYCINE

I took into consideration glycine - the simplest amino acid (endogennic), an element of proteins. The influence of hydrogen peroxide on glycine has been examine. Hydrogen peroxide produced may in turn continue oxidation:

$$H_2NCHR - COOH \xrightarrow{H_2O_2, NH_3} O = CR - COOH + h\nu$$

During this process some secondary emission has been detected (Figure 1). The fact that quartz rather than glass permeable for this radiation indicates that the latter emission belongs to the UV range of spectrum. It was interesting to investigate for how long time it is possible to reveal this secondary radiation. The results presented in Figure 2 show that the effect was quite high within 20-30 minutes for the beginning of the experiment (after adding NH_3). Then it decreased by the next 1 hour (23).

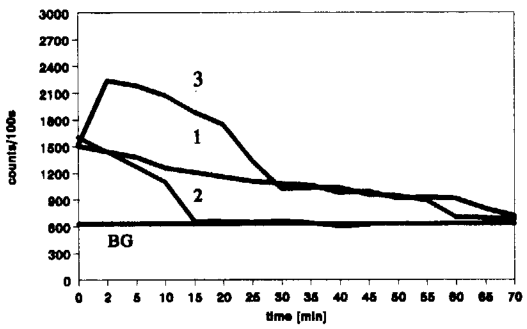

Fig.1. Secondary emission from Gly (different ammonia concentration)
1:Gly-0.87M,hyd.per-0.7M,amm-0.7M
2:Gly-0.87M,hyd.per-1.125M,amm-0.875M
3:Gly-0.9M,hyd.per-0.9M,amm-0.7M

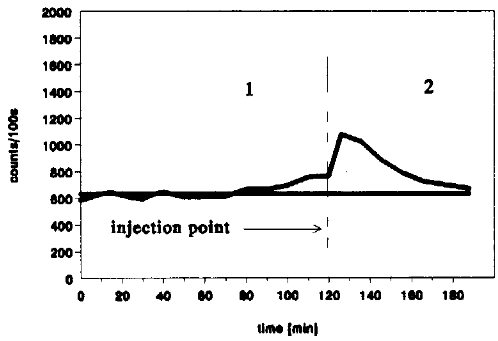

Fig.2. Gly emission as a function of Ammonia concentration.
1:Gly-0.87M,hyd.per-0.7M,amm-0.35M
2:Gly-0.8M,hyd.per-0.67M,amm-0.67M

If water solution of glycine was irradiated by gamma rays we received the following :

$$\gamma + H_2NCHR - COOH \xrightarrow{H_2O, NH_3} O = CR - COOH + h\nu$$

I conclude that this UV quantum is nothing else as the hypothetical Gurwitsch mitogenetic radiation.

3.b. EXPERIMENTS WITH HUMIC ACID

Humic substances (HS) belong to the most widespread biopolymers. However exact structure of HS is unknown it suggests that these compounds could be treated as a rich source of energy, carbon and nitrogen for soil microorganisms. From the energy point of view, the transformation process of plants' or animals' materials into humic substances, is exergonic one. The degradation of humic acids (HA) by ionizing radiation (IR) influence certain physical and chemical properties of soil and aquatic environment..

As the consequence of HA' degradation the following processes are observed:

- direct stimulation or inhibition of soil's and plants' microorganisms by products of HA degradation;
- influence on the soil structure through changing sorptive, chelate, oxido-reduction properties and organic substance mineralization;
- sensibilized degradation and activation of organic compounds contained in superficial soil layer (especially pesticides).

Ionizing radiation in biopolimers is known to cause the following chemical processes:

- chemical compounds decomposition (for example : di-sulfide, hydrogen and peptide, deamination and decarboxylation), which caused biopolimers degradation;
- creation of non-specific chemical bounds in biopolimers (covalence, hydrogen, ionic) which caused polymerization and aggregation of molecules and incorporation of atoms and small molecules;
- other modification of aminoacids residuum (changing electrical charge, for example).

On the other hand the specified chemical changing can create next changes of physical and chemical properties, such as: spectral characteristics, viscosity, constant of sedimentation, molecular mass, isotopic exchange ability and so on.

More often biological influence of IR is indirect, based on the secondary ionization (it refers to hydrated habitats generally).

Because processes of the oxidative degradation are exergonic, we can experimentally observe some energetical stages, which conditioned creation of excited molecules. As the consequence chemiluminescence (CL) emission is measured.

In my experiments HA (SERVA) has been examined. The solution of HA (200 mg HA in 1000 cm^3 of 0.1 N Na_2CO_3) was irradiated in Russian RChM-gamma-20 (Co-60) equipment in the following absorbed doses (1 kGy, 2 kGy, 5 kGy, 19 kGy, 40 kGy, 50 kGy, 60 kGy and 90 kGy) has been.

RESULTS

After absorption of high doses of IR by HA some degradation processes have been observed. The secondary chemiluminescence accompanied to this process. Only HA in a dried HA form irradiated was even at 90 kGy stable,. After irradiation HA changed its color from dark-brown to straw-colored. For higher absorbed dose the effect of colors' changing was more visible (described by the absorbancy or transmittance, at λ= 254 nm) and the intensity of CL is higher. Furthermore, relation between intensity of chemiluminescence and absorbed dose rate (Fig.3) and between transmittance and absorbed dose rate (Fig.4) has been found.

CONCLUSIONS

All experiments leads to the following conclusions – after the process of HA irradiation in high doses we observed :

- oxidative degradation; it caused creation of low molecular products with increased amount of COOH, i.e. class of fulvic acids;
- polymerization of HA and its fragments caused creation of high molecular products (humins).

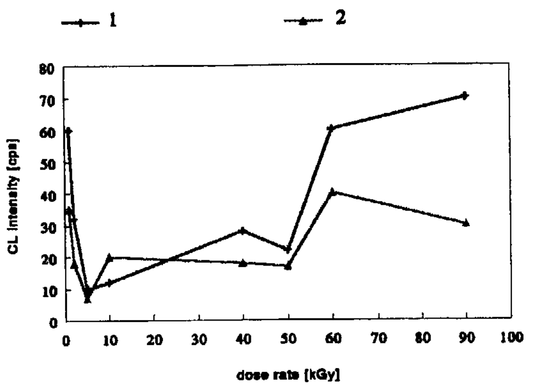

Fig.3.Intensity of chemiluminescence and absorbed dose rate of gamma irradiation ^{60}Co (1-immediate measurement,2-delayed 40min)

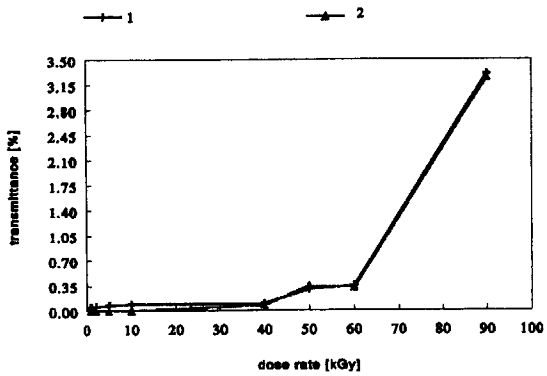

Fig.4 Relations between transmittance and absorbed dose rate gamma irradiation ^{60}Co for λ =254 nm (1-immediate measurement,2-delayed 40min)

For the absorbed dose higher than 50 kGy the process of HA radio-degradation was strongest.

There is almost no published research on the influence of ionizing radiation on HS. What would be the fate of this the most important and vital component of soils and waters in the case of an nuclear accident?

4.a. HOW TO EXPLAIN CREATION OF SECONDARY UV EMISSION AFTER IRRADIATION OF IR?

If we irradiate some living objects with low doses of IR macromolecules of DNA, RNA, proteins will probably turn to excited states. As a result of these processes the polaritons are created. Polaritons create the subsequent coherent emission from DNA. This secondary radiation (the so-called DNA fluorescence) has much longer wavelength than primary radiation, which excited DNA molecules. This secondary radiation with a wavelength in UV region is analogous to postulate by Gurwitsch mitogenetic radiation MR.

Therefore, I deduce that IR can create secondary UV. On the other hand, only IR without excessive reduction can penetrate a deep region of a microorganism, because UV is easily absorbed by biological tissue.

4.b. MEDICAL ASPECT OF RADIATION HORMESIS RH AND CERENKOV HORMESIS CH.

We know epidemiological evidence which showing that human cancer mortality rates are lower in areas of high NBR than in low-level radiation regions. Some physicians postulated that low-level doses of whole-body irradiation may reduce cancer induction - see UNSCEAR 1994 Report[24]. This hormetic phenomenon appears in this respect as a possible new method of therapy. Maybe in the near future we will irradiate our children like now we are inoculating them. It is surprising proposal but if we remember how vaccine works in human organism we understand easily the idea of hormetic therapy. ***Based on the experiments and epidemiological evidences the following doses are recommended: 20 mGy/y for selected organs and 100 mGy/y for whole-body chronicle irradiation.***

As I mentioned before Cerenkov radiation is totally absorbed inside cells. Consequently these photons must be play very important part in energetic balance in living organism.

I postulate that Cerenkov radiation may converse - like IR - into UV photons. In my opinion this is very important problem because the simple calculation shown that for ^{40}K about 10 Cerenkov photons will be created during 1 second in 1mm of water's layer. Consequently for adult (70 kg) we should measure more than 10^8 Cerenkov photons per 1 sec. For phosphorus ^{32}P and carbon ^{14}C less but still very high number - Tab.3.

Element	Atom's number	Disintegration/sec
T-3	$1.7*10^9$	3
C-14	$8.1*10^{14}$	$3.1*10^3$
K-40	$1.2*10^{21}$	$4*10^7$

Tab.3

I think research on the influence of Cerenkov or natural background radiation on living systems should be advanced. Maybe this is among the other important factors not only in the evolution of biological systems but in the creation of Earth's life in general.

I proposed deexcitation processes in biomolecules as a common denominator of UV and ionizing radiation interacting with living cells, underlying both radiation hormesis and creation the secondary UV, which can be identify with postulated by Gurwitsch mitogenetic radiation MR.

It is therefore extremely important and interesting for scientists to find out to what extent might the low-level radiation be beneficial to most individuals.

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3.19 EXTENSION LECTURES: THE EFFECTS OF RADIATION FROM ATOMIC BOMBING

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ABSTRACT

About 56,000 A-bomb survivors are living in Nagasaki city even today. Nagasaki citizens, whether they are A-bomb survivors or not, can not live without concerns on the existence of radiation effects. They have fears of any amount of radiation and are afraid that it may harm their life. As results of studies in the university on radiation effects are not familiar to the citizens, we have started extension lectures on "the effects of radiation from A-bombing" to them since 1990. We discuss the problems as well as significance of the extension lectures by reporting the details of the extension lectures which we have managed in the past.

1. Introduction

About 56 thousand A-bomb survivors live in Nagasaki City today, and many people in the city are related to the survivors, including family including the second generation of survivors, relatives and acquaintances. People who have came into the city after a long time of A-bombing and who are not directly related to the A-bombing are also conscious of radiation from A-bombing. Unlike conventional bombing, A-bombing makes survivors, as well as citizens not related to the survivors and live in the city, afraid of its effects. However, studies performed in the university are not always understood by citizen. We have opened the first extension lectures on the effects of A-bombing in Nagasaki in 1990. From 1995 we have been planning the extension lectures every year.

2. Opening of Lectures

Following 6 sessions were held since 1990 to 1998.

(1) September, 1990: 5-day course of 1 hour 45 minutes on Friday
(2) July, 1995: 3-day course of 3 hours on Friday
(3) August, 1996: 1-day course of 4 hours
(4) August, 1997, 1-day course of 3 hours

(5) August, 1998, 1-day course of 3 hours

(6) December, 1998, 1-day course of 2 hours and 15 minutes

3. Contents of Lectures

Following contents were included in the extension lectures performed in the past.

(1) Character of Radiation:
- Power of A-bombing
- Radiation from A-bombing
- Radiation and radioactivity
- Radiation and active oxygen
- Measurement of radiation: practice

(2) Effects of Radiation on Human Beings:
- Radiation and human cells
- Radiation injury
- A-bomb syndrome
- Early effects of Nagasaki A-bombing
- Late effects of Nagasaki A-bombing
- A-bombing on Nagasaki and cancer
- Fifty years of study on leukemia induced by A-bombing
- Cellular damages induced by radiation and its defense mechanism

(3) Health Control:
- Medical data base of A-bomb survivors
- Medical examination of A-bomb survivors and its benefit
- Health control of A-bomb survivors
- Health of aged persons

(4) Application of Radiation:
- Clinical application of radiation and radioisotopes
- Radiation diagnosis and radiation therapy
- Radiation for leukemia treatment
- Application of radiation and radioisotope in life science

(5) Effects of Accident of Chernobyl Atomic Power Station:
- Situation of accident of Chernobyl atomic power station
- Health problems of Chernobyl accident

4. Discussion

To make clear the problems and solution of the extension lectures, questions are proposed and answers to them are presented in the followings.

(1) What idea do the citizens have on radiation?

a: They have feeling of fears of radiation without reliable reasons.

b: They think that even a very small dose of radiation induces injury.

(2) What don't they know?

a: They don't know that people living on the earth are exposed by natural radiation.

b: They don't know that they contain radioactive ^{40}K in their body.

c: They don't know that low level radiation induces no injury.

d: They don't know well that radiation and radioisotopes are applied in medical treatments.

(3) What should we consider for the extension lectures?

a: We should try to make the citizens understand scientifically and medically what they don't know.

b: We should try to use words which they use in their daily life, not technical terms.

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3.20 STUDIES OF RADIOLOGICAL CONSEQUENCES ON THE REPORTS OF CHERNOBYL ACCIDENT

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Summary

1) Relation of radiation related quantities such as radioactivity, exposure, absorbed dose, dose equivalent, effective dose equivalent and radiation protection standards were explained as easy as a beginner could understand. 2) Using published data including IAEA data in the report "One Decade After Chernobyl (Summary of the Conference Results, 1996)" and some reports, outline of explosion, exposure dose and radiation effects which gave to the human body were briefly described and some rational ways for understanding the data were shown.

1. Introduction

It is considered that there are several causes which bring about excessive radiation-phobia in majority of public. These are 1) a human can not recognize the existence of the radiation with five senses of sight, hearing, smell, taste and touch, 2) the straight line relation hypothesis between radiation exposure and its biological consequences would produce misunderstanding in public, as if the relation is a fact and 3) a rational way of understanding radiological consequences may be insufficient in many people.

Here, in connection with the last subject, I attempted to give some rational ways for understanding the radiological consequences written in the reports of the Chernobyl accident which is a matter of great concern to us. It is another reason of choosing the reports of Chernobyl accident to probe a possibility of putting these reports to some use in school education.

2. Radiation related quantities and radiation protection standards.

Before going to the matter of Chernobyl accident, I described about radiation related quantities and radiation protection standards including risk coefficient for a better understanding of matters. For the radiation related units, there are five principal quantities such as radioactivity, exposure, adsorbed dose, dose equivalent, effective dose equivalent and risk coefficient. The former three are physical quantities and the latter three are quantities for radiation protection.

a. Radioactivity (Bq, Ci, dpm and cpm)[1,2]

A quantitative expression of intensity of rdioactive nuclide is the radoactivity, abbreviated by symbol A. The SI unit of radioactivity is the Becquerel (Bq) defined as the number of disintegrations per second (dps): 1 Bq = 1 dps. It is a very small activity and usually multiples of it are used: PBq, TBq, GBq, MBq, kBq. The traditional unit of activity was Curie (Ci). Although the use of the Ci unit is not recommended it is defined to be 1 Ci = 37 GBq = 3.7×10^{10}.

Activity is often characterized by the number of disintegrations per minute (dpm): 1 dpm = 60 Bq; 1 Ci = 2.22×10^{12} dpm. Taking the degree of efficiency of the measurement to be η, we can formulate the following relationship between the counts per minute (cpm) and the activity in dpm: 1 dpm = $1 \times 1/\eta$ cpm.

In the following description, I deviate sometimes from the SI recommendations and use Ci (as well as its fractions mCi, μCi and multiples MCi, kCi).

b. Exposure (C/kg and R) and Exposure rate (C/(kg·s) and R/h)[1,3,4]

The electromagnetic radiation (gamma rays or X rays) causes ionization in air. The measure of the interaction is characterized by the exposure abbreviated by symbol X. The SI unit of exposure is coulombs per kilogram of air (C/kg). (amount of 1 kg of air corresponds to the volume of 773 liter of air at temperature of 0 °C and pressure of 1 atm.) The traditional unit of exposure was Roentgen (R): 1 R = 2.58×10^{-4} C/kg; 1 C/kg in air = 38 Gy in water (see section **2.c.**). The exposure is called by the name of "radiation dose", too.[4]

Exposure rate is exposure per unit of time, stated as coulombs per kirograms per second (C/(kg·s) or A/kg). The traditional value of 1 R/h is equivalent to 7.167×10^{-8} A/kg.

c. Adsorbed dose (Gy and rad)[2,3,4]

The energy of both corpuscular and electromagnetic radiation is adsorbed during the passage through an organism in the same manner as in any other material, by ionization and excitation of atoms or molecules of the material. In a biological system this ionization causes damage directly by disruption of chemical bonds in the cell. The interaction of the radiation with water both inside and outside cell nucleus produces free radicals which also damage the cell by causing oxidation-reduction reactions.

As a result of interaction between radiation and a material, the amount of energy absorbed in the irradiated material per unit mass is called the absorbed dose abbreviated by symbol D. This applies to all radiations and material. The SI unit for adsorbed dose is Gray (Gy). One

Gray means that one joule of energy absorbed per 1 kilogram of material; the traditional unit of absorbed dose was rad (rad): 1 Gy = 100 rad = 10000 erg/g = 10000000 erg/kg = 1 J/kg.

If radiation dose is 1 R, then absorbed dose will be almost 1 rad. If the value of exposure is estimated in absorbed dose in water, 1 C/kg in air is equivalent to 38 Gy:

$$\begin{aligned}
1\ \text{C/kg} &= 2.998\cdot 10^{6}\ \text{esu/g} \\
&= 2.998\cdot 10^{6}\ \text{esu/g} \times (1/4.803\cdot 10^{-10}\ \text{esu/ions}) \times 34\ \text{eV/ion} \\
&= 2.122\cdot 10^{17}\ \text{eV/g} \\
&= 340000\ \text{erg/g} = 34\ \text{Gy in air} \\
&= 34\ \text{Gy in air} \times (\text{electron density per gram of water} \\
&\qquad / \text{ electron density per gram of air}) \\
&= 38\ \text{Gy in water}
\end{aligned}$$

4 Gy of electromagnetic radiation (: 4 Sv) of the adsorption dose (which brings 50 % death) causes 53000 of ionizations per human cell nucleus. In comparison with the number of atoms (: approximately 10^{11} in DNA strand (wt. 5.6 pg) of a human nucleus, the number of ions formed by irradiation is very small. However this quantity of adsorption dose brings about serious biological effects (see section **2.f.**).

d. Dose equivalent (Sv)[1-3)]

The degree of biological effect is depend on the kind and energy of the radiation, even in cases where the absorbed dose is the same. In order to take into account the different extent of the biological effects of different radiation, the concept of dose equivalent abbreviated by symbol H was created. The dose equivalent is used only for radiation protection at the low exposure dose. In the estimation of degree of biological effects at high exposure dose, the concept of the relative biological effectiveness (:the RBE value) is used. The dose equivalent can be obtained by multiplying absorbed dose, D, by a quality factor, Q, and modification factor, N : $H = D\cdot Q\cdot N$. The quality factor relates to the radiations of different LET (linear energy transfer). For example, quality foctors of 1 for beta rays (electron rays) and gamma rays (X-rays), and 20 for alpha rays are currently used. The modification factor adjust for differences due to irradiation conditions, such as exposure rate, however, at present, a value of N is taken as 1.

The SI unit of dose equivalent is Sv: 1 Sv = 1 J/kg. The fractions mSv, μ Sv are also used. The traditional unit of dose equivalent was rem: 100 rem = 1 Sv. If the gamma rays or X-rays are externally exposed to the human body, 1 Gy of adsorbed dose become 1 Sv of dose equivalent; 1 rad likewise become 1 rem: 1 Gy = 1 Sv; 1 rad = 1 rem.

On 1990 ICRP recommendation, the term of "dose equivalent" was renamed to "equivalent dose". Under current Japanese laws and ordinances

(Concerning Prevention of Radiation Hazards), the name of dose equivalent is still used.

e. Effective dose equivalent (Sv)[1,3,5]

Radiation effects on the human body appear in two form: although the relationship between exposure dose and biological effect is still a matter of conjecture, it is now accepted that the probability of occurrence of some late and somatic effects (e.g. cancer) and genetic effects, rather than the severity of the effects, varies with the magnitude of the radiation exposure (: the straight line relationship). Threshold dose can not be assumed below which some harmful effects may not occur. This kind of effects is called stochastic effects. In contrast, the acute and somatic effects (e.g. loss of hair) and some of late and somatic effects (e.g. leukemia) depend on the magnitude of the dose received, and there may be a threshold dose below which no detrimental effects can be observed. These effects are non-stochastic effects. On 1990 ICRP, the term of "non-stochastic effects" was renamed to "deterministic effects", but the old name of "non-stochastic effects" is still accepted in Japanese law.

Within the range of low doses under keeping properly the radiation protection rules, the number of radiation workers or public suffering from a deterministic effects is virtually zero. However there must be serious concern about stochastic effects. For the stochastic effects, the sensitivity to radiation varies with the tissue (or organ). Even if dose equivalent is the same, the probability of occurrence of radiation effects depends on the tissue which is irradiated. In order to assess the total stochastic effect on various tissues throughout the body, effective dose equivalent, abbreviated by the symbol of H_E, is used. To get an effective dose equivalent, tissue dose equivalents, H_T, multiplied by weighting factors for tissues, W_T, (expressing each tissue's sensitivity to radiation) are added together; Unit is Sv (or rem):

$$H_E = \Sigma_T W_T H_T$$

f. Radiation Protection standard[3,5,6]

At an exposure dose of 0.25 Sv or less, no clinical symptoms by non-stochastic effects are recognized. The excess exposure of a whole-body to radiation in one time causes a harmful acute effects. A minimum lethal dose is 2.25 Sv. A dose about 4 Sv brings 50 % death within 30 days. At 7 Sv, the probability of death is 100 %.

The aim of radiation dose limitation in the ICRP (International Commission on Radiological Protection) recommendation is to prevent the stochastic effects of cancer (see section 2.e.). Although the straight line relationship between radiation exposure and its biological consequences for stochastic effects is assumptive, these error, if anything, is on the side of safety

For a radiation worker, the ICRP, in 1977, recommended the effective dose equivalent limit of 50 mSv (5 rems) per year. For public, in addition to 2.4 mSv, which was estimated as an annual effective dose equivalent due to natural background, a whole-body exposure to radiation was limited to 1 mSv (100 mrem) per year. For the annual dose limit of radiation worker, the value of 50 mSv are still accepted in present Japanese law, although, in 1990, the ICRP recommended new effective dose equivalent limit of 20 mSv/y for a radiation worker.

Risk coefficient[3]: The degree of occurrence of harmful effects induced by exposure is called a risk. The risk does not mean that harmful effects will occur, it is only the probability that they will occur. The degree of risk is represented by a risk coefficient. Present Japanese law was based on the ICRP 1977 recommendations and has accepted a risk coefficient of 1.65×10^{-2}/Sv which is a cumulative value of probability of occurrence of lethal cancer on every tissue and organ.

In 1990 the ICRP recommended new risk coefficient, newly named nominal lethality probability coefficient, of 5.00×10^{-2}/Sv for public including children and 4.00×10^{-2}/Sv for a radiation worker. But author describe with use of the risk coefficient accepted in Japan in the text.

3. Studies of Radiological Consequences on the Chernobyl Accident

3.1. Outline of explosion[7,8,10,11]

At am. 1:23 on 26th April 1986, an accident of explosion of reactor unit occurred at unit 4 of the Chernobyl nuclear power plant (graphite-moderated light-water-cooled reactor; 1000 MW of electric power). 10 km north of Chernobyl, Pripyat having population of 45 thousand is located and 130 km south, Kiev having population of 2.5 million is located. This accident was an occurrence during shutdown of the reactor for routine maintenance. At the time of accident an experiment was carried out and the reactor staff did not keep to the operating rules. The reactor became uncontrollable, causing the increase of output by about 100 times of the rated output with the steepest ascent that resulted in a generation of enormous amounts of steam, an explosion and the ejection of enormous amounts of rdioactive material.

Releases of radioactive materials was as follows: the total activity of all the radioactive materials: around 12×10^{18} Bq including noble gases (^{85}Kr, ^{133}Xe etc.) $6\text{-}7 \times 10^{18}$ Bq, ^{131}I $1.3\text{-}1.8 \times 10^{18}$ Bq, ^{137}Cs ca. 0.09×10^{18} Bq, ^{134}Cs ca. 0.05×10^{18} Bq and ^{90}Sr 0.01×10^{18} Bq. About 3-4 %

of used fuel in the reactor as well as up to 100 % of noble gases (Kr,Xe) and 20-60 % of volatile radionuclides (20-40 % of Cs, 50-60% of I) were released at the time of accident. The amount of radioactivity was assumed to be 200 times of radioactivity of both Hiroshima and Nagasaki atomic bombs together.

It is considered that if the 1000 MW nuclear reactor involves a radioactivity of $40x10^8$ Ci after 1 day from the time of shutdown, this activity decreases to $10x10^8$ Ci after 1 month, to $1x10^8$ Ci after 1 year and $1X10^7$ Ci after 10 years. [10] Present total activity in the destroyed Chernobyl reactor is estimated to be $700x10^{15}$ Bq ($1.9x10^7$ Ci).[7]

3.2. Exposure Dose[1-12]

a. The persons who received exposure to radiation[7]

The response to the accident was carried out by the initial persons having dealt with accident and a large number of specified workers called "liquidators" and so on. The number of persons who received exposure and the individual exposure dose of them are shown in Table 1. The group 1 of several tens persons received a lethal dose of 1000 mSv. The group 4 was the inhabitants having lived within a distance of 30 km

Table 1. The number of persons who received exposure to radiation.

Groups of persons who received exposure to radiation	Number of persons	Exposure dose mSv
1. Initial persons having dealt with accident	several tens	1000 (100 rem)
2. Liquidators (workers such as operators, non-professional personnel, etc on a period of 2 years.)	200,000	100 (10 rem)
3. Persons who were registered as involved in activities relating to the reduce of extent of disaster.	600,000 ~ 800,000	
4. Inhabitants having been evacuated from their home during a period from Apr. 27 to the middle of Aug. '96 in Mogilev and Gomel districts.	116,000 (fewer than 5 % had received doses greater than 100 mSv; fewer than 10 % had received doses greater than 50 mSv)	

(Between 1990 and the end of 1995, furthermore, decisions were taken to resettle the persons of 53,000 in Ukraine, 107,000 in Belarus and 50,000 in Russia.)

from the power plant and having been evacuated; their exposure dose exceed the annual effective dose-equivalent limit of 50 mSv/y (5 rem/y) for radiation worker (formal standard value for enforced evacuation).

b. The exposure dose of inhabitants[9)]

The exposure dose of inhabitants who were evacuated is shown in Table 2. The inhabitants of 135,000, having been evacuated, received a collective effective dose-equivalent of $1.56x10^4$ man-rem (the value in Table 2 differ from the value in Table 1 because of difference of cited references.) The number of fatal cancers, being revealed in future, due to the accident was estimated to be 160-230. (Author's note: $1.65X10^{-2}$ $x134.9x10^3X0.155$ = 258, where $1.65X10^{-2}$ is a risk coefficient per Sv. The assumed fatality against to the population in question is 0.2 %.) The fatalities of 100-500 was assumed among the persons of 24000 having been exposed to high dose radiation, where the risk coefficient was 0.0125-0.05 /Sv[10)]. (Author's note: 0.0125x24000x0.44 = 132 (fatality = 0.4 %), 0.05X24000X0.44 = 528 (fatality = 2 %))

Table 2. Exposure dose of inhabitants who were evacuated.

Distance from power plant(km)	Persons ($x10^3$)		Exposure dose (rem)	
Citizen of Prypyat who were evacuated within the 27th Apr.				
3	45		3.3	
Persons who were late for evacuation.				
3 -7	7.0		54	
7-10	9.0	(24000 pers.	46	av.
10-15	8.2	in total)	35	44
15-20	11.6		5.2	
20-25	14.9		6.0	
25-30	39.2		4.6	
	* 135.9 in total		av. 11.5	

* Collective effective dose-equivalent = $135.9x10^3$man x 11.5 rem
= $1.56x10^4$4 man-rem

c. Collective effective dose-equivalent for public[9)]

It was estimated that the people of 74.50 million living in Ukraine (pop. 50 million), Belarus (pop. 10 million) and Russia (pop. 150 million) received 290,000 man-Sv of collective effective dose-equivalent over their lifetimes of 50 years (i.e., per caput effective dose-equivalent was 290,000 / $74.5x10^6$ = 0.0039 = 3.9 mSv/person/lifetime). The fatality due to the committed dose was assumed to be 0.006 % ($1.65X10^{-2}x0.0039$ = $6.4x10^{-5}$), which would be impossible to distinguish from the spontaneous mortality due to cancer (26.5 %).

d. Territories with radioactive contamination[11,12]

There are two contaminated territories of 1) central region centerring around the atomic power plant in Chernobyl, Ukrine, and 2) Bryansk-Belarus contaminated region, north of Chernobyl, ranging over Mogilev-Gomel districts in Belarus and Bryansk district in Russia Federation.[11] Chernobyl lies near the north border of Ukrine (600,000 km^2) being contiguous to Belarus (210,000 km^2) and Russia (17070,000 km^2).

Three years after the occurrence of accident, the distribution of ^{137}Cs, whose half life (30 y) is very long and which can be detected easily, in the ground surface was revealed. The contamination density of 37 kBq/m^2(1 Ci/km^2, 0.001 mCi/m^2) - 555 kBq/m^2(15 Ci/km^2, 0.015 mCi/m^2) was measured at the area of about 100,000 km^2, and the activity levels in excess of 555 kBq/m^2 (15 Ci/km^2, 0.015 mCi/m^2) was measured at the area of larger than 100,000 km^2. The contamination areas of high level of 1480 kBq/m^2 (40 Ci/km^2, 0.04 mCi/m^2) and 5200 kBq/m^2 (140 Ci/km^2, 0.14 mCi/m^2) were found in the central region and the Bryansk-Belarus contaminated region respectively. The values of these high contamination densities (ca. 200 Ci/km^2) are understandable, if the ^{137}Cs activity of $2X10^6$ Ci ($0.074X10^{18}$ Bq) that is released came down to cover the ground within 10,000 km^2.

Present author notes in parentheses that the exposure rate at the distance of 1 m from a point radiation source of ^{137}Cs of 1 mCi can be calculated to be 0.35 mR/h (: external exposure dose rate of 3.5 μ Sv/h). Using this value being the case for a point radiation source, the annual external exposure dose are tentatively estimated to be 1.23 mSv/y and 4.4 mSv/y for the radiation source of 1480 kBq and 5200 kBq which existed on the ground surface of area of 1 m^2:

$$0.04\times 0.35 = 0.014 \text{ mR/h} = 0.14 \ \mu\text{Sv/h} = 1.23 \text{ mSv/y}$$

$$0.14\times 0.35 = 0.05 \text{ mR/h} = 0.5 \ \mu\text{Sv/h} = 4.4 \text{ mSv/y}$$

These values are 2 - 10 times of natural terrestrial annual dose of 0.4 mSv/y (worldwide average value)[10]. Although these estimation are a little underestimated, these additional external exposure doses due to the contamination would be reasonable in the order of magnitude. The authorities recommended resettlement to the population living in areas with the contamination densities more than 1480 kBq/m^2.[11]

In the report of 9 years after the occurrence of accident from Bryansk, an affair of radioactive contamination is almost the same as before[12]: the minimum value of contamination density of the territories was 57 kBq/m^2 (0.0015 mCi/m^2) and the maximum was 3486 kBq/m^2 (0.094

mCi/m²). An internal exposure due to the eating habits of inhabitants was 0.2 - 1.4 mSv/y.

3.3 Radiation effects which gave to the human Body

a. Acute radiation syndrome

The 12 hours after the occurrence of accident, patients of 499 were transferred to Kiev and Moscow. A total of 237 occupationally exposed individuals were suggested to be suffering from clinical syndromes due to radiation exposure. The 149 patients were mild case, 55 middle case, 21 serious case and 21 extreme serious case. Their exposure doses were in the range of 1 - 10 Gy. The medical treatment such as shower washing with soap, blood collecting, urine test, measurement of radioiodine in the thyroid, hole body radioactivity measurement, treatment for burn and bone marrow failure. The number of persons who received exposure to radiation and who died by acute radiation hazards is shown in Table 3.

Table 3. The number of persons who received exposure to radiation and who died by acute radiation hazards

Clinical observed effects		Number of persons
Occupationally exposed individuals of clinical syndromes due to exposure		237
Patients of acute radiation syndrome		134
The dead out of these 134 patients within the first three months		28
Patients received doses greater than 10 Gy and received intestinal function change:	11	
The dead out of the 28 patient who died, with skin lesions that affected over 50 % of total body surface area:	26	
The dead, out of these 134, who died over the past ten years after the acute effect		14

b. Late and somatic effects

There is the thyroid effects as a clear evidence of public health effects of radiation exposure due to the Chernobyl accident. The increase of the thyroid cancer was observed in children. During 9 years since the accident occurred, the thyroid cancer was diagnosed in the cases of 800 children under 15 years old. More than 400 of these cases were in Belarus.

The incidence of thyroid cancer increased to $4.5X10^{-5}$ (cases of 400 /

pop. Belarus of 10^7) with significant high rate in comparison with the spontaneous incidence (10^{-6}) of thyroid cancer. For the affair of appearance of late and somatic hazards between the cases of Hiroshima and Chernobyl, the differences were found as shown in Table 4 (WHO report).

Table 4. Difference of type of appearance of late and somatic hazards between the cases of Hiroshima and Chernobyl

	Hiroshima	Chernobyl
Exposure	Momentary external exposure with large quantities of dose	External and internal exposure with small dose rate for long time
Incidence of of radiation induced thyroid cancer	Increase in the first 10 years after exposure	Increase in the 4 - 5 years after exposure
Incidence of radiation induced leukaemia	Increase in the first 2 years after exposure; Showing the peak of incidence in the first 7 years after exposure	

Among the inhabitants living in the contaminated territories, to date, an increase of incidence of leukaemia due to the radiation exposure did not observed. Among the 7.1 million inhabitants of contaminated territories and strict control zone, the fatalities due to radiation induced leukaemia were assumed to be the order of 470.[7] In the 1977 ICRP recommendation, the risk coefficient for leukaemia is 0.2×10^{-2}/Sv. If individual life dose is 30 mSv, the fatalities due to radiation induced leukaemia is calculated to be 470 (: $0.2\text{x}10^{-2}\text{x}0.03\text{x}7100000$). This value would be impossible to distinguish from the spontaneous mortalities of 250000 due to leukaemia (: $3.5\times 10^{-3}\times 710000 = 25000$).

The fatalities due to radiation induced leukaemia among the 200,000 liquidators (see Table 1) was assumed to be 200[7] (Cf. $1.65\text{x}10^{-2}\text{x}0.1\text{x}200000 = 330$). This value would also be difficult to distinguish from the spontaneous mortalities of 700 (: $3.5\text{x}10^{-3}\text{x}200000 = 700$).

c. Health effects coming from spiritual stress

Health effects of social severance due to the enforced evacuation and resettlement, and anxiety of hereditary effects on the descendants were increased.

4. Conclusion

At first the mutual relation of radiation related quantities such as radioactivity, adsorbed dose, effective dose equivalent, risk coefficient, etc. were explained together with radiation protection standards for a better understanding of the Chernobyl accident. In the description of consequences of Chernobyl accident, the radioactive contamination was explained in paying attention to the unit of contamination density. The fatality due the radiation induced cancer was estimated with use of radiation risk coefficient. These attempts would be a help of taking out of some rational ways in understanding the data shown in the reports.

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3.21 THE AUSTRALIAN NUCLEAR ASSOCIATION'S AWARD SCHEME FOR THE ADVANCEMENT OF NUCLEAR SCIENCE AND TECHNOLOGY AWARENESS IN SECONDARY SCHOOLS IN AUSTRALIA

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The Australian Nuclear Association (ANA), following the death of the founding treasurer of the Association in a motor vehicle accident, decided to commemorate his long-standing efforts on behalf of the Association through a Memorial Fund, set up in his name, from donations of the membership, for a scheme to advance awareness of nuclear science and technology in secondary schools in Australia. Thus, the ANA David Culley Memorial Award Scheme was established in 1993 to assist with projects chosen with selected secondary schools; David having been an educator himself and at that time, also a staff member of the Australian Nuclear Science and Technology Organisation (ANSTO). For the award scheme to work, a member of the ANA executive provides a link between the Association and a senior specialist staff member of ANSTO, where and with whose co-operation in the area of the project's topic some assistance may be given, together with the school science staff for the operation of the project. The Association provides a cheque to the school to cover basic expenses that may be encountered by the awardee school in the implementation of the project.

The initial undertaking of the scheme involved a competition, limited to those Sydney based secondary schools within the immediate municipal local government district of the Lucas Heights research reactor of ANSTO (HIFAR), being invited by the ANA, to apply for assistance in an experimental project in which an application of nuclear science, specifically neutron activation analysis (NAA), would be able to demonstrated. Co-incidentally, this municipal region in the South East of Sydney, contains the sites of the first recorded landings on the East coast of Australia by Europeans; Cook of Britain in April, 1770, which led to the colonisation by the British, followed by La Perouse of France two weeks later. The region also boasts the well known surf beach of Cronulla, with nearby Gunnamatta Bay behind the headland.

Although there were several applications from the schools of the region the clear winner, as decided by the selection committee, was De La Salle College, Cronulla. Their proposal incorporated a plan to measure the level of various pollutants in local waterways and from the waste water outfall from that region of Sydney. At this time there was significant interest within the same local community in possible levels of radioactive waste water that may have emanated from ANSTO as the waste water outfall also includes the ANSTO sewer discharge. (Thus the trigger for the school's interest may well have been an interest backed by both their geographic location and the parental political influence within the school).

The Association, through a member of the ANA executive further discussed the proposal with the school's physics teacher. The initial plan of waste water effluent analysis, both for radioactivity content and for heavy metals by NAA yielded no significant pollutant levels in either case. After further discussion with the science staff it was decided to make the project more "interesting" by amending the aim to centre on NAA of various heavy metals, specifically within the region of Gunnamatta Bay near to the school. So the first project of the ANA David Culley Memorial Fund was developed with assistance, and indeed close liaison, from the Director of the ANSTO

NAA Becquerel Laboratories Division, Dr. David Garnett. Students from the school together with their teacher and Dr. Garnett redefined the parameters of the project to examine regions of the beach area for heavy metal content. Many of the students of the school use this and adjacent sectors of the beach for recreation throughout most of the year. A second set of samples for comparison was gathered from near the local sports oval.

Several of the students visited ANSTO during the processing of the samples in preparation for activation and again during the counting process. The raw data was presented to the physics students for their own analyses with the results ultimately allowing the students to develop their own animated presentation of their work at the subsequent ANSTO "Open Day". The project took significantly longer than was initially thought, partially due to the overriding requirements of the general curriculum workload, and to the extensive extra curricula activities of secondary school students in sporting and other recreation activities. The results, which included the plotting of Arsenic against Chromium concentrations (four distinct regions of interest) for the first set of samples and the level of gold against distance from the local oval (two distinct regions of interest) posed more questions in the minds of the students than were able to be hypothesised at the time.

ANSTO, as part of their general public relations program provide an Open Day each two years for clients, for local schools and tertiary institutions, and for the general public. This provides an opportunity for visitors to see the operation of the Australian principal nuclear activities venue and site of Australia's only nuclear research reactor. It was indeed an honour for the first ANA David Culley Memorial Project to have been included.

This project set the pattern for the ANA David Culley Award: as most projects to date have been underestimated in the overall times required. However, this factor is now incorporated within the process of liaison with the school to allow as many of the students as practical to be included often through the combination of students from two year levels, viz., Years 10 and 11 or 11 and 12.

The Australian secondary education system covers the years 7 to 12 with the schools being responsible for preparation for the Higher School Certificate series of examinations of Year 12 under State Education Departmental supervision. Although each State of Australia is autonomous in its education program, the examinations in the individual States are broadly consistent between themselves. Also, the Australian secondary education system allows for two types of secondary schools to operate in parallel: those operated by the State (i.e. Government Schools), and those under private (i.e non-State) control, the latter often of a religious or sectarian base, yet with compulsory registration and standards under the particular State system.

For the second ANA David Culley Memorial Award a different approach was tried. Rather than an "open" invitation for a variety of schools to make a submission to the Association, the broad context of an agricultural flavour for the award was set in order to spread the interest (and opportunities for participation) to a larger region than hitherto. Assistance was sought from Landcare Australia for a recommendation of possible Agricultural High Schools that may be interested in participating: Agricultural High Schools being part of the State education system being generally located outside the main metropolitan areas of Sydney and environs, whereas the previous awardee belonged to the Catholic Education System.

Several of the State Agricultural High Schools were contacted with one, the Farrer Memorial Agricultural High School, at Calala (near Tamworth), the centre of a major grain and grazing region some 320 kilometres North of Sydney, proposing their investigation into the silting of the local water supply, in a project designed to compare the historical and recent erosion rates in the catchment of the Moore Creek Reservoir that occurred through concentrated tree felling activities shortly after the reservoir's construction. The reservoir is now completely full of sediment and cannot contribute to the local water management system. (Again note the possible local political interests behind the proposed project). In this case, Dr. Peter Airey, the then Chairman of the ANA, worked closely with the Farrar Memorial Agricultural High School overseeing the low level counting of Be7 and Cs137 in the students sediment soil profile samples: thus differentiating between new and older silt. With modern erosion rates confirmed as much lower than the earlier rates, comparative estimates of actual erosion could contribute greatly to any decision on the future of the reservoir.

Some difficulties were experienced in the carrying out of that year's ANA David Culley Memorial Award because of the distance between Sydney and Tamworth and the infrequent contacts between the parties and delays in the student's visit to Sydney with accommodation being outside the parameters of the ANA's consideration: local drought conditions limiting the availability of the school's excursion funds. However, following the visit to ANSTO by the students the low level counting results were able to be presented which allowed determination of the rate and times of silt build up to be calculated.

Having made approaches to one school within the Catholic education system and one within the State education system (albeit outside Sydney), the third award was made under an again modified system of selection by approaching a large Protestant private girls' school, Pymble Ladies' College of some 1500 students, which had expressed an interest in pursuing a multidisciplinary concept based on anthropological specimen C 14 dating of remnants of various Aboriginal activities that had then recently become available, being exposed during the construction of a nearby freeway. The application of carbon dating principles was driven by the physics students as their contribution to the overall team.

Unfortunately, with many other groups having access to the limited range of specimens (and finding that many of the Aboriginal artefacts had, in fact, been interfered with, and permission of the local Aboriginal community inordinately delayed), the school concluded that although the principles of their initial investigations would be maintained, the central project would be shifted to effectively complete a major investigation in co-operation with the Australian Museum in the dating of a large (and basically undisturbed) Aboriginal midden in a different location, yet still near Sydney.

Samples of sections of the Aboriginal midden were made available through the Museum and with the permission of the local Aboriginal tribe members for carbon dating, using the ANSTO atomic mass spectrometry facilities in co-operation with the head of the physics section, Dr. Claudio Tuniz, whereby minimal sample size specimens were able to be analysed. The results provided the students with the term over which the midden had been used by the local tribe, this working in well with the student's Aboriginal studies program.

The 1997, and fourth ANA David Culley Memorial Award coupled the Association's executive recommendation to incorporate a sector on neutron diffraction, with an industrial emphasis. This time a Catholic regional secondary school, Loyola College, in the industrial sector of

Western Sydney was selected. The school, only some four years old, consists solely of Years 11 and 12, drawing its students from five parochial Catholic schools within the district. The school has some 250 pupils from over 50 national cultures - a most exhilarating educational environment! The school science club, following acceptance by the school administration, and comprising students from both Years many of whom were 'new' to the school, virtually drove the program with the advice and assistance from the two chemistry and physics teaching staff members: these two staff members having industrial experience in radiochemistry and nuclear activities respectively, in government and industrial laboratories prior to teaching.

The project, which relied on the comprehension of the responses to Bragg's Law, and wave and penetration properties of neutrons in various media, required the teaching staff and the Year 12 group to bring the newer pupils to this level of understanding. Also, prior to any demonstrational program at HIFAR, a senior health physicist from ANSTO's Health and Safety Division accompanied by a neutron diffraction specialist from the neutron physics group under Dr. Chris Howard provided resumes of the requirements and facilities at ANSTO, discussing with the science club members how to demonstrate stress relationships within various engineering structural materials under "in-beam" working conditions. The group of students visited HIFAR having some of their own ideas demonstrated in the operations. Stress analysis was shown to be of particular relevance to many of the students, especially those living within the heavy industry zone of Sydney and being aware of nearby industrial practices.

This year's award was made to Trinity Grammar School, Melbourne, a Protestant private boys' school some 1000 kilometres south of Sydney, and under a different State jurisdiction to the previous awards. Included in its curricula, each boy spends time at the school camp near Bendigo, the centre of a former major gold mining region of central Victoria.

Again, NAA was the choice in nuclear techniques recommended by the ANA executive committee for demonstration. To date the students have carried out their own preliminary investigations on the applications of NAA (with particular reference to ore analysis) having some guidance from Dr. David Garnett of Becquerel Laboratories, and are scheduled to collect a limited number of initial trial rock samples from a region expected to yield significant traces of gold during their stay at the school camp this week. These will be prepared for shipment to Sydney for analysis. Next year the second part of the project will be carried out based on the initial sample results. With the second half of the present student team assuming responsibility for the newcomers, no doubt some modification of the sampling zone will follow. Thus the new team would be expected complete the project, including visiting ANSTO early in the new year.

The ANA, over the past four years has hosted the "Nuclear Science and Engineering in Australia" series of conferences, each held over two full days and in conjunction with the Australian Institute of Nuclear Science and Engineering (AINSE) and the Nuclear Engineering Panel of the Institution of Engineers, Australia (IE Aust). Having both the opportunity and the consent of the conference organising committees, the 1995 and 1997 conferences included poster displays of the ANA David Culley Memorial Award projects, the first two at ANA '95, with the second pair at ANA '97, where students of the respective schools (accompanied by a school staff member) were able to discuss their projects with the conference delegates.

It is hoped a similar opportunity will be available to the current awardee at the ANA '99 Nuclear Science and Engineering in Australia conference.

In order to maintain the balance of choice with the ANA David Culley Memorial Award the next award will need to be a High School within a State education system.

The ANA is very grateful for the co-operation and involvement of both the ANSTO Administration and individual staff members, as well as the staff members of the participating schools, and especially the enthusiastic and rewarding response of the students.

3.22 WOMEN SCIENTISTS JOINING ROKKASHO WOMEN TO SCIENCES

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ABSTRACT

Women scientists generally play a great role in the public acceptance (PA) for the national policy of atomic energy developing in Japan. The reason may be that, when a woman scientist stands in the presence of women audience, she will be ready to be accepted by them as a person with the same gender, emotion and thought to themselves. A case of interchange between the Rokkasho women and the women scientists either resident at the nuclear site of Rokkasho or staying for a short time at Rokkasho by invitation has been described from the viewpoint of PA for the national policy of atomic energy developing, and more fundamentally, for promotion of science education.

1. INTRODUCTION

Rokkasho-mura is located in the center of the Peninsula Shimokita and on the Pacific Ocean side of Aomori Prefecture, north end of the Honshu Island of Japan. The peninsula is well known for its shape of axe, and called as the Peninsula Axe, a grip of which corresponds to the position of Rokkasho. There exists a base of the oil storage for emergency and a base of atomic energy in the village and thus the village plays a great role in the policy for energy and now becomes well known. The U-235 enrichment plant, the storage center of low-level drums from domestic RI facilities , the storage center of vitrified residue of domestic burnt nuclear fuels re-processed in France or in UK and returned by ship, and the cooling pool of burnt nucler fuel brought from domestic nuclear power stations are in operation. The plant for re-processing of the domestic burnt nuclear fuel is under construction. Rokkasho is characterized as a nuclear site of the vitrified residue storage and the re-processing plant both of which are found only there in Japan.

2. METHODOLOGY

In the village, many organizations are engaged in PA activities on their own viewpoints. We describe PA activities performed by those organizations and discuss what is the most desirable PA activity from the viewpoint of the public. Organizations we refer to here are as follows:

1. Japan Nuclear Fuel Limited (JNFL).

2. Institute for Environmental Sciences (IES).
3. Social Education Section (SES), Rokkasho Education Commitee (REC).
4. the Reading Circle, the Rokkasho Culture Society (RCS).
5. the Society of Japanese Women Scientists (SJWS).
6. the Soroptimist International of Aomori (SI Aomori).
7. the Peninsula Shimokita Activation Society.

2-1. Japan Nuclear Fuel Limited (JNFL)

JNFL is a practicer of the national policy for atomic energy developing. It has a special facility of circular type building for PA named Rokkasho Visitors Center (RVC), which exhibits panels for outline of Rokkasho nuclear site and the national policy of energy, a model of about 2/3 scale in length of the re-processing plant, and life-sized models of stainless steel vessels for high-level vitrified residue and low-level drums in each storage center as well as a science museum. Panels describing fundamental principles of related nuclear techniques, panels and specimens for geological problems and mineralogy on the siteroblem, and apparatus to demonstrate radiation are exhibited for visitors to obtain basic knowledges and to understand scientific and technical aspects of the policy. Manpower of RVC is supplied by JNFL and electric company, and included persons employed after retirement from Rokkasho village office at comparatively high rank , and young ladies employed from all over Aomori Prefecture. In this way, RVC provides considerable chances of employment for the regional people. PA of the RVC is characterized as that of the promoter of the policy.

2-2. Instiute for Environmental Sciences (IES)

IES was established in 1990 as a foundation under Science and Technology Agency (STA) on demand from Rokkasho Village and Aomori Prefecture[1]. The main theme of investigation at the Institue consists of dynamical aspect of elememts circulation in the environment at the present stage for operation of the RP plant in near future, high technology for closed environment for long stay of human beings in cosmic space or on the lunar surface in future, and biological effects of extremely low-level radiation on mice. Studies on local industy, agriculture and fishery are also recommended and will be promoted on demand from various kinds of regional organization. As for PA, lectures on scientific topics were requested by various kinds of groups in the regional society even at early stage of the establish, although no special staff was provided for the purpose. In most cases, scientists were invited as lecturers for classes of Villagers School by the organizer the Social Education Section, for example, a woman scientist[2,3] of IES was invited as a lecturer for Ladies Class of the School. In 1994, PA division was set up under the name of the Regional Collaboration Office, and two positions in charge of PA were provided by IES. For the first step to the regional people, hearing about science education was made[4] from the principals of the junior high schools in the village. Panphlets on scientific topics met in the daily life named *IES Mini Encyclopedia*[5] have been published once a month, and widely distributed in Rokkasho and surrouding villages and towns. Facilities of IES are always opened to visitors. Special events are held for villagers on some national holidays. IES Science Experiment Class is opened at either IES or village facilities on village festivals. Also requests are often made for sending lecturers on scientific theme[6-10]. The feature of PA by IES may be said to be regarded as mainly so-called a "top-down" PA on the course of the upper organization, although the attitude of IES is neutral to promotion of the national policy for atomic energy.

2-3. Social Education Section (SES), Rokkasho Education Commitee (REC)

Social Education Section, Rokkasho Education Commitee is responsible for all phases of education except school education. Social education has been done at community centers intersperced in the village. The Community Center which located adjacent to the village office and has been the biggest one, was used for events by villagers. In 1995 construction of the building with a theater and the Villagers Library was planned toward completion in near future. Then, SES organized the Rokkasho Culture Society (RCS) as users of the facilities. REC, to which SES belongs, organized the Library Consolidation Commitee for opening of the Library, and officially appointed[11] for IES Regional Collaboration Staff to be a member of the Commitee. Official appointments to scientists as well are often made by various organizations[12,13]. SES also officially demanded for IES Reginal Collabaration Staff to be a representative of the Reading Circle[14], one of the clubs organized under RCS. RCS consists of both the old clubs by villagers own with long history and newly organized ones in 1995. PA by SES is characterized as a "top-down" PA on the policy of village administration. It may be, however, said to be changable by impacts from other new organizations in the village.

2-4. The Reading Circle, the Rokkasho Culture Society (RCS)

One substantial representative was appointed by SES from village women. Then she recommended eight persons as charter members of the circle. During three years, members of the circle increased to twenty-one persons, and bulletins of the circle[15] accumulated seventy issues. Literacy for self-expression was especially recommended among the members. After activities for one year, annual compiling of the bulletins was made at their own expense, and named *Massages from Rokkasho Women*[16], in which one[17] of the members wrote that she expressed herself in the ultimate. The book has led them to discover their own ability of expression. The second volume of *Messages from Rokkasho Women*[18] was compiled in the next year, in which Scientific articles were written by villager members[19, 20] as well. The third volume of the *Messages from Rokkasho Women*[21], was compiled in this year, in which one of villager members confesses that, apart from merit or demerit of the nuclear facilities siting in Rokkasho, owing to these facilities, we greatly appreciate to obtain intimate acquantance with women scientists[22]. In addition to reading and writing, they appealed their thouth by way of actions. Events and conferences are they held or joined as follows:

1. Exchange Meeting with the North-east Branch, the Society of Japanese Women Scientists, Tomari, Rokkasho, Nov. 1995
2. Exchange Meeting with the Summer School of Nuclear Chemistry, Hachinohe, Aug. 1996. Transportation was supported by Japan Atomic Energy Relations Organization.
3. The 1st Festival Rokkasho Culture Society, Obuchi, Rokkasho, Mar. 1997
4. Exchange Meeting with the Soroptimist International of Aomori, Rokkasho Visitor Center, May 1997. Transportation was supported by Mutsu Ogawara Development Bureau, Aomori Prefecture.
5. The 1st Conferance for Rokkasho Women Massages from the Frontier of Energy Base, Rokkasho Culture Exchange Plaza, Oct. 1997. The Conference was supported by the Ministry of Education through SJWS, and collaborated by the Soroptimist International of Aomori.
6. The Prefectural Conference of '97 Partnership for Men and Women Cooperative Participation, Aomori, Nov. 1997. Transportation was supported by SES, Rokkasho Education Commitee.
7. Annual Conference for Sciences of Feminism and Gender 1998, Workshop for Group Activities, Ranzan, Aug. 1998. Transportation of one person is supported by the National Women Education Center.

Activities through these publications and events are regarded as a so-called "bottom-up" PA by villagers themselves, and is so creative that we may call it Self Acceptance rather than PA. Through these activities of their own accord, they become more interested in scientific aspects of the nuclear facilities siting[23]. Scientific topics[23-25] as well as radiation sciences[12, 26-28] were often introduced in the Villager School and also in outside organizations.

2-5. The Society of Japanese Women Scientists (SJWS)

SJWS was establised in 1958 for the purpose of science for peace appealed by peace-loving people including Raichoh Hiratsuka, a famous feminist, and Prof. Shin'ichiroh Tomonaga, a Nobel laureate in physics 1965. For the first time and even long after the establishment, SJWS has been only a group of women scientists for their friendship. SJWS, however, recently has been active in introducing science experiments[29] to children. Women scientists have played a great role in Rokkasho[30-50], Aomori and other cities[51-64] for people, especially, for women to feel intimate with science[65, 66] through friendship.

2-6. The Soroptimist International of Aomori (SI Aomori)

This club is Aomori City Branch of the Soroptimists International which is worldwide known organization of women with profession and social status. Members of SI Aomori in the capital of the Aomori Prefecture are interested in the Mutsu Ogawara Development and the national policy of atomic energy developing in the Peninsula Shimokita, and cooperative to Rokkasho Women. The Economical and Social Development Service Commitee, the Environmental Service Commitee, and the Public Infomation Commitee played a important role in the Conference in Rokkasho.

2-7. The Peninsula Shimokita Activation Society

This society is famous for its typical botom-up activities, for example, the Dream Axe Train from Shinjuku Station to directly Mutsu Station. The Motto of the Society is "Activation of the Peninsula Shimokita for the Shimokita People and by the Shimokita People"[67]. The members consist of meyers of 11 local governments in the Peninsula Shimokita, heads of both public and private enterprices relating to energy, information, transpotations on land and sea, members from relating bureaus of the prefecture, and scientists. One of the most emphasized activities is drowing-up of *Long-term Vision for the Peninsula Shimokita*[67], which is entirely self-made plan through sincere studies and discussions by the members. The present version of the Vision has been recently accomplished its role, because many items in the Vision have been already realized. Now, discussions for *Long-term Vision for the Peninsula Shimokita, Part II* are going on.

2-8. Other organizations

Mutsu Ogawara Development Bureau, Aomori Prefecture (MO Bureau) and Japan Atomic Energy Relations Organization should be also reffered in the context of PA. The Peninsula Shimokita has been characterized by the long history of development under governmental planning since Meiji era, mainly because of low productivity of agriculture due to a special climate condition. The development related to the present atomic energy industry is also one of these kinds of the plannings. Aomori Prefecture as local government is also responsible for the planning, and is promoting it. People can be subsidized by the MO Bureau for regional industry, transportation for inspection of the facilities, and requests for lecturers. MO Bureau is important from local activities, while the other is responsible for all aspects of PA activities in all over Japan, especially in East Japan. The two organizations were contributable to our activities. The purpose of the present report, however, is rather bottom-up activities of the regional people than top-down and governmental ones, and details will be described elsewhere.

3. DISCUSSION

Practical re-processing in big scale has not been experinced in Japan, and re-processing in Rokkasho itself should be regarded as a kind of grand experiment for national policy for atomic enegy developing. Thus, safety and reliabilily are important aspects in this field, and especially, the latter is related to human relations of people with scientists and engineers of the national or private organizations responsible for the national policy of atomic energy developing. The technical problem has a contemporary limit due to the nuclear materials at the present time: their origins, places of occurrence, preparation methods, and analytical chemistry. Engineers and scientists as well are responsible for investigation of these basic aspects of the problem. Mass media should write only what is necessary from view point of science and technology. They should not stir up people to any directions. Teachers should introduce nuclear science, especially, radiochemistry in the curriculum through elementary and junior high school without hesitation and delay. Radioactive elements are source of energy: decay heat, electrons of not only natural, that is, negative charge but also positive charge, rare gases and rare metals. There exists not "waste" but "source of energy" in vocabulary of the nuclear and radiochemistry. This year is the century anniversary of discovery of Polonium and Radium. Madam Curie and one[68, 69] of the contemporary women scientists were sinsere in studies handling radioactive samples in large quantities or during experiments for many hours with their own hands under the atmosphere of radioactive gases, and died from probable effect of radiation. It would be suggested that sincere and sustainable study with enpowerment of literacy[70] for apprehension and own expession for communications are the most desirable PA activity from the viewpoint of the public.

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3 .23 RADIATION EDUCATION VERSUS „RADIOPHOBIA" – PUBLIC PERCEPTION OF RADIATION

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ABSTRACT

In this article the author presents the basis and reasons of the public radiophobia in Poland. He mentions about person's mentality historically based on the "cold war" and Soviet's military and technologically domination in this part of Europe.
Besides of the historical and sociological sources he pays attention on a few aspects, which – in his opinion – intensified the negative public responses: Chernobyl catastrophe, the coal-lobby influences, the political parties (not only "green") games during election time, existing of old conventional coal power stations, accessibility of own cheap coal, cost of transformation from communistic to free-market economy, low-level of public pro-ecology thinking and so on. On the other hand the author describes some non-realistic attitudes of society – for example – they accept nuclear medicine while do not agree to develop nuclear power engineering.
Finally he presents conclusions, which can change public perception of radiation.

1. INTRODUCTION

The majority of people active in social and economic policies and majority of experts dealing with radiation believe that the radiation and nuclear power program may be developed and implemented only with public consent and acceptance.
In Poland during parliamentary debate on "Foundation for the Polish energy policies up to 2010" the importance of public attitudes toward radiation has been recalled repeatedly in the context of the future development of nuclear power in Poland.
In the governmental document, accepted by Polish Parliament on 11 January 1996, it has been stated that "nuclear power plant construction is not foreseen up to the year 2010; nevertheless it has been assumed that the appraisals of the economic feasibility and the public acceptance level for such investments will be conducted".
Thus, the need for such assessments of public opinions and attitudes toward radiation and nuclear power has been recognized and accepted by the highest legislative power organ in Poland.
The first public opinion polls on the attitudes toward above problems have been conducted in August 1989. The subsequent four series of assessments of public opinion and social attitudes have been performed by the "Demoskop-market and social research" company and have been commissioned by National Atomic Energy Agency and by Polish Power Grid Company. They were conducted in December 1991, in November 1994, in August 1996 and in May 1998.
The questions covered the following topics:

- position on the nuclear power;
- level of information on the nuclear power;
- opinions on various ionizing radiation applications.

The statistical estimation error for the sample numbering 999 people is equal to 3.2% with the level of confidence 0.95 %.

The following socio-demographic characteristics have been taken into account: gender, age, education level, place of residence, type of work, professional position and place of employment.

2.PUBLIC ATTITUDES TOWARD NUCLEAR POWER IN 1989-1998

Fig.1 shows the distribution of replies to the question if, among other types of energy sources, the nuclear energy should be used to satisfy national power demands.

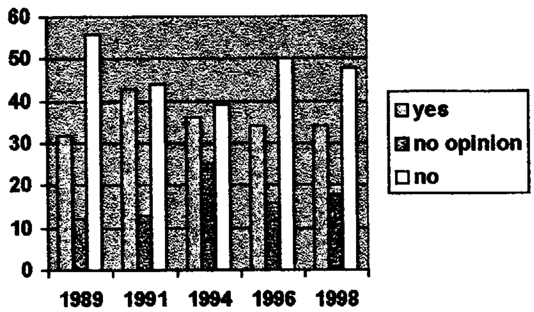

Fig.1.The respondents' attitudes toward nuclear power in 1989, 1991, 1994, 1996 and 1998.

From the numbers quoted it may be concluded that the most dynamic change in public attitudes toward nuclear power in Poland occurred in 1989-1991. In the following years the population has been divided into three groups: the nuclear power proponents (≈35%), opponents (≈40-45%) and undecided (≈15-25%).
The significant increase of the fraction accepting the nuclear option at the turn of eighties and nineties may be explained by the change in the socio-political situation. The feelings have been quieted, the emotions subdued.
The more difficult question is: why, during the recent years, the number of nuclear power proponents in Poland is smaller than the number of its opponents?
The possible explanation of this social phenomenon include the low level of the social awareness as regards the topic in question, but this is not the single reason and probably not the most important one. The opinions on the nuclear energy applications for electricity production are formed not only on the basis of knowledge but also are influenced by emotions.
It is very difficult to assess this emotional component of the attitudes toward nuclear power. It may be deemed significant.

The emotions are intensified by periodically recurring rumors of some nuclear accident, which cause very strong public reactions. On the occasion of 10-th and 12-th anniversary of Chernobyl accident, some very suggestive TV programs have been shown, including some unpublished documentary pictures of the disaster. The respondents in the 1998 polls, asked for a statement on benefits and threats related to the nuclear energy applications, answered : nuclear power means threat – 55%, it means benefits – 29%. The people in Poland are afraid of nuclear power because they are being systematically alarmed and intimidated.
The 1998 polls confirmed the correlation found previously (1989), namely that the higher education level, the higher acceptance of nuclear power.
In 1998, as in 1991 and 1994 the responses "difficult to say" which indicate lack of interest or lack of information, are given mainly by people with only elementary education, farmers, people with the smallest incomes, women and older people. The fraction of " difficult to say" answer for the questions addressing the general attitude toward nuclear power, is similar to the

fraction of such answers given to questions on other national social or political problems - for example - the parliamentary elections of the consequences of the NATO membership.
Fig.2. shows the man and women opinion on nuclear power uses.

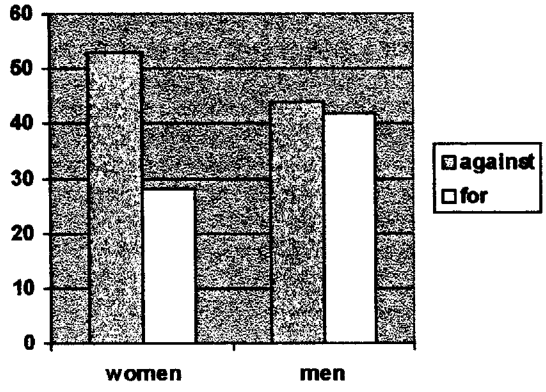

Fig.2.Men and women opinions on nuclear power uses.

The young people (up to 24) display above average acceptance, while those aged over 60 – less than average.
Very high acceptance of nuclear power has been seen among students and businessman-entrepreneurs – Fig.3. and Fig.4.

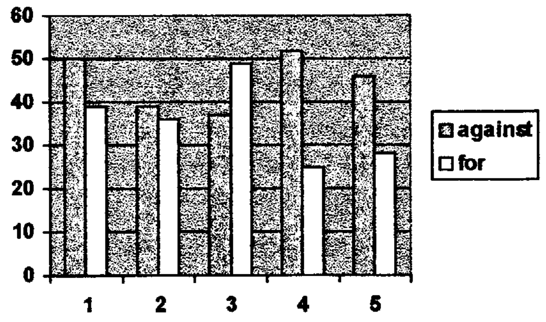

Fig.3.Respondents' opinion on the possible nuclear power uses, according to the type of work (1-employed, 2-unemployed, 3-pupils/students, 4-pensioners/disabled, 5-homemakers).

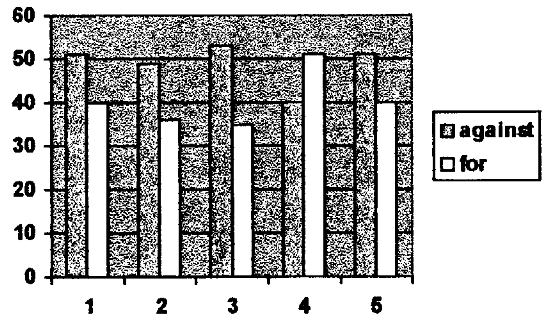

Fig.4. Respondents' opinions on the possible nuclear power uses, according to the work position (1-intellectuals/proffesionals, 2-white-collar workers, 3-manual workers, 4-entrepreneurs, 5-farmers).

3. THE LEVEL OF PUBLIC KNOWLADGE ON THE RADIATION AND NUCLEAR POWER BENEFITS AND HARMS

The relevant knowledge and the access to the information on atomic problems evidently influence the public attitudes toward radiation and nuclear power plants development in Poland. The question: do you feel that you are adequately informed on radiation and nuclear power problems by newspapers, radio and TV ?" the fractions of assenting answers in various years have been as on Fig.5.

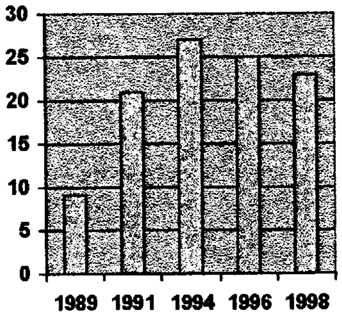

Fig.5. Respondents' opinions on the adequate information on radiation and nuclear problems.

Among those who feel that they are better informed of the radiation and nuclear power benefits and detriments are mainly the people with higher or occupational education and the most wealthy. The people employed in the institutions financed from national budget feel themselves adequately informed on those matters.

The problem of information is connected to the problem of trust and confidence in various source of information on atomic problems. The polls from 1996 and 1998 confirm the high level of trust bestowed in Poland upon the ecologists. Even more trusted are the research scientists (nuclear physicists-30%) and engineers (17%) – Fig.6. The politicians have to expect nearly no trust at all. According to the 1998 report, the confidence and trust level granted to ecologists decreased significantly as compared to that in 1996, by 6%.

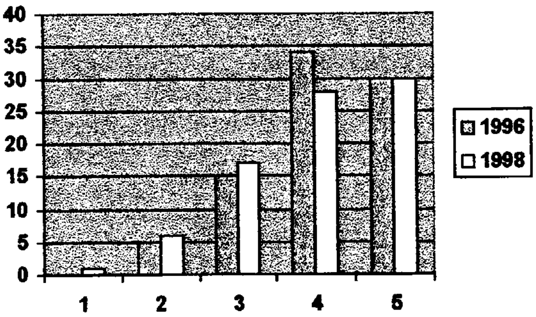

Fig.6.Reliable information source – in 1996 and 1998
(1-politicians,2-journalists,3-power engineers,4- ecologists,5-nuclear physicists).

4. OPTIONS ON VAROIUS IONIZING RADIATION

The respondents have been asked about their opinion on food for assuring better hygiene. 40% of respondents assent to this method (39% were against it), but this consent appears to be rather weak. Numerous responses "rather yes" (33%) and discrepancy between "decidedly not" (14%) are indicative of this weakness. The characteristics shaping in the strongest way the respondents" consent to food irradiation for hygienic purposes are : gender, age and place of residence. Males, respondents' young or middle aged and larger cities inhabitants accept food irradiation much more frequently than the others.

Moreover, the respondents have been asked about their acceptance of ionizing radiation applications in three other fields: in the arms and explosives detectors, for radiological thoracic examination and for industrial process control.

It turned out that all these applications enjoy a similar and high (60-70%) approval level. Quite evident relatively enthusiastic, as opposed to the response to food irradiation for hygienic purposes, is seen in much more abundant "decidedly yes" answers (from 23 to 27%). The objection against ionizing radiation uses in these fields is relatively small and fluctuates from 18% for thoracic examinations to 16% for radiation use in the search for arms and explosives.

The respondents have been asked to point to those ionizing radiation applications which, in their view, should be specially promoted and popularized. The following six possibilities have been offered : industrial applications, food irradiation for hygienic purposes, disposable medical equipment sterilization, medical diagnostics and therapy, applications in geology, hydrology and environmental protection, works of art. radiative maintenance and examination. The chart of the support for all types of application is shown in the Fig.7. The acceptance is given in terms of an average, which – depending on the acceptance scale – could assume the value between 1 (the lowest acceptance) and 5 (the largest acceptance).

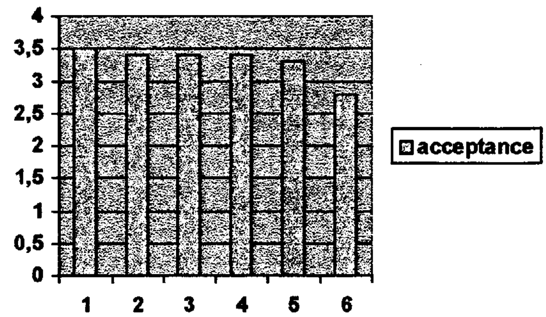

Fig.7. Support for various ionizing radiation applications (1-medical equipment sterilization, 2-works of art radiative maintenance and examination, 3-geology, hydrology and environmental protection, 4-medical diagnostics and therapy, 5- industrial applications, 6- food irradiation for hygienic purpose).

The disposable medical equipment sterilization enjoys the largest acceptance. The smallest is given to food irradiation for hygienic purposes. For all applications the total approval index has been found, as an average over all individual ratings. This average value has been found to be 3,3.

The acceptance of different ionizing radiation applications is connected with the acceptance of nuclear power in general. This conclusion, even if seemingly somewhat obvious, confirms the existence of a group of people, who consistently express approval for nuclear power and fear neither various applications of ionizing radiation nor using the atomic nucleus for acquiring electric energy. Presently, only 10% of the population belong to this group.

5. SUMMARY AND CONCLUSIONS

Pudlic opinion in Poland is not disposed toward electricity production in nuclear power plants and radiation. The conviction that one is satisfactorily informed on power supply matters is very weak. Even if the information not necessarily the most important factor in shaping

human attitudes, the public information problem becomes one of the key issues for the institutions interested in radiation and nuclear power development in Poland.
To be more precise : if pupils and students attending various schools are ready to support the radiation and nuclear power program, thus and so the nuclear matters should be included in the educational curriculum (on all school levels).
Also potential investors in future NPPs should involve themselves in broad educational campaigns. Various media may take part in such activities, especially TV with its educational programs.
The older people, uneducated, poor, rural and small inhabitants, women, unemployed and retired are among those most afraid of the radiation. Their views should be taken into account when taking up the activities aimed at changing the Polish public attitudes toward radiation program.
71% of Poles want to restrict coal combustion. It's a good sign.
The polls results confirmed the significant support of Poles (over 60%) for various ionizing radiation applications. This means that the radiation uses may be developed in Poland on a broader scale and unhindered.
Stability is one of the characteristic traits of public attitudes. Nevertheless, the results presented here should inspire a national agenda for activities including educational and informational tasks as well as those influencing emotions, for demonstrating the benefits from radiation and nuclear power. Thoughtful and persistent activities of all involved communities and institutions may lead to significant improvements in the knowledge concerning radiation, thus – to a possible change in public attitudes toward radiation and nuclear power option in Poland.

How to prevent a rumor and protect from nuclear panic (Polish experience).

Nuclear rumors started to appear after the Chernobyl accident. In spite of the principally correct behavior of the authorities and nuclear community following the disaster, the public was terribly scared by the accident. Any cancer cases, skin disasters, allergies were associated with the reactor meltdown in Chernobyl.
In the atmosphere of fear, with a lack of sufficient information and a very low radiation awareness, it was not difficult to spread a rumor about a new nuclear threat.
In last years in Poland every few months new gossip about nuclear accidents spread out. In 1995 there was widely know rumor on nuclear accident in Jaslovskie Bohunice in Slovakia. Another gossip about nuclear catastrophe in Mochovce was also spread, although, as it is well known, not one nuclear reactor is operating yet in Mochovce.
In May 1996 a gossip about nuclear accident in Chernobyl spread throughout Poland. The rumor was so serious that people stayed in long queues to get stable iodine, in kinder gardens the children were kept inside. Telecommunication company registered thousands of extra long distance calls. On May 9-th the rumor reached its peak. The geography of spreading the rumor is not exactly known. The biggest number of reports about supposed radiological risks were noted in West and South of Poland. The large city of Opole has been paralyzed for several hours.
There are not any credible information why and where this gossip came from? It is generally accepted that the rumor started after intensive campaign in mass media on 10-th anniversary of Chernobyl disaster. The media added to this rumor, especially one of the private radio stations, which broadcast news about the accident. Some informers pointed to a local German radio station as the original source of the rumor. It may be worthnoting that in early May of 1995 there were quite strong protests in Germany against transportation of radioactive waste to the German repository in Goerleben.

In Poland journalists tried to verify the rumor in different, not always properly selected government agencies. Many different journalists asked even the President of Poland and other representatives of public life whether there was a real danger.
Many people who requested that it should take a stand on the supposed nuclear accident approached the National Atomic Energy Agency. The NAEA is a particular institution – it is at the same time government body and a specialized agency. Therefore it enjoys more confidence than other government agencies.
In order to give journalists the most convincing explanation the operator of the Chernobyl NPP was contacted and the Polish radiation monitoring stations were requested to take measurements. With the necessary information collected, a press conference was called during which the precise information was given, including the time of the conversation with the Chernobyl NPP operator, his name, the reactor capacity during the conversation and different data describing radiation levels in Poland, i.e. dose rate, air contamination. Determined, reliable and credible presentation of this information in mass media – supported by statements of the authorities from Ministry of Environment Protection, Ministry of Public Health and Ministry of Defense calmed down the panic immediately. From one day to another the topic vanished from public life. What's more interesting – there were attempts to describe and explain the whole problem and demands to punish irresponsible journalists who caused the panic.
It is not easy to answer the question how to prevent a rumor and protect from nuclear panic. It seems that one of the reason for occasionally spread rumors is the memory of the 1989 accident, refreshed at least once a year at the end of April. Another reason why people pick up their ears to various unverified news may be the condition of the sarcophagus of the destroyed reactor, as well as the safety of reactors in this part of Europe. The media many times reported various incidents in those NPPs.
An important factor that makes the public in Poland oversensitive is illegal transport of radioactive and fissionable materials from the so-called "post-communistic" countries.
The sense of danger and fear is aggravated by irresponsible publications. With little knowledge of radiation issues and lack of confidence in the state authorities, the public is easily deceived and frequently yields to panic.
The question is then how to prevent rumors, how to nip the rumor-raised panic in the bud.
The conclusions which should be drawn from the above mentioned incident (which was the biggest but not the only one public event in Poland in last few years) could be as follows :

- each gossip should be addressed as soon as it arises at the best by the competent authorities or person with high scientific standard or social prestige;
- each information on nuclear accident and incidents and their results – should be done quietly and thoughtfully;
- press law or other law acts should include procedure for consideration of responsibility of media people for widespreading false, not documented information, which can cause serious social problems (in different fields);
- the cooperation between nuclear institutions with journalists should be closer and should be based on partner and friendship relation principle;
- in bilateral agreements signed by Poland among with Ukraine, Lithuania, Russia, Slovak Republic necessity of the mutual early notification, even in regard to the smallest incidents, must be included;
- the systems of radiological monitoring should be developed in such a way that they will give the quickest and most exact information about actual radiation level;
- the education of society in radiation and radiological protection questions should be carried out constantly, consequently and more effectively;
- the public should be prepared for the eventuality of a nuclear threat;

- the reactor emergency simulation exercises should be carried out to practice steps required in such a situation;
- citizens should have an easy access to written information how they should behave when radiation emergency is announced.

The above conclusions could create a possibility for changing the public attitude towards radiation and nuclear power in Poland.

(This article based on the Report on public opinion polls – "Polish society attitudes toward nuclear power and ionizing radiation applications" which has been performed by "Demoskop" and has been commissioned by National Atomic Energy Agency).

4. Work Shops

(ワークショップ)

A. Educational Curriculum Concerning Radiation in Primary, Secondary and Junior High School

B. Experiments and Demonstrations for Radiation Education

C. How to Teach Radiation as a Source of Risk

JP0050108

JAERI-Conf 99-011

4.1 Present Status and Problems of Radiation Education in Japanese high school

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Abstract

Radiations always exist in nature and are necessary in various fields of our daily life. Radiations are utilized for nondestructive inspection in industrial uses, diagnosis and medical treatment, tracers in agricultural research, and so on. Researchers make good use of radioactivity. However, the fears of radioactivity remain in the public due to reports by mass media, accidents of nuclear power station, treatment of nuclear waste, and atomic bomb. Therefore the public tend to see the negative images of the radiation. Radioactivity can be dangerous. But it is hard to say that radiations are always evaluated appropriately.

To solve the problems of misunderstanding, we focused the study on the radiation education curriculum. In this research, we studied the radiation education from the following four points: "physics field", "physical experiment", "chemistry field", and "comprehensive study time." Two themes of the former were performed in the actual lessons. Two themes of the latter were the investigation of the current state and the tentative plan.

The research have to be continued in the future.

4.2 放射線教育カリキュラムの課題と現状

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要旨　放射線教育は幅広い分野にわたる内容を含んでいるため，カリキュラム研究に際しては，総合的な検討を要する．本研究では，“物理分野”，“物理実験”，“化学分野”，そして“総合的な学習の時間”の４つの視点から検討を進めた．前者の２テーマは実際の授業で実践した．後者の２テーマは，それぞれ現状の調査と試案の作成を行った．今後も研究を継続する予定である．

1．はじめに

放射線に関する用語[1)]は，今や新聞やニュースなどでも知られている一般的な科学用語と言える．一方，それらを支える放射線教育は，理科や地歴・公民科をはじめとする幅広い分野にわたる内容を含んでいる．ところが，新学習指導要領[2)]では，各教科の教育内容が厳選されるため，放射線教育のカリキュラムを総合的に検討しなければならない時代にある．筆者らは，多岐にわたる課題の中から，いくつかの観点にしぼって研究を進めた．

一般に，高等学校教育では，放射線に関する事項は物理分野で教えることになっている．そして，ニュートン力学やマクスウェル電磁気学といった古典物理を学んだ後に，量子論，相対論，原子，分子，そして放射能などを学ぶカリキュラムになっている．広井[3)]は，物理分野の視点から放射線教育のカリキュラムを検討した．具体的には，放射線を学んだ後に，ニュートン力学などを学習させるカリキュラムを開発し，それを実践した．最初に放射線に関することを学習することにより，これから学ぼうとする物理学の全体像を一つ一つ示すことができた．学習目標を明確にさせることができる利点のあることがわかった．

本論文では，さらに，物理実験の視点から“物理における放射線のグループ実験”，化学分野の視点から“高校化学での放射線教育の扱い”，そして新学習指導要領の視点から“放射線教育を考慮した「総合的な学習の時間」案”について検討したので報告する．尚，「総合的な学習の時間」とは，教科ではなく領域を指し，創意工夫を生かした教育活動の展開を図ることが原則である[4)]と言われている．

2. 物理における放射線のグループ実験

自然科学における実験の重要さはいうまでもないが，できれば演示実験という生徒にとっては間接の体験よりも，グループ実験という直接体験の方が実験の印象が強い．特に，40人学級の日本では，後ろの席の生徒には演示実験の全貌がわからず，生徒に与えるインパクトは小さい．しかし，生徒による放射線のグループ実験を実践しようとするとき，以下のような壁がある．

(1) 放射線測定器が高価なため，グループ実験をしようとすると，かなりの費用が必要である．

(2) グループ実験は教授者には準備，実験，後かたづけのうえでかなりの負担になる．

(3) 予算が捻出でき，教授者の意欲が十分で，実践する条件が整っても，手本とすべき実験内容や授業カリキュラムの実践の積み上げがないので，手探りで試行錯誤することになる．

上記(1) に関しては，空気ＧＭカウンターという教育用の放射線測定器を開発して対処した．空気ＧＭカウンターについてはポスターセッションでの発表「空気ＧＭカウンターの製作と活用」[5) を参考にして欲しい．ラッキーなことに旧式のコンピューターが更新され，10台の旧式コンピューターが使えるようになった．コンピューターは放射線の数を数えて表示するだけだから，旧式のもので十分である．

(2) に関連して，霧箱で放射線の飛跡を見る実験は今回はあきらめた．

(3) については，実際の授業内容を紹介することで，一つの試行錯誤例を示したい．物理実験機器の工夫もさることながら，どういうカリキュラムを組むかということが大切だということを痛感した．

授業を行った鎌ヶ谷西高校は，就職・専門学校・短大・4年生大学進学のすべての希望者がいる，進学校ではない普通の学校である．

1時間目：放射線の基礎知識（講義と演示実験）
- 原子と原子核
- 放射線と放射能
- 放射線の種類
- 放射線の測定
- 電離作用と透過力

2時間目：「放射線を目で見てみよう」（ビデオと補足の講義）
- 原子力研究所製作のビデオを視聴し，内容を補足する．

3時間目：身近な放射線（生徒実験）
- バックグランドの放射能強度測定
- プロメティウムとマントルの遮蔽実験
- 食塩と塩化カリウムの違い（カリウム40からの放射線測定）
- 空気中の塵の放射能強度測定

4時間目：原子核の崩壊（講義）

・原子核の崩壊
・放射性系列
・半減期

5時間目：原子核崩壊の模擬実験（コンピューター使用の生徒実験）
・崩壊確率を与え，モンテカルロ法で模擬実験をする．

6時間目：トロンの半減期の測定（生徒実験）
・トリウムを含むマントルから放射性の気体トロンを抽出し，それを空気GM管に直接注入して半減期を測定する．

7時間目：「放射線と人体」（講義）
・電離作用と生体への影響
・確定的影響と確率的影響
・自然放射線による被爆と医療被爆

8時間目：原子力発電の是非（ビデオと若干の補足）
・原研製作ビデオ「あなたもディベートしてみませんか」の視聴

生徒に対してアンケート調査はしていないので，授業に対する客観的な評価はできないが，放射線は目に見えないもので危険なものであるが，身の回りにありふれているものでもあり，物理の法則にしたがっていて，決して神秘的なものではないということがわかってもらえたのではないかと思う．

3．高校化学での放射線教育の扱い

高等学校の化学分野での放射線教育の扱いを検討するため，（1）学習指導要領と，それに伴う教科書の記述の歴史的変遷，（2）イギリスの教科書の一例を調査した．これらをふまえ，高校化学での放射線教育について記す．

（1）学習指導要領と教科書の記述

今日までの約50年間の日本の学習指導要領（理科）[6]は，表1のように変遷してきた．放射線教育に関わる内容の内，各科目で扱われる主な項目は，表2に示す．

このような変遷に伴い，教科

表1　学習指導要領の理科の科目

年	科目
1952（昭和27）	物理，化学，生物，地学
1955（昭和30）	物理，化学，生物，地学
1960（昭和35）	物理A，物理B，化学A，化学B，生物，地学
1970（昭和45）	基礎科目，物理I，物理II，化学I，化学II，生物I，生物II，地学I，地学II
1978（昭和53）	理科I，理科II，物理，化学，生物，地学
1989（平成元）	総合理科，物理IA，物理IB，物理II，化学IA，化学IB，化学II，生物IA，生物IB，生物II，地学IA，地学IB，地学II
1999（平成11）[2]	理科基礎，理科総合A，理科総合B，物理I，物理II，化学I，化学II，生物I，生物II，地学I，地学II

書の記述も変わってきた．

高校の教科書の中で，放射線に関する記述の特徴を記す．

１９４８年（昭和２３年）発行の教科書（柴田，津田，島村；大日本図書）では，放射線の種類，自然放射性元素，人工放射性元素，キュリー夫人，放射性壊変，原子爆弾，将来のエネルギー産業など幅広い話題と展望が記されている．１９５５年（昭和３０年）になると，自然放射性元素や人工放射性元素の用語がなくなり，放射性元素として説明されている．原子爆弾やエネルギー産業の記述がなくなり，かわりに化学作用や生理作用，そしてガン治療などの説明がある．また，放射性元素の発見と化学

表２　学習指導要領（理科）の項目と説明

年	科目	学習指導要領（抜粋）
1955（昭和30）	物理（５単位）	原子核の崩壊；α線・β線・γ線，原子核の崩壊，原子エネルギー（原子については，簡単に扱う．）
	物理（３単位）	原子核の崩壊；原子核の崩壊，原子エネルギー（原子については，簡単に扱う．）
	化学（５単位）	放射能，原子核反応（放射能については，現象を理解する程度とする．）
	化学（３単位）	放射能（放射能については，現象の理解の程度とする．）
1960（昭和35）	物理A	原子，原子核；原子模型（原子は１個の原子核とそのまわりを回る何個かの電子とからなることを扱う．），原子核の電荷と質量，原子核の変換，放射能
	物理B	原子，原子核；原子模型（原子は１個の原子核とそのまわりを回る何個かの電子とからなることを扱う．），原子核の電荷と質量，原子核の変換，放射能
1970（昭和45）	物理Ｉ	放射能（「放射能」については，放射線の種類，強さ，作用などを扱い，応用についても簡単に触れること．）
	物理ＩＩ	原子と原子核；原子の構造，原子核の構成，原子核の変換，核エネルギー
	地学ＩＩ	地球内部における放射性元素
1978（昭和53）	理科I	太陽エネルギー，原子力の活用（「太陽エネルギー・原子力の活用」については，エネルギー資源としての利用を扱い，放射能にも触れること．）
	物理	放射能，核エネルギー（「核エネルギー」については，原子力の利用とその安全性の問題にも触れること．）
	地学	太陽；太陽の形状，太陽の活動（「太陽の形状」については，太陽を恒星の一つとして扱うが，そのエネルギー源である核融合反応については，その概略を扱う程度にとどめること．）
1989（平成元）	総合理科	人間と自然；資源・エネルギーとその利用（自然を総合的にとらえ，人間生活とのかかわりを中心に扱うこと．例えば，水資源，化石燃料，太陽エネルギーなどを取り上げ，資源・エネルギーの有限性や再利用にも触れること．また，放射能及び原子力の利用とその安全性の問題にも触れること．）
	物理ＩＡ	エネルギーと生活；太陽エネルギーと原子力（原子力については，放射能及び原子力の利用とその安全性の問題にも簡単に触れること．）
	物理ＩＢ	放射能（放射能及び原子力の利用とその安全性の問題にも触れること．）
	物理ＩＩ	原子の構造；原子核の変換
	地学ＩＡ	資源と人間生活；エネルギー資源（太陽放射の熱エネルギー，化石燃料及び核燃料のエネルギーを中心に扱うこと．）
	地学ＩＢ	太陽と恒星；太陽の形状と活動（地球に及ぼす影響にも触れ，核融合反応については概略にとどめること．）

理論への影響なども議論されている．１９６２年（昭和３７年）の教科書（大日本図書）では，特に，原子核分裂，連鎖反応，爆発のエネルギー，発電などの記述が詳しくなった．また，アインシュタインによる質量とエネルギーの関係，太陽の原子核反応，水素爆弾などの記述がある．１９６４年（昭和３９年）の「化学B」の教科書（大日本図書）では，ウラン・ラジウム系放射性元素のおもな壊変系列の図などがなくなり，放射性元素の用語とキュリー夫人の略歴などの簡単な記述で終わっている．１９７２年（昭和４７年）の「基礎理科２」の教科書（坪井，木下，鈴木；大日本図書）では，放射線と放射能，霧箱の実験，サイクロトロンによる原子の変換，ラジオアイソトープ，トレーサー，炭素１４の年代測定，核分裂，連鎖反応，原子炉，地球上でのカリウム４０の熱量，太陽の原子核反応などが紹介されている．１９７６年（昭和５１年）の「化学II」の教科書（柴田，島村，吉岡ほか；大日本図書）では，人工放射性元素と天然の放射性元素の簡単な紹介のみである．１９８２年（昭和５７年）の「化学II」の教科書（大日本図書）では，キュリー夫人の説明が加えられている．１９８４年（昭和５９年）の「理科I」の教科書（三輪，市川，中村ほか；三省堂）では，放射線量と突然変異の関係，放射能，放射性元素，核分裂反応，核融合反応，エネルギー源としての原子力などの記述がある．１９８５年（昭和６０年）の「理科I」の教科書（市川，中村，渡辺，藤伊ほか；三省堂）では，エネルギー資源の観点から，放射線の種類，放射能，放射性同位体，核分裂反応，核融合反応，そして核エネルギーや原子力，核廃棄物処理の検討の話題などが取り上げられている．

（２）イギリスの教科書の一例

海外の教科書の特徴[7]を述べる場合は，その国によって教科書の位置づけが異なっていることをふまえた上で議論を進める必要があるが，本報では，イギリスで使用されている「KEY SCIENCE」[8,9]の一例を紹介するにとどめる．本書は，「GCSE」向けに書かれた書籍であり，「物理編」，「生物編」，「化学編」の三分冊に分かれている．

「化学編」の中で，放射線については，放射能，放射線の種類，半減期，放射性同位体の利用，放射能の危険性，原爆の仕組み，広島に投下された原爆，原子炉，原子力発電所，水爆，放射性廃棄物（低レベル，高レベル），天然放射線，スリーマイル島・チェルノブイリ事故などが詳述されている．

（３）展望

５０年ほどの高校化学の教科書の変遷をたどると，放射線に関する記述は，少しずつ削減されていることがわかる．イギリスの教科書と一律に比較することはできないが，大きく異なっていることは明らかである． 森永[10]は，国民の基礎的な知識として，放射線教育を「化学」で取り上げることを提案している．具体的には，「放射能は一つの核の性質として詳しく扱う」，「トレーサーの概念を導入」，「放射線の性質に触れること」としている．事実，放射性同位体は，高校の化学分野に関係の深い医学，農学，薬学，生物学等で重要な役割を果たしている．

今後，日本の高等学校の化学分野で放射線教育を導入することが可能であるかどうかについては，さらに，教育的な観点から研究を進める必要があると考えている．

4．放射線教育を考慮した「総合的な学習の時間」案

放射線は自然界を構成する重要な要素の一つであるということばかりでなく，非破壊検査に代表される工学的な用途，診断や治療に代表される医学的な用途，そしてトレーサーとして生物学の領域での用途などさまざまな実用分野で，無くてはならないものであるにもかかわらず，原子力発電所の事故や原爆に代表される大量の放射線被ばくによる影響の恐ろしさばかりがマスコミに取り上げられ，放射線の正しい姿が捉えられていない．このような事態の中で，冷静に客観的に学習すること[11)]ができるのが，学校教育の大きな利点の一つである．

また，（エネルギー問題に絡む）原子力発電に付随する放射線・放射性物質に関して，あるいは，必要性・重要性が増すであろう医療放射線に関して，考え・判断することが求められていくであろうこれからの社会の中では，一般的な知識・教養として，中等教育としての組織化された放射線教育が重要になっていくと思われる．

しかしながら，理科のカリキュラムの中で放射線教育をしていくことが困難な状況が生まれようとしている．そこで，新しく実施される「総合的な学習」の枠内で，放射線教育を考慮したカリキュラムを私案としてお示ししたい．

I. ガイダンス（1h）

II. 日本のエネルギー事情（原子力発電の現状）（2h）
　調査：エネルギーの種類・輸入先と割合
　調査：エネルギー問題の過去・現在・未来

III. 原子力発電の原理と問題点（1h）
　調査：① 原子炉の種類と特徴
　　　　② 日本の原子力政策（の特徴）と将来像，および問題点

IV. 放射線の種類と性質（2h）
　講義：放射線の種類と性質
　実験：①霧箱の観察実験
　　　　②「はかるくん」・GM管などによる計測実験

V. 放射線の利用（2h）
　講義：医療による放射線量
　調査：工学的使用例の調査

VI. 放射線の影響とそのリスク（1～2h）
　調査：放射線の影響の分類と具体事例
　調査：放射線被ばく量とリスク

VII. リスクの考え方(リスクの算定の仕方)と様々なリスクの値（1～2h）

実習：各自の思いつくリスク例の提示とそのリスクの値の見積もり
VIII. 諸外国の(原子力発電の現状と)エネルギー政策（３～５h）
調査：諸外国のエネルギー政策の調査
スイス・ドイツ・スウェーデン・アメリカ・フランスなど
発表：諸外国のエネルギー政策の調査（プレゼンテーション）
グループ発表：各グループ１～２カ国
報告：日本と諸外国のエネルギー政策について（レポート作成）

５．まとめ

日本と海外とでは，放射線に対する認識[12, 13]が大きく異なっている．特に，二見[13]は海外の教育事情を詳しくレポートし，教育の重要性を指摘している．

今後も，放射線教育のカリキュラムの重要性は，学校教育の現場からだけでなく，国内外の各方面からも，正しく客観的な議論が望まれることと思われる．２１世紀にふさわしい放射線教育のカリキュラムの再構築が必要な時代となってきている．

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4.3 Radiation Education and Scientific Literacy

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I'm impressed with the several efforts that the teachers have shared us to find a better educational method for the problem of energy, nuclear power and radiation. What I'd like to discuss today should be the followings.

Thinking about Japanese Education systems, I can see a certain things missing in the current systems and perhaps we need a different viewpoint to prepare for the 21 century of energy and radiation education. That is why I'd like to make a speech in the point of view "Radiation Education and Scientific literacy".

First of all we must examine our traditional education. In our education we had a viewpoint that science and technology should serve the human lives and our industries. But the more developing our science and technology, the more evil influences, atomic bombs, environmental pollution and so on, have been exerted on us, while in the International Symposium of Physics that was held about forty years ago, some researchers insisted that 'To legacies science as the universal value of our great culture' should be the standpoint of education.

To teach science on these three view points, we used the method " teach it to pupils and students and learn it by heart" we did transmit learning systems, ideas and knowledge as our great cultural legacies to the young. The new roles of science education, however lie in developing themselves to cope with the changes of societies and live happy lives by means of thinking about or solving the problems of science. So we must teach it in the different method from what it was.

There is a great problem of "nuclear power" in our country. In Japan a number of people fell victims to "atomic bombs", so that it is quite natural for them to reject nuclear electric power and radiation. But the teachers should have the ability to judge fairly. So far, they can't teach the projects and the problems of nuclear powers without standing on either side of 'for' or 'against'. This isn't the fair and right method of teaching the problems.

Many years ago, I went to Sweden to research the problems of energy and environmental education, when I was impressed by the Swedish attitude for nuclear powers.

They have had their own sense of values for them.

By the way the symposium of the OECD education was held in Tokyo in December, 1996. Judging from the researches of 14 countries, Japan is in a very low level next to Portugal in scientific literacy, while we have the best knowledge of science and mathematics in the science attainments of IEA.

Generally speaking, the result of scientific literacy is consistent with that of science attainment, but not in Japan. We have had and will have many complicated problems on energy, nuclear power and radiation. Recently in Japan our teaching curriculums have been revised. As there're the general learning programs, all the school subjects will be able to cooperate one another to have students develop themselves.

This national curriculum of England has been started as the cross-curriculums to learn energy and environmental problems. Our research mission did first report as the method of teaching them. This is the way to learn not only positive opinions but negative ones as well, and then to obtain mutual consents.

For Japan to survive in the world, we must bring up those who listen to others and follow the general consensus. As the education of radiation, by giving the exact knowledge about the security and risk of radioactivity and atomic power, we should bring them up to judge many problems fairly; the scientific literacy.

I'd like to discuss them in the workshop.

4.4 放射線教育と科学リテラシー

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［講演要旨］

先生方の講演で理科教育・物理や化学等の指導や授業の中で、どうやったらエネルギーや原子力教育、また放射線教育が効果的に行えるかについての様子をお聞きし、その努力に対して敬服しました。

これまで私は学校教育の中で、エネルギー・原子力や環境に関する教育の在り方を考えてきましたが、どうも日本の教育には欠けている部分があるのではないか、21 世紀に向かって今までとは違った視点で教育の目標や方法を考えていかなければ、対応するエネルギーや原子力・放射線教育ができないのではないかという強い気持ちを持っております。そのようなことから、違った視点で提案したいと思います。

タイトルは「放射線教育と科学的リテラシー」でありますが、この“サイエンティフィックリテラシー”はエネルギー・原子力や放射線等について教育をする上で必要なことであります。このことを考えるに当って、これまでのわが国の科学(理科)教育がどのような考え方で行われてきたかを概観してみます。

これまでの理科教育では、その目標を設定するための視点について、その一つは『科学・技術が人間の社会生活や産業の発展に貢献すること』ということが挙げられます。この視点は日本の近代化が始まった明治以降から現在まで、理科教育としてずっと続いてきたきたことであります。

次は、科学・技術が進展してきますと、人間や社会環境にとってマイナスの面も出てまいります。例えば、科学技術の研究開発の結果として原子力の研究が原子爆弾の開発に、工業の進展や社会生活の高度化によるエネルギーの大量消費が環境汚染や破壊などといった、『科学・技術の発展が人間性の向上に相反すること』などの問題が出てまいりますと、それらに対応した教育も考えなければならないこともでてきます。

もう一つは、40 年程前に欧州で国際物理教育会議がありましたが、そのとき、物理学というものは音楽や美術のように情操教育と同じ立場で教えるべきであるという主張がありました。このことは『科学を優れた人類文化としての普遍的な価値として認めること』と言えます

が、この視点も科学（理科）教育の目的として考えられてきました。

このような、三つの視点を基に理科教育が行われてきましたが、このような理科教育では、例えば、物理学の学問的な体系や概念とか知識・内容などの既にできあがったものを、文化遺産として伝達する学習方法がとられます。その学習では、科学的な知識や内容の理解と定着が目的の教育にしかなりません。

ところで、理科教育の役割について考えてみますと、科学の体系や知識を伝達することだけではなく、新しい科学の課題や創造的な問題について、論理的な思考や問題解決をさせる中で人間形成を図るといった目的があるということがあげられでます。従って、これまでとは違った視点や観点で理科教育の目的を考えなければならないことになります。では、その視点や観点は何かというと、その時代や将来の社会の変化に対応して豊かな生活ができるための資質の育成ということがでてきます。

我が国において解決すべき大きな課題の一つに、原子力問題の解決がありますが、日本は世界で唯一の原子力爆弾の被爆国であるためか、原子力や放射線に対する拒否反応が強く、原子力政策等での大変強い反対運動が見られます。この影響を受けて、学校教育の中でも教師の多くにが同様な原子力に対する反対や偏った考え方が見られます。

日本の学校教育では、原子力や放射線の問題のように価値観や政治・政策的な判断が求められるような学習内容を教える時、教師は反対派側の考え方に立つか賛成派側の考え方に立つか、どちらかの側の考え方をしないと教えたことにならいと言った気持ちがあるようです。このような考え方による教え方がどうも間違ていると思っているというのが私の率直な感じであります。どのような考え方の教育が良いのか悪いのかは、後でご議論いただきたいと思います。

以前に私はエネルギー・環境教育の調査のためにスウェーデン等欧州諸国に行きましたが、そのときに感じたのは欧州諸国の多くの国民は一人一人がエネルギーや原子力、放射線の問題に対しの価値観や判断力について、きちんとした意識や意見を持って対処いるのを見ました。そして、学校での教育の中で、市民一人一人が責任を持って問題や政策について判断し自ら決定することのできる資質の育成が行われているようです。

このような教育の問題についてですが、1996 年の 11 月に東京で OECD の教育に関するシンポジウムがありました。そのシンポジウムでアメリカのミューラー氏の発表された『OECD 諸国の科学技術への一般的理解：比較分析』での、世界 14 カ国の調査結果を見ますと、現代の社会に生活する市民に求められている“科学の基礎的な方法を

知り、科学技術を含む政策議論を理解することができる資質”、すなわち「市民の科学的リテラシー」の水準(レベル)が、日本はポルトガルに続いて下から数えて２番目と極めて低いのです。それでいて 1996 年に行われた IEA（国際教育到達度評価学会）の理科学力(知識・理解)の調査結果を見ると、我が国は世界諸国に比べて理科・数学ともにトップレベルの位置にいます。

このことは、我が国では従来の科学(理科)教育では、科学や数学の知識内容やその理解という面では効果を上げていますが、科学技術の政策の判断や決定に対処するための能力や資質が欠けており、そのレベルが極めて低いといった深刻な問題が挙げられるのです。

これから２１世紀に向けて、エネルギー、環境、原子力、放射線等の科学技術に関する複雑な問題が、これから一層多く出てくることが予想されますが、それらに対応できるための市民の資質や能力として、我が国の科学(理科)教育として科学の体系や内容の理解だけでなく、科学的リテラシーの資質形成を重視した教育へ、一層の転換を図る必要があると思います。

そういった観点から、表題に掲げました「放射線教育と科学的リテラシー」について申し上げているということでございます。

現在、文部省の方で教育課程の改訂が行われ、新しい学習指導要領が作成されています。その中に、小・中・高等学校の全てに、教科間の連携を図りその枠を越えて学ばせる学習として、「総合的な学習」が必修として創設されました。

この「総合的な学習」は、実のところイギリスのナショナルカリキュラムの中に、エネルギーや環境について学ばせる「クロスカリキュラム」というのがございますが、それを参考にして持ち込まれた学習方法でして、教科・科目の枠を越えた多面的な学習、例えば、理科や社会科、また家庭科・保健体育等をクロスして学習していくという方法が取られるものです。

これは、私達の調査団が欧州にエネルギーと環境教育がに行きまして、イギリスから資料を戴いてきて報告したのが最初でございます。その教育ではどういった学習が行われるかといいますと、討議やディベートによる学習、リサーチ学習といった研究的な学習といったものによって、エネルギーや原子力・放射線問題、環境問題等の価値観の対立している問題について学習させることができる。

また、例えば、原子力問題等の円卓会議で、参加した人達が話し合っても全然歩み寄ることがない、反対派側は反対の主張だけをする、賛成派側は賛成の意見だけを述べるといった状態である。日本の国民はそのような資質欠けているという問題があります。この「総合的な

学習」では、これまで日本では欠けていた、合意形成の資質を形成する教育として効果的な学習方法であります。

これから世界の中で日本人として生きていくためには、いろいろな事態や場面に即応して互いに歩みよることができ、他人の発言もよく聞き、コンセンサスを持って対処できる国民を育てていく必要があるということが私の科学教育に対する考え方でございますし、そのことが、私の申し上げたい科学(理科)教育での科学的リテラシーの育成ということでございます。

放射線教育としての立場で申し上げますと、「放射能」とか「放射線」だとか「原子力」等の正しい知識・理解とともに、それらに対する拒否反応の解消や安全性、リスク等の問題も含んで、公正な判断できる思考力などの資質の育成を目指し、科学教育を考え見直していく必要があるということが私の提案でございます。

ワークショップでの問題提起として、議論していただければと思います。

4.5 THE IMPORTANCE OF EARLY-SCHOOL RADIOACTIVITY EDUCATION IN CULTIVATING PROPER REFLEXIVE JUDGEMENT ON RADIATION

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ABSTRACT

An attempt is made to draw a preliminary conclusion on the effectiveness of early-school education on radioactivity, based on two cases of student responses. The first is the returns of questionaires circulated at two colleges, which were typical of an engineering college and a liberal-arts college, respectively.

The second is the reactions of liberal arts students to observed, unexpected levels of radiation in their environment. Their reaction was dominated by their preoccupation on radiation, rather than by the quantitative data they themselves collected on the spot. Thus classes in early schooldays are considered to play a vital role in cultivating proper judgement they are to rely on as general citizens.

1. INTRODUCTION

In the present Japanese curricula at the elementary and junior-high schools, the topic of radioactivity appears to be covered only in connection with hisotrical incidents of casualties, the typical of which are the Hiroshima and Nagasaki casualties, and the Chernobyl accidents. Thus at the level of compulsory education, attempts are barely made to introduce this topic in the context of science teaching . In an attempt to correct such insufficiency, and to provide the next generation with properly balanced knowledge, there have been many attempts at the university level of this country, typically at engineering colleges, but much less at liberal arts colleges.

The present observation was made in one of such minority attempt. From the outcome of the present observation, the importance of early-school education is strongly felt in bringing up general citizens with proper knowledge and sense of judgement in this subject. The attempt is still preliminary, and needs further data collection.

2. METHODOLOGY AND DISCUSSIONS ON THE OUTCOME

(1) Returns of class-room questionaires on radioactivity and nuclear power

In the fall of 1996, a questionaire on radioactivity and nuclear power was circulated at classrooms in Colleges A and B. At College A which is an engineering college, a group of 28 students within the electrical engineering department filled it out, the 26 of which were male students. In College B which is a liberal arts college, a group of 171 students within a class of contemporary social topics filled it out, the 154 of which were female.

In response to the seven statements (**Q1 - Q7**) listed in Table 1, the students were requested to make a proper choice out of true and false markings for each. The correct choices (answers) are indicated in Table 1 in parentheses. The **Q1** through **Q4** are the questions related to radioactivity, while **Q5** through **Q7** are energy-related:

TABLE 1: Questions in the Questionaire

Questions on radiation:

Q1: Without any artificial radioactive materials, no radioactivity would exist in natural environment (False).

Q2: The radiation dose received annually at the boundary of a nuclear power plant is less than the dose received inside an aircraft during one round-trip flight from Tokyo to New York (True).

Q3: Hereditary abnormalities have appeared with a higher percentage among the progenies of those who received the A-bomb radiation at the city of Hiroshima than among the progenies of the average population in this country (False).

Q4: During the soidum leakage accident of MONJU (A Japanese fast breeder reactor) in December of 1995, radioactive material leaked out of the secondary cooling system together with sodium (False).

Questions on energy and nuclear power:

Q5: In the light water reactors which are currently operating at Japanese nuclear power plants in general, plutonium fissions is contributing to electricity generation, in addition to the uranium contribution(True).

Q6: To prevent converted use of nuclear fuel to weapons, the International Atomic Energy Agency (IAEA) periodically inspect all the Japanese nuclear power plants (True).

Q7: Less than 50% of the energy consumed in Japan is supplied by energy sources imported from overseas(False).

Note: To briefly comment on the questions that are specifically Japanese: In **Q2,** the annual dose received at the boundary of nuclear plants in this country is less than the regulation value of 0.05 mSv per year, while the dose received during a round-trip flight between New York and Tokyo is estimated to be above 0.06 mSv at least (Refs. 1, 2 and 3). In **Q4,** the secondary cooling loop sodium is independent from the primary loop sodium which is radioactive. In **Q7**, Japan relies on imported energy sources for more than 80 percent of her energy consumpiton.

TABLE 2: TheReturns of the Questionaires (Percentages of Correct Choices)

The Response to the Questions on radiation:

Questions	Class in College A	Class in College B	The Case of Contrast
Q1	96.4	93.6	---
Q2	89.3	38.1	O
Q3	42.9	19.9	O
Q4	57.1	21.1	O

(TABLE 2 continues to Page 3)

TABLE 2(Continued):

The Response to the Questions on Energy and Nuclear Power			
Q5	71.4	80.1	---
Q6	81.5	87.0	---
Q7	96.4	84.3	---

The returns of questionaires are summarized by the percentage of correct choices in Talbe 2. It is found that the existence of natural radioactivity is known fairly well in both classes. We see in addition that the two classes responded differently to the questions on radioactivity, while similarly to the ones on nuclear power. The significantly different responses found in **Q2, Q3,** and **Q4** in particular may be attributed to three tfactors: (a) the discipline received in College A on engineering in general, or (b) the lecutre possibly received by a portion of the class in College A on radioactivity specifically, or (c) the different gender composition of the two classes.

Unfortunately the effect of the factor (c) cannot be isolated in the present insufficient data collection scheme, and is not to be discussed here. The effect of the factor (a) may be that discipline in engineering has had an effect of training in quantitative thinking, although the training itself is not directly related to radioactivity. In any case it is reassuring on one hand that students who are to become professionals in engineering have correct knowledge or judgement in this technical field. On the other hand, the situation in College B gives us a serious task.

Soon as the graduates from this college, the students will join the mass of general citizen in this country without detailed knowledge, who will influence social decision-making in near future. The graduates from liberal arts colleges in this country are said to be majority in number over those from engineering or science colleges. It is very important therefore to nurture the next generation with correct sense of general judgement in radioactivity, even without professional discipline in engineering or radioactivity. In this regard, the following observation gives us a hint for the direction of our effort required.

(2) Students' Reaction to the Dose Rate Found in Their Environment

In the past three years (1996-1998) at College B, with which the present author is affiliated, attempts have been made to let the students monitor ambient radiation in their environment with portable survey meters. Two to three hundred portable monitors were rented from Institute of Radiation Measurements (Houshasen Keisoku Kyoukai), Tokai-mura, Ibarakiken, and allocated to classes in the following scheme(TABLE 3):

TABLE 3: Allocation Scheme of Survey Meters in the Class

110 monitors allocated	among a class of 260 students	in 1996,	lent	for a week,
230	among a class of 460	in 1997,		for two weeks,
380	among a class of 380	in 1998,		for two weeks.

The choice of locations for measurements was left up to students. Requested in the report which they are to turn in are the reason for the specific choice of locations, students' prediction of the radiation level at the locations they chose, and the agreement or discrepancies found, and the reason for discrepancy if found. The examples of typical measuring spots are: locations in campus, vairous spots they go through on their commute, their part-time job offices, spots in downtown, and thier residences. In their residences, most of the students try to measure specifically the dose at the room they daily spend their time most, namely their study or their living room.

On the average, the dose rate values in the Nagoya downtown varies from 40 to 80 nSv/h, in the campus from 20 to 70, and in their residence from 40 to 80. Thus in many cases the students find dose rates in their residence higher than those in downtown and subway. The reaction in such a case is interesting, and worth careful scrutiny .

In most cases they can manage to overcome the surprise they feel in their first encounter with natural radiation, by convincing themselves by reading the lecture materials. But higher dose rate in their own study room than in downtown is harder for them to accept. They have already been told that the natural dose rate varies from prefecture to prefecture in this country, and that there have been no difference observed in the probability of cancer appearance among those prefectures. The difference in the dose rates between the highest and the lowest values over the country, which has been reported by literature(Ref.3), is of the order of 40 nSv/h, and so any dose rate difference smaller than 40 nSv/h need not to be worried about.

They confess, however, " I am scared," or they assert, "We should not overlook this reality. We need some measure to improve this situation." It appears that they are looking at such background (natural) radiation with the kind of feeling which they have toward chemical contamination with toxic materials. Rather than trying to make any judgement by comparing the measured value quantitatively with data that have been supplied in the lecture, they react with anxiety they had had a priori. It is not a logical judgement, but is reflexive reaction.

It is exactly this kind of reaction which often dominates the attitude of public when they encounter articles on radioactivity in press. It is infered that such attitude has long been formed by contacts in the past with sensational headline articles in press, which only emphasize the hazard of radioactivity, without quoting any specific dose values.

3. CONCLUSION

The reaction the students showed toward the unexpected level of radiation is regarded as exactly the kind of mentality that currently prevents logical reasoning and discussions on radiation utilization for the future in a broard aspecct. It should have a close connection with the fact that radiation is invisible, and that they have never verified or felt the existence of radiation with their five senses. If such lack of verification experience on radiation is the major reason for such mentality, laboratory classes in elementary or high-schools, where students themselves participate, will be the key to the solution. The reasoning in lectures alone would not solve this problem.

It is suspected that the current educational systems are sending out young generation to the society with the mentioned mentality, who would become press reporters soon, and who would contribute to illogical articles. In order to cultivate proper reflexive judgement in general citizen, and to erase their illogical preoccupation on radiation, radioactivity education in early school days is considered absolutely necessary. The education in university level would help only in the professional domain. In this sense, the author would like to send his sincere message of support to high schools or elementary school teachers.

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JP0050113

4.6 Experiments of the ^{42}Ar-^{42}K Generator

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Abstract

Very simple short half-life radioactivity source is obtained safety in classroom. Using this generator many experiments for radioactivity and ionizing radiation are carried out.

1. Introduction

A long half life argon generator (33 years), from which one can obtain short half life (12.5 hours) potassium radioactivity any time, has been developed and used for students in university and high school. This argon generator was produced by cyclotron, irradiated ^{3}H (triton) for noble ^{40}Ar gas. This reaction is s written as follows.

$$^{40}Ar + {}^{3}H \rightarrow {}^{42}Ar + p$$

The decay scheme of ^{42}Ar -^{42}K nuclei and cross section of device is shown in Fig.1 and Fig, 2.

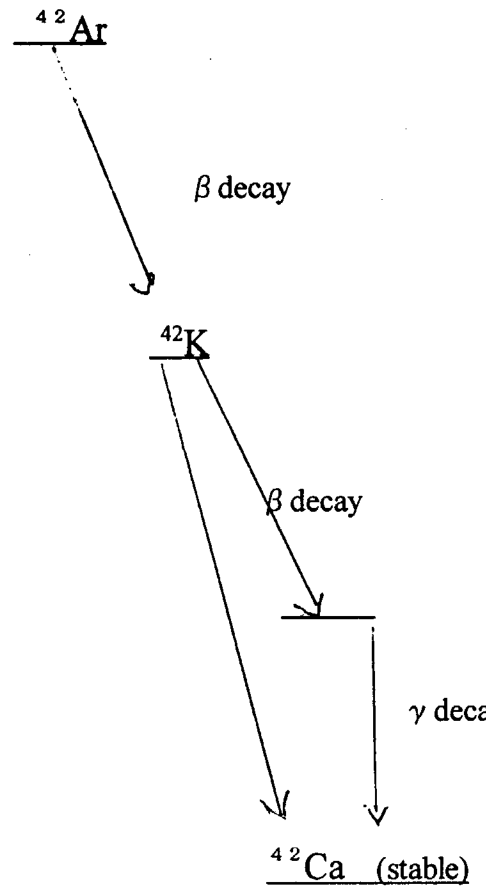

Fig.1. Decay scheme of ^{42}Ar-^{42}K nuclei.

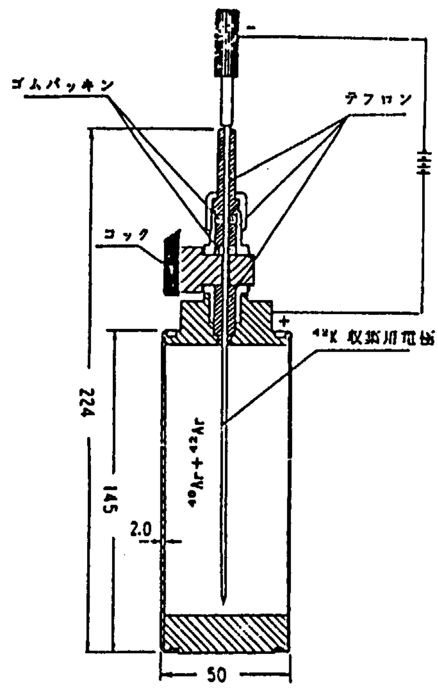

Fig.2.Cross section of device.

2. Setup of Instrument

A noble Argon gas which included in a small gas bomb is neutral. However Potassium makes positive ion. If there is an electric field, the potassium ion were collected a negative electrode. About 100 V DC voltage is applied 1-or 2 days with battery.

Water and used glass tube for milking a small polyethylene cell. Then the needle electrode inserted in the grass tube. Potassium ion melted in the water. This process is called "milking", which like relation between cow and milk.

3. Method of demonstration

An example of the ^{42}Ar-^{42}K generator is presented. The very simple procedure to extract the milking procedure of ^{42}K radioactivity is demonstrated. One can carried out many interesting experiments as follows.

(1) Half life of ^{42}K radioactivity.
(2) Absorption of radiation.
(3) Inverse square law.
(4) maximum energy of β ray.
(5) Energy spectrum of γ ray.
(6) Law of nuclear decay
(7) Transport of potassium ion in pure water with high electric field by DC voltage.
(8) Auto radiography
Etc.

4. Conclusion

This ^{42}Ar-^{42}K generator has excellent properties as an educational tool for teaching radioactivity and ionizing radiation. Its use is recommended not only in colleges and universities but also in high schools.

Teaching radioactivity has been very much neglected because of many reasons in schools and even in colleges and universities. However our life is so strongly dependent on nuclear energy and nuclear radiation.

The greatest merit of generator is its inherent safety because of the chemical inactivates argon and also the fact that one can use small generators under the limit of the law. Another merit is its convenience because of the rather long life of ^{42}Ar (33 years), and the procedure to obtain ^{42}K is very simple and interesting radioactivity.

The law limit in Japan is considered to be 3.7×10^4 Bq. This quantity is enough to do many interesting experiments.

JP0050114

4.7 空気GMカウンターの製作とその活用

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要旨

矢野[1]・米村[2]式の空気GM管を用いて教育用のGMカウンターを自作した。空気GM管は測定器としては限界があるが、環境等の低線量の測定や教育用としては優れた側面を持っている。安価に製作できるので複数台製作し、物理IBの放射線についての授業の中で、生徒用のグループ実験として使用した。この実践も併せて報告する。

1．はじめに

一般市民の放射能に対する意識は「放射能＝恐いもの」というのがおおかたの反応だと思う。一方で医療、工学、農業などで数多く放射線が利用されている。日常の中で上手に放射線とつき合えるように、またいざというときにもパニックに陥ることなく対処できるように、放射線の実践的な知識を身につけることは市民にとって大事なことである。しかし放射線検出器は高価なので、簡易測定器として空気GMカウンターを自作した。身近なところに普通に存在する安全な微量放射線源を用いて、実験を通じた放射線教育を、高校の物理の授業の中で試みた。

2．空気GMカウンターの製作

(1) 矢野・米村式空気GM管とその特徴

プラスチックの円筒の内壁に沿って紙を入れ、これを陰極にする。陽極は直径0.15mmの銅線（ごく普通のビニール被覆線の内部にある細い線）を二つ折りにして、図1のようにゴム栓にとりつける。窓はラップフィルムにする。放電は先端放電になる。また連続放電にならないように、高抵抗物質の紙を用いて放電をとめる。陰極に紙を用いるというのは矢野先生のアイデア、心

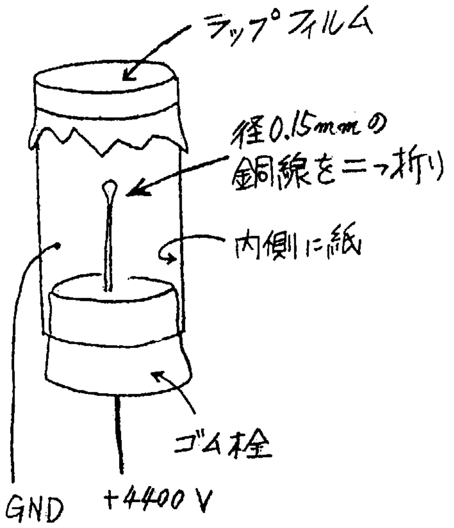


図1　空気GM管

線を二つ折りにするというのは米村先生のアイデアである。内部のガスは空気以外に、ガスライターに用いるブタンガスを測定の前に注入する。ブタンガスのような炭化水素は、電子の衝突によって励起された原子から放出される紫外線（連続放電の原因になる）を吸収する効果がある。また、普通のＧＭ管は管内を1/10気圧程度に　減圧してあるが、空気ＧＭ管では減圧はしない。その特徴は以下の通りである。

① 動作電圧が高い。
4000V前後の高電圧をかけなければならない。

② 分解能が悪い。

③ ＧＭ管の感度は窓の口径で決まるが、かなり大きくできるので、環境等の低線量の測定に向いている。

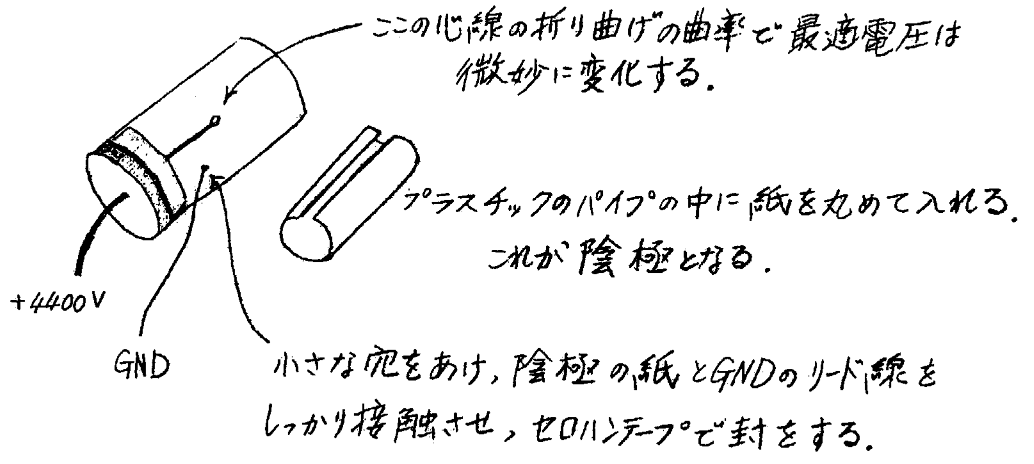
④ 製作が容易である。

⑤ 安価に製作できる。

⑥ α線を測定できる。

（2） 実際の空気ＧＭ管の作成

作成の仕方を図２に示す。ＧＭ管が高電圧発生回路での発振信号を拾わないように、ＧＭ管の外側をしっかりとシールドする。心線にゴミが付着すると連続放電を起こしやすくなるので、ときどき心線をアルコールで拭く。また、陰極の紙とGND線の接触が悪くなると不安定になるので、そのときはしっかりと接触し直す。



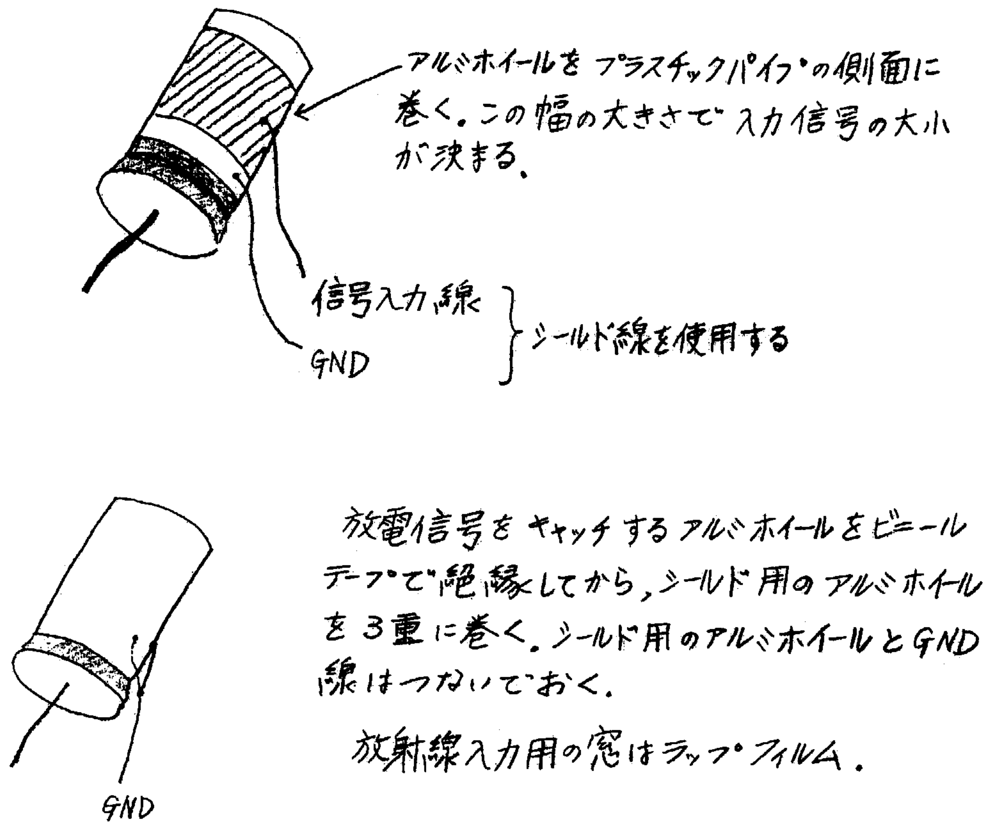


図２　実際のＧＭ管の作成方法

（３）高電圧電源の製作と高電圧の測定方法

図３のように、4000V程度の高電圧を達成するために、トランジスターとトランスを組み合わせて発振させ、昇圧した電圧をダイオードとコンデンサーによるコッククロフト倍電圧回路でさらに昇圧する。トランスには巻き線比の高いサンスイのドライバートランスST-26を用いる。図の赤とか緑と書いてあるのは被覆線の色である。12VのACアダプターを電源とし、電源コントロール部の半固定抵抗で、最終的に最適な電圧が得られるように調整する。コンデンサーとダイオードの組み合わせは9段連結とする。コンデンサーは0.1μFで耐圧630Vのものを用い、ダイオードは耐圧1000Vの10D10または1N4007を用いる。100MΩの抵抗はＧＭ管が発振信号を拾ったとしてもその振幅が放射線パルス信号よりも小さくするのに必要である。

空気ＧＭ管を正常に動作させるときの最大のポイントは、適正な高電圧を安定して与えることである。そのためには数千ボルトまではかれる電圧計が必要であるが、一般にはそのような電圧計は市販されていない。そこで、高電圧を正確に測定する簡便な方法は1GΩの抵抗と1MΩの抵抗を直列に接続し、電圧を 1000：1に分圧して高入力抵抗電

圧計で1MΩの両端の電圧を測ると、その 1000倍が測定すべき電圧となる。入力抵抗の高いデジタル型のテスターを用いてもよい。

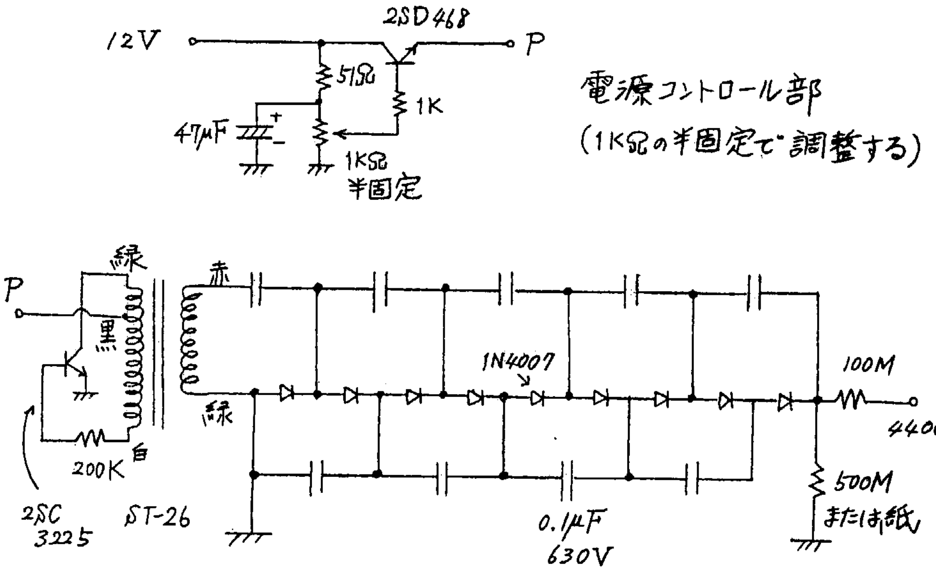


図３　高電圧電源回路

（４）放射線検出回路

図４が回路図である。LMC662は片電源オペアンプICが2個組になっている。一つを放射線パルス信号の増幅に、もう一つを信号とノイズを分離するコンパレーターとして用いる。4528はパルス整形用のICが2個組になっている。パルス幅は時定数0.1μFのコンデンサーと200kΩの抵抗の積で決まり、20msecである。この信号をコンピューターまたは万歩計に入力する。空気ＧＭカウンターの全体写真を次ページに示す。

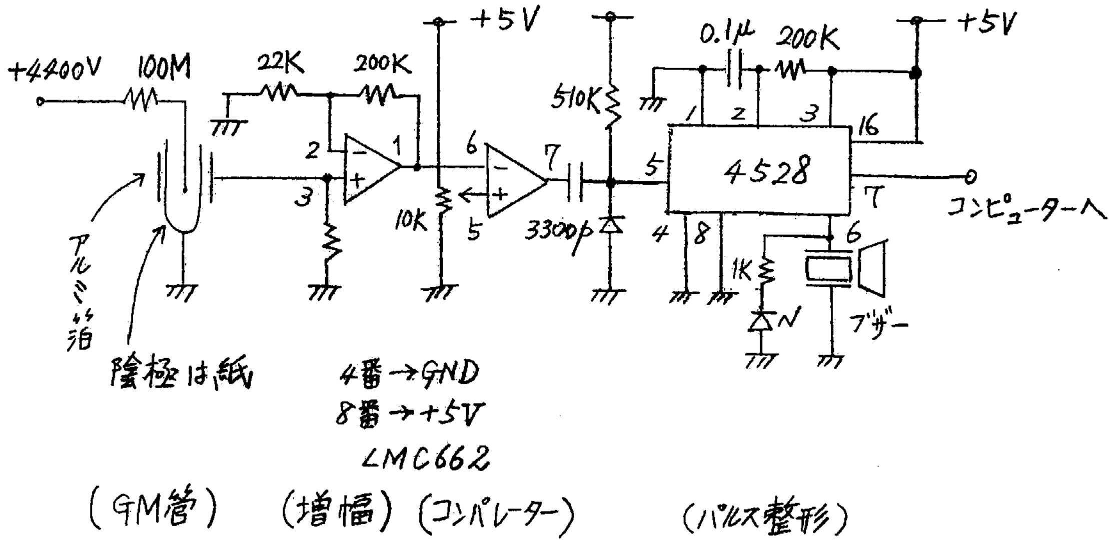
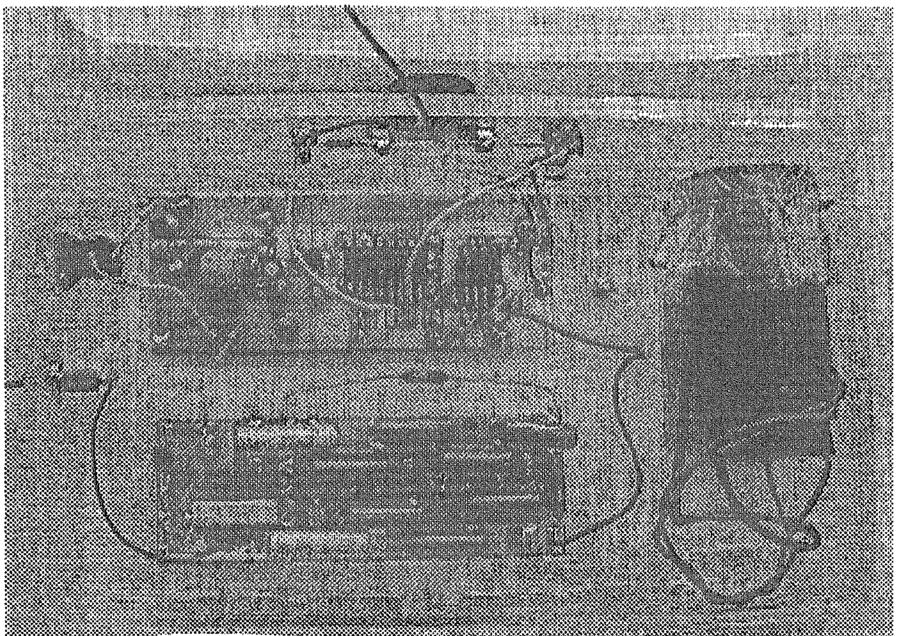


図４　放射線検出回路



空気ＧＭカウンターの全体写真

（５）　空気ＧＭ管の動作特性

ＧＭ管の前方に、β線源のプロメチウム１４７を置いて空気ＧＭ管の電圧特性を調べた結果が図５である。4000V～4800Vの間がプラトー領域と考えられる。使用電圧を4400Vにとると、放射能強度は100Vあたり0.75%ずつ増加している。プラトー特性としてはなかなかよい値である。芯線の太さや二つ折りの曲率に依存するが、空気ＧＭ管は動作電圧がおよそ4000Vと高いが、プラトー領域は約1000V程度もあるという特徴がある。したがって、静電気ＧＭ管という使い方が可能なのである。

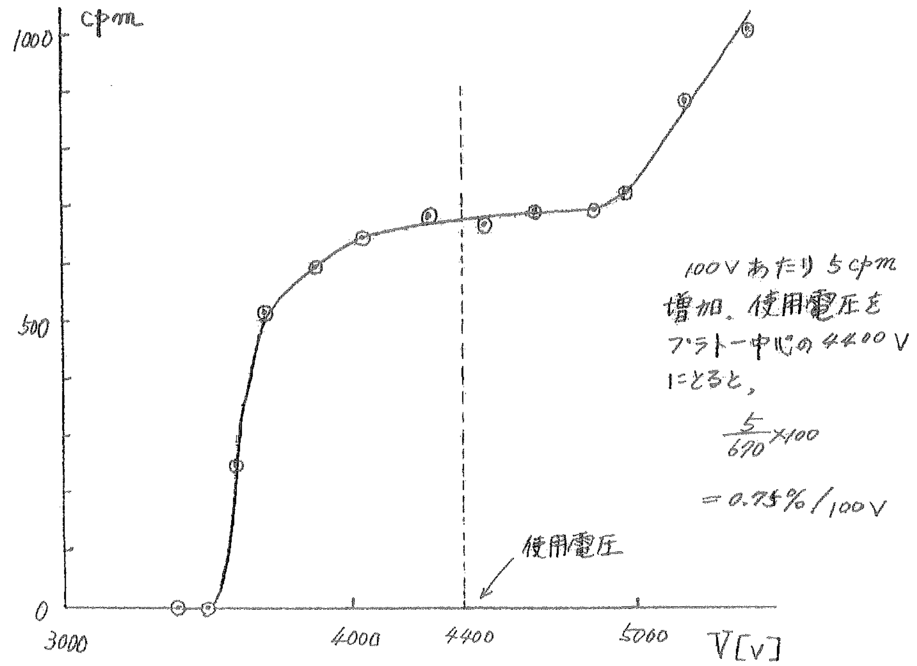


図５　空気ＧＭ管の電圧動作特性

GM管の前方にプロメチウム１４７を置き、２秒ごとにGM管に入射する放射線の数を1000回測定し度数分布をとってみると、ポアソン分布に近い分布を示す。このことから空気GM管が測定器として信頼できることもわかる。

３．身近な放射線の測定

(1) 塩化カリウム

バックグランドの10倍以上の放射能強度が測定される。

(2) 空気中の浮遊塵の放射能強度

二つ折りにしたキッチンペーパーを掃除機のホースの先に着け、輪ゴムで止めて、５分から20分空気中の浮遊塵を吸引する。これをGM管に密着させて測定すると、かなりの放射能強度を持っていることがわかる。半減期は約45分であった。最近、木造家屋（私の家）での測定で、浮遊塵の放射能が検出された。石膏ボードが原因ではないかと思われる。

(4) トロンの半減期の測定

トリウム系列のラドン220、通称トロンの半減期は56秒である。トロンは気体であるから、この放射性元素だけ独立に取り出すことが可能である。トロンはα崩壊であるが、これを空気GM管の中に直接注入すれば、半減期を測定することができる。

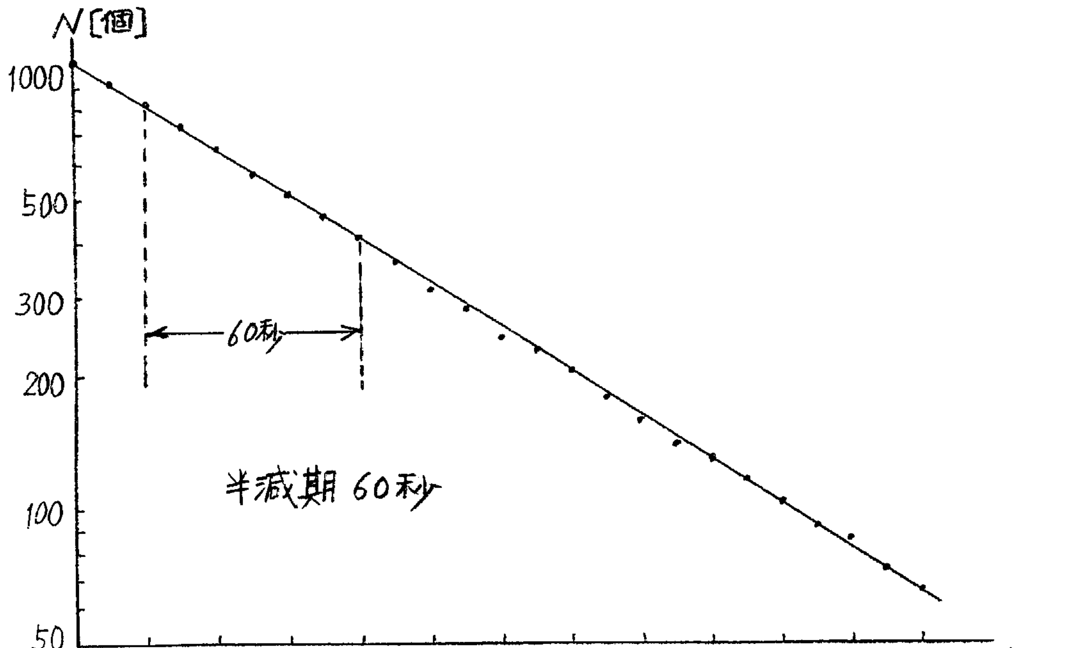
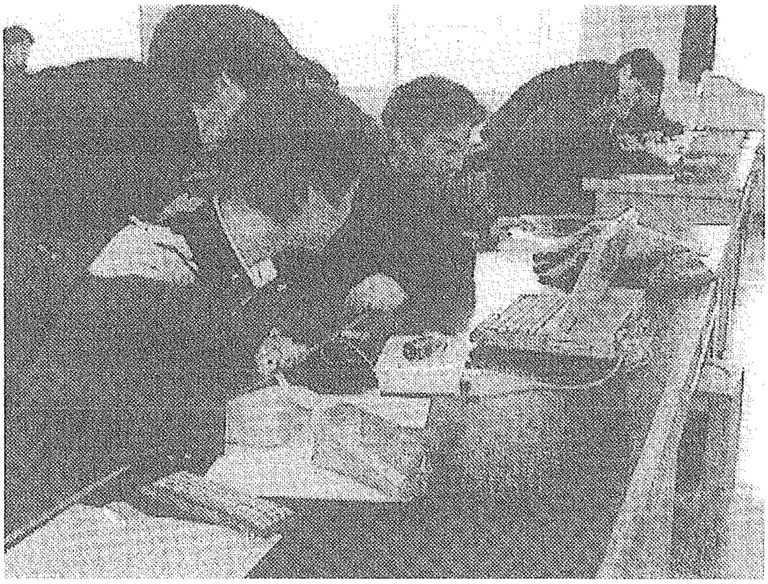


図６　トロンの半減期の測定

原子核や放射線の教育の中で崩壊と半減期の概念は重要であるが、今まで手軽に実験する方法がなかった。キャンプなどで使うガスランタンの芯に使う網袋（マントル）はトリウムを含むものがあるので、これを５枚ほどフィルムケースに詰め込んでおくと、数分で中にトロンが充満してくる。この中の空気を注射器で引き出せるようにすれば、トロンだけを抜き出して実験することができる。崩壊原子の数を累計し最初のトロンの原子数と仮定する。次に各時刻の残存原子を求め、片対数グラフにしたものが図６である。測定によると、約60秒である。かなり満足のいく値であろう。

４．鎌ヶ谷西高校での授業実践

鎌ヶ谷西高校は、就職・専門学校・短大・4年生大学進学のすべての希望者がいる、進学校ではない普通の学校である。1998年の1月に8時間の授業プランで放射線教育を実践した。放射線実験は８人ずつのグループで、５台の空気ＧＭカウンターを使用した。授業プランは以下の通りである。



トロンの半減期測定の授業風景

１時間目：放射線の基礎知識（講義と演示実験）
　原子核の構成・放射線と放射能・放射線の測定
　・放射線の種類とその透過力
２時間目：身近な放射線源を用いた放射線の実験（生徒実験）
　バックグランドの放射能強度測定・グロー管とマントルの遮蔽実験
　・食塩と塩化ナトリウムの違い・空気中の塵の放射能強度測定
３時間目：原子核の崩壊（講義）
　原子核の崩壊・放射性系列・半減期

４時間目：原子核崩壊の模擬実験（コンピューター使用の生徒実験）
崩壊確率を与え、モンテカルロ法で模擬実験。
５時間目：トロンの半減期の測定（生徒実験）
前記測定法参照
６時間目：「放射線を目で見てみよう」（ビデオと補足の講義）
原子力研究所製作のビデオを視聴し、内容を補足する。
７時間目：「放射線と人体」（講義）
電離作用と生体への影響・Ｓｖの説明
・自然放射線による被爆と医療被爆・放射線の量と影響の関係
８時間目：原子力発電の是非（ビデオと若干の補足）
原研製作ビデオ「あなたもディベートしてみませんか」の視聴

計画した内容が多く、特に１時間目の予定した演示実験すべてはできなかった。しかし、放射線は目に見えないもので危険なものであるが、身の回りにありふれているものでもあり、物理の法則にしたがっていて、決して神秘的なものではないということがわかってもらえたのではないだろうか。生徒にとくに好評だったのは、２時間目の身近な放射線測定だったようだ。

５．おわりに

私が空気ＧＭ計数管の研究に最初に取り組んだのは、今から６年前であった。それまでの先駆的な研究のまねをしてみてもなかなかうまく動作しなかった。陰極に紙を用いること、4000Vという高電圧を安定して加えること、炭化水素ガスを充填することなどのポイントをクリアして初めて安定して動作することが可能になった[3]。さらに、ＧＭ管をシールドすること、ＧＭ管の陽極には100MΩ程度の高抵抗を直列につなぐことなどの、技術的な発見が加わり、使いやすい手軽な装置になったと思う。

今回の放射線教育を実践するための資金として、鎌ヶ谷市の奨励金研究の制度を利用させていただいた。ここに改めて感謝申し上げます。

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JP0050115

Text of the key note lecture at the Workshop C of the First International Symposium on Radiation Education, December 13, 1998, Hayama, Japan

4.8 RADIATION AS A SOURCE OF RISK

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Abstract: Essence and nature of ionizing radiation as a source of risk are reviewed. Following to the appeal of necessity and importance of campaign for enlightening risk management, of individual and of society, background knowledge and information helpful to the promotion and discussion are summarized, also.

Keywords: radiation, risk, benefit, mortality, management, pedagogy.

要約：リスク要因としての電離放射線の本性が概観される。リスクとその管理法についての啓蒙活動の必要性と重要性を訴えるとともに、それに必要な知識や情報がとりまとめられている。

JP0050116

4.9 リスク要因としての放射線

加藤　和明

茨城県立医療大学

この山が私をつくってくれた。山には危険があるが、その危険が人をきたえる。それが人生のテーマでもある。
ゲルギエフ（指揮者、キーロフ歌劇場舞台監督）

1.　序言

こんにち、私たちは、放射線との付き合いなしに生きて行くことができません。それは三つの理由からです。第一は、私たちの住む世界、生活環境には、自然がもたらす放射線が充満（？）しているからです[第１図]。私たちは、先祖代々、自然放射線にさらされた環境の下で生命の再生産を続け、もっと長い時間スケールでいえば進化を続けて来ました。進化は生物の種が環境の変化に適応して生き延びるために必要なことであり、進化の主たる引き金は自然放射線が担っているという説があります。また、自然放射線が人体にもたらす程度の線量は、生体の反応を活性化させる働きを持ち、総体的に見て人の健康にポジティブな効果をもたらしているのではないかという説（放射線ホルミシス論）も出てきています。そうだとすれば、自然放射線も、熱や光や水、空気と同様、私たち個人個人や人類の生存にとって、なくてはならないものの一つかもしれません。

一方、放射線は私たちの文明を発展させる手段として重要な働きをしてきました。人類が放射線の存在を自覚し積極的にそれを使うようになったのは、1895 年にレントゲン教授がX線を発見してからのことであり、この 100 年の間に科学の分野でノーベル賞を授けられた仕事の 1/3 以上は何らかの形で放射線に関連したものであるといわれています。人類がつくりだし、使いこなしている放射線の種類は最早元素の数を超えています。 物質文明、精神文明の別を問わず、文明を更に発展させ、私たちの生活がより一層豊かなものとしていく上で放射線が有用であり、必要であることはこれからも変わることがないでしょう。これが第二の理由です。

今二十世紀は、電気と放射線で文明を築きその成果を楽む世紀であったといえましょう。この事情は世紀が変わっても変わりそうにありません。変わるであろうとか、変わるかも知れないと思わせる兆しが見あたらないのです。このような文明の成果として私たちが今日その恩恵に浴している最大のものは、医療の世界に於ける放射線の利用と核エネルギーを電気エネルギーに転換する原子力発電です。今日の医療は放射線なくして成り立ちませんし、資源、特にエネルギー資源に恵まれない日本にとって、日本人という“種”の生命を保存するための“コメ”であるエネルギー資源が長期的かつ安定的に確保されるということは、個人の場合に生命維持に必要な空気や水を心配しないで済むということと同レベルの重要事です。このように高度に発展・発達した文明の成果を享受するに際して不可避的に付随する放射線の出現があります。これが第三の理由です。

現在日本の国民がこの３種類の放射線にどれくらい身を曝しているかというと、1992 年の調査報告[5] で、１年に総量で 3.75 mSv、医療が 2.25 mSv で 60 %、自然が 1.48 mSv で 39 %、残りは原子力発電所や教育・研究機関などの放射線施設などにおける放射線とのつき合いによるものですが、これがなんと 1 % に満たないのです[第２図]。しかし、この事実を定性的にも定量的にも正しく理解している人の数は非常に少ないのが実状です[第３図]。原発からの放射線被曝に、間違って偏った大きな重みの掛けられているケースが多いのです。これは、マスコミが毎年大きく取り上げる、夏の定例行事と化した「広島・長崎の原爆被災」関連のニュースや、チェルノブイリ原発の事故と絡めてしばしば取り上げられる「原発と放射線をキィーワードとして含む出来事」の報道が、心証的に大きなインパクトを与えているせいであると思われます。専門家にとって、予想される被曝や放射性汚染は事故でも異常でもありませんが、マスコミはしばしば「事件」に仕立てます。

こうして、世の中に沢山の「放射線嫌悪症」や「放射線過敏症」を生み出しました。放射線の怖さを過小評価するのは良くないが、過大に評価し恐がりすぎたり、影に怯えたりするのも良くありません。ここで、チェルノブイリ原発の事故を振り返ってみましょう。1986 年 4 月に起きたあの事故では、30 人ほどの人達が放射線を過剰に浴び、急性の放射線症で亡くなりました。ICRP（国際放射線防護委員会）が創出し勧告している放射線防護の体系は、日本を含む世界の主要各国が結果としてこれを採用し国策としていますが、実はこの体系は、制御できる被曝を前提・対象としており、戦争やチェルノブイリのような事故による被曝は対象としていないのです。 国やその構成員である個人の生命を大きく脅かすこれらの“リスク源”や“リスク”にどのように対応するかは極めて重要な課題ですが、私たちが日常生活で否応なしに付き合っている放射線の被曝に伴うリスク管理の問題とは異質のものであり、区別して扱われるべきものと心得ます。放射線が人の健康に与える影響については、過小でも過大でもなく、適切に恐がることが肝要です。

この世には、個人や社会の生命を脅かすもの（リスク）が、多種多様、無数に存在します。そのどれかを退治したとき、別のものが勢いを増したり、新手のリスクが顔を出してきたりすることは、往々にしてあることです。特定のリスクを狙い撃ちし、リスクフリーを目指すということは、その限りにおいては結構なことであり、異を唱えるに及ばないと思われるかも知れませんが、実は理に適ったことではありません。リスクの源は無数といって良いほど存在しますし、リスクが小さくなるにつれてそれを下げるのに要する労力、コストが増大するからです。私たちに与えられている資源や時間は有限であり、それらを最適に配分してより有効に使うことが重要です。最適配分の評価基準は有効性ですが、これは個人や社会の価値観によって決まります。

個人で制御可能なリスクは自らの判断・責任で行われることが望ましく、個人では制御できないけれど社会としては可能なリスクは社会が責任を持って行うべきです。神様以外制御できないリスクは心配しても始まりません。それこそ杞憂というもので、ストレス過剰による健康への悪影響の方がリスクとして大きくなるでしょう。

安全や安全管理の基準は社会と当事者との契約であるというのが私の考えですが、合理的な契約は、契約の両当事者が同レベルになければできないことです。放射線の安全管理に関しては、人々の我が身に対する放射線被曝（リスク）の受容レベルが、あまりにも広範囲に分散していて［第4図］、社会としての意志集約は極めて困難な状況にあります [1]。二十一世紀に生きる人達は、リスクとその管理法について知識と技術を身につけることを最低限必要な素養の一つとし、社会全体の安全文化の薫育を図って，上記の契約が何処においても、迅速にして且つ合理的にし締結できるよう世の中を変えていかなければなりません。そのための方策をご参加の皆様と一緒に考えるというのがこのワークショップの趣旨であります。

以下は、リスク要因の一つである放射線を中心に、討議に必要と思われる基礎的な事柄のおさらいです。

2． リスク

生命の本質は再生産を通じて生命の保存を図るということであり、生命の宿る物体である生物すべてに共通する宿命はその命に限りがあるということである。人間とて例外ではない。人は誰しもいつか死ぬ。今日、日本は世界の中で第 1 級の長寿命国といわれている。寿命というのは生まれたときから死ぬまでの時間の出生時における期待値である。その寿命を、今仮に、男女共通に 80 年としよう。もしもすべての人が誰しも 80 歳の誕生日を迎えた日に死を迎えるようになっているとしたら、単位時間あたりの「死ぬ確率」、死亡率 M(t) は

$M(t) = \delta(t\text{-}80)$， t：生存時間［年］

とディラック（Dirac）関数形となる。しかし実際はこうならないことを誰でも経験で知っている。また、死亡率が生まれてから死ぬまでの期間一定で不変、つまり、

$M(t) = 1/80\ [y^{-1}]$

ともならないことも、経験上知っている。実際は、死亡率は性別や年齢に依存し、横軸に年齢、縦軸に死亡率をとって描いた曲線（Mobility Curve）［第5図］は工業製品の故障率の時間推移を示

すワイブル (Weibull) 曲線に似たものとなっている。死亡率の増大をリスクといい、リスクの増大をもたらす事象や行為をリスク要因（リスク源）という[1]。大雑把に言って、死亡率は 20 歳で 1/1,000、40 歳で 1/500、50 歳で 1/200、60 歳で 1/100 程度である。死をもたらす原因は、癌などの疾病に罹ることや自動車などの事故に遭うことなど、様々である。まこと、生きているということ、生を営むということは、リスクとの戦いであると言える。

我々が生を営むために必須のものが沢山ある。太陽からの光、水、空気、‥‥ 等々がなければ我々は生きていけない。ところが、こういった必須のものでも、採りすぎると身体（の健康）に悪いのだということがはっきりしてきた。空気を吸うことにより体内に活性酸素がつくられ、生命再生産の処方箋である DNA に傷をつける[2]。空気を吸わないと酸素を採れないから生きていけないが、同時に加齢・老化を進めることになるというわけである。熱や光を一度に大量浴びると火傷をしたり眼を潰したりする。水を無理して沢山飲むと苦くなってきて身体が受け付けなくなる。塩でも砂糖でも薬でも、度を越して摂取すれば毒と化すのである。

3.　放射線

物事を定義するのに二つの方法がある。帰納的定義と演繹的定義である。「アルファ線があります、ベータ線があります、ガンマ線があります…これらを放射線といいます。」というのが前者で、「運動エネルギーをもって空間を飛んでいる素粒子（またはその結合体である裸の原子核）」というのが後者である。前者は分かりやすいが適用限界がぼやけるのでので一般向け、後者は正確で応用が利くので専門家向けである。

4.　線量

放射線が物体に入射すると物理的作用を引き金に様々の反応を誘起し、最終的に様々の影響をもたらす。これを科学の対象として取り扱うには、定量的な因果関係を樹立する必要がある。ミクロの世界の物（モノ）の理（コトワリ）もマクロの世界のそれと共通するものが多い（例えばエネルギーのもっとも低い状態が一番安定であるなど）が、異なった趣もある。その最たるものは、「量の取りうる値が不連続で離散的」であることや、状態間の遷移等「事象の生起が確率的」であることである。マクロの世界では原因があったら結果が出るのは約束されたことであり、確率 100 % である。言ってみれば物理の論理は「必然性の論理」で成り立っている。これに対し、ミクロの世界では原因があっても結果は一意に定まらず、ある原因がある結果を引き起こすこともあれば引き起こさないこともある。しかしその確率はきちんと決まっているのであって、その意味で定量的因果関係が在るといえるのである。物理の論理は「蓋然性の論理」と呼ばれる。

放射線の物体に及ぼす影響を扱う科学で原因の量としているのが「線量」である。物理的作用を引き起こすもとはエネルギーであると考え、放射線によって物体に与えられたエネルギー密度を基本の線量とし、「吸収線量」と呼んでいる。特別の単位グレイが使われていて、1 Gy = 1 J/kg である。

ところが、放射線の人体に及ぼす影響は、吸収線量が同じ量であっても必ずしも同じでないことが多い。放射線の種類やエネルギーの違いにより、また人体の放射線に対する感受性の部位による違いにより、影響の発現に違いが生じるのである。そこで、防護の目的には、上記 2 種類の補正を荷重係数の形で織り込み、一定量の線量が常に一定量の効果・影響を生ずるよう調整したものを使

---

[1] リスクという言葉は多くの分野で使用されているが、その定義や概念規定は一様ではない[4)]。放射線防護の分野ではこのように確率で定義してきたのに対し、原子力安全（Nuclear Safety）の分野では期待値（災害の規模 x 発生確率）を用いている。

[2] 発癌や遺伝障害のもとになっているといわれる 8-オキソグアニンやチミングリコールは、放射線によってもつくられるが、毎日吸っている酸素によってもつくられる。酸素によってつくられる 1 日当りの量は、控えめに見積もっても、一般人に対する放射線の年限度である 1 mSv の線量がつくる量に匹敵するという[6)]。

う。最初の補正を施こしたものを等価線量、二重に補正したものを実効線量と呼ぶ。ここでも特別の単位シーベルトが用意されていて、 1 Sv = 1 J/kg である。

5．放射線防護の目標

現在の放射線防護システムは、確定的影響については完全阻止、確率的影響についてはそれのもたらすリスクをある限度内に抑制することを目標としていて、等価線量は前者の、実効線量は後者の目標を達成するための手段として使用される。

確定的影響というのは皮膚の障害や白内障、脱毛や血球数変化など目に見える身体的障害のことで、線量がある値（しきい値）を越えない限り発生しないが、 発生したときの障害の程度は受けた線量に依存する。

確率的影響は、生命再生産の処方箋である DNA の遺伝情報が放射線により傷つき、生命再生産が上手くいかなくなることで起こる障害であって、個体を維持するのに必要な細胞に起こると発癌、子孫をつくるのに必要な細胞に起こると遺伝障害に結びつく。

管理の対象は、実際上リスクの限度内抑制となっていて、放射線防護の分野では線量に実効線量、影響にリスクが採られていると言って良い。

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5． 生活環境放射線 (国民線量の算定), (財) 原子力安全研究協会, (1992).
6． 田ノ岡 宏：私信 (1998).

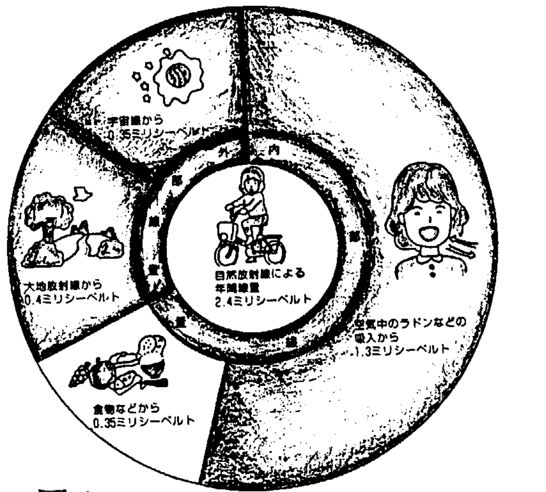

図1　自然放射線の内訳（全世界平均，1988年国連科学委員会報告）

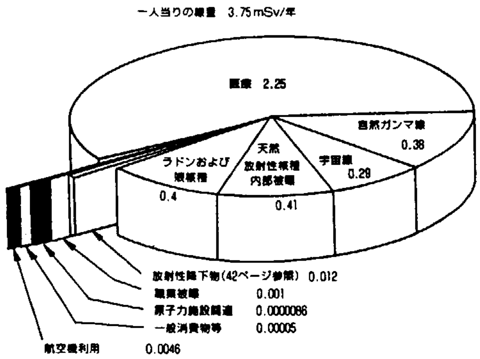

図2　日本人の環境放射線被曝線量（mSv）
［「生活環境放射線」原安協-231、1992より］

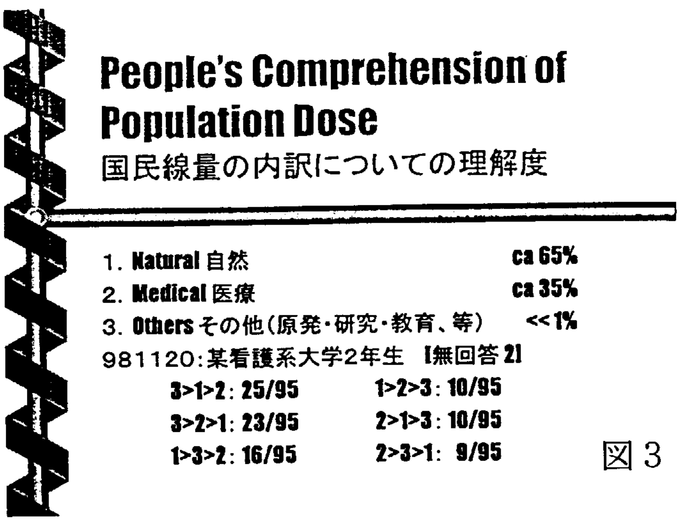

図3

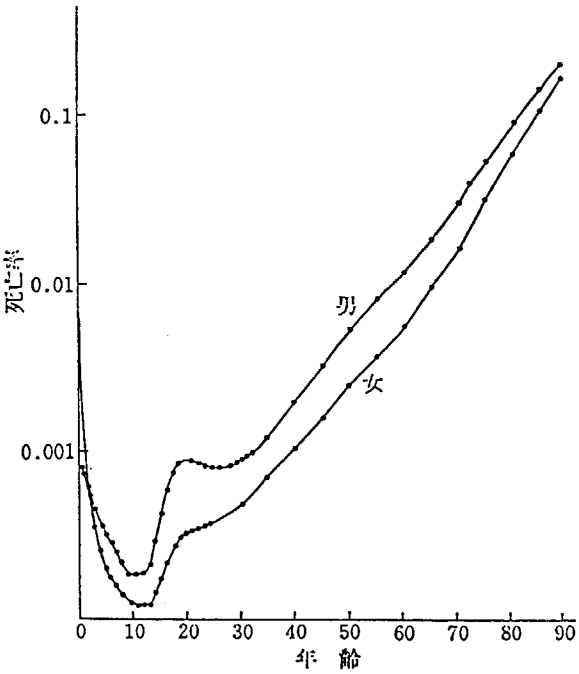

図5　年齢階級別死亡率曲線（1984年簡易生命表より）

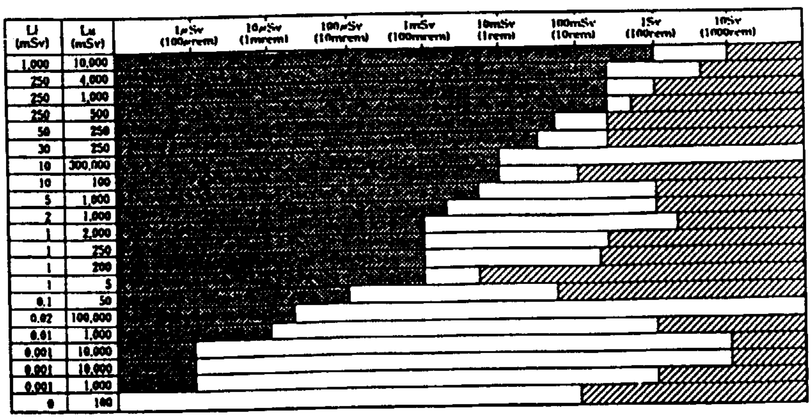

図4　一般人〔自然放射線のレベルを正しく認識している人の中から任意に選んだ21人〕（グループA）の放射線受容レベル

レベル1〔Ll〕：身体に放射線を受ける場合〔全身均等，外部被ばく〕，これ以下なら特に被ばくが気にならないという線量。

レベル2〔Lu〕：同じく，これ以上では怖くていやだという線量。

リスク要因としての放射線
RADIATION AS A SOURCE OF RISK

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WHAT is Radiation ?
放射線とは ?

In Broad Sense: Elementary Particles with Kinetic Energy

In Narrow Sense: Ionizing Radiation

帰納的定義と演繹的定義
Inductive- and Deductive-Definitions

Inductive-D: Easy to Understand
　Suitable to non-Specialists 一般向

Deductive-D: Precise to Understand
　Suitable to Specialists 専門家向

e.g.: fruits and vegetables

Radiation and Matter
放射線と物質 / 物体

Inter-Elementary Particles Interaction
　→ Macroscopic Effects

素材 : 共通 (素粒子)

素粒子間相互作用→巨視的影響

Radiation and Human Body
放射線と人体

Material 素材 : Elementary Particles
　[common 共通]

Inter-Elementary Particles Reactions

→Chemical Rs → Biological Rs

→Detrimental Effects to Health

Effects of Radiation on Human Body
放射線の人体に及ぼす影響

Deterministic Effects: 確定的影響

急性死、白内障、皮膚損傷、等

Stochastic Effects: 確率的影響

発癌、遺伝障害

Human body seen from Rs: very sparsely distributed elementary ps in empty space

1. 無数(60兆?)の微小生命体の集まり
2. 生命再生産を邪魔＝生命再生産の処方箋(DNA)にキズ
3. 放射線と処方箋との相互作用
4. キズの修復
5. ホルメシス効果

Scales: Macro to Micro
マクロの世界とミクロの世界の寸法

Human Body 人体	1 m
Cell 細胞	10 μm
DNA（生命再生産処方箋）	10 nm
Atom 原子	100 pm
E. Particles [Radiation]	1 fm

n = 10(-9): ナノ, p = 10(-12): ピコ, f = 10(-15): フェムト

Physics of Micro-World
ミクロの世界の"物の理(コトワリ)"

Discreteness 離散的
Probabilistic 確率的
Logic 論理
必然性→蓋然性

Lethal Dose 致死線量: ca 10 Gy (Sv)

Whole Body, Instantaneous Exposure (1 hr)

e.g.: γ-rays of 1 MeV
- fluence ψ ~ 1.5 x 10(+12) [cm(-2)]
- wave length λ ~ 10(-10) cm
- [π [λ/2]**2]* ψ ~ 10(-8)
- heat up: 10 J/kg / 4.2 J/cal ~ 0.002°

Science on Effects
影響の科学

Quantitative Causality Relation
定量的因果関係の確立
Quantization of Cause and Effect
原因と影響の定量化

Radiation Dose : Quantity of Cause
放射線の線量: 原因の量

dose: 線量／剤量／用量
基本線量: 吸収線量 [1 Gy = 1 J/kg]
物体中の注目点におけるエネルギー吸収密度
防護(用加重)線量: [1 Sv = 1 J/kg]
- 等価線量 Equivalent Dose
- 実効線量 Effective Dose

Dose 線量

Fundamental Dose: Absorbed Dose
吸収線量, D
1 Gy = 1 J/kg
Weighted Dose: Effetive Dose
実効線量, E = Wt・Wr・D
1 Sv = 1 J/kg

Risk リスク

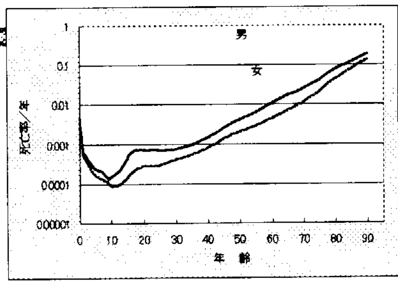
Risk = Increase in Mortality
リスク＝死亡率の増加：確率
＊リスクの概念規定は分野により異なっている。
＊通常は損失・損害等の＜期待値＞
＊Katoh は"余命損失の期待値"提唱

Aim of Radiation Protection (ICRP System) 放射線防護の目標

Deterministic Effects	確定的影響
Prevention	完全阻止
Stochastic Effects	確率的影響
Suppression of Risk	リスク抑制

Mortality Curve (Japan) 生命図（死亡率曲線）

平成6年簡易生命表より



Dose Limit <Effective Dose> 線量限度値 <実効線量>

現行法 (ICRP1977年勧告等準拠)：
- 職業人：年 50 mSv
- 一般人：年 1.0 mSv

改正法 (ICRP1990年勧告準拠)：
- 職業人：年 50 mSv, 5年 100 mSv
- 一般人：年 1.0 mSv

放射線以外のリスク要因 Risk Sources Other than Radiation

Wild Beast, Starvation, War(Calling-Out Paper), Disease(Cancer, TB, AIDS, etc.), Accidents(Burning, Falling-Down, Automobile, etc.), Disaster caused by Nature(Earth-Quake, Flood, Typhoon, Meteorite, etc.), Aging, etc.

リスクと便益
Risk vs Benefit

リスクフリー追求：
望ましいことでないし可能でもない
ALARA（ICRP）：
リスク要因間に見られる**trade-off**の関係

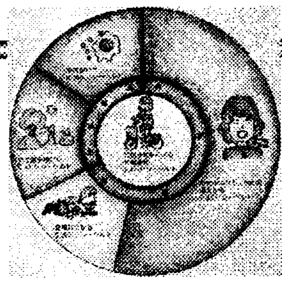
Criteria of Safety [Safety Control]
安全（管理）の基準

社会との契約 **Contract with the Society**
基準は社会の状態に依存
契約を合理的に行うための条件
個人の価値観の多様化
個人のリスクと社会のリスク：**NIMBY**
e.g. チェルノブイリ原発事故

How to associate with Risk?
リスクといかに付き合うか？

杞憂 → ストレス
リスクフリー：（財的／人的）資源は有限
リスクの制御：
感覚の補償／量的判断力（量の違いは質の変化をもたらす）

Natural Radiation in Japan [annual dose] 自然放射線による年被曝線量と内訳



自然放射線の内訳（全世界平均，1988年国連科学委員会報告）

リスクへの対処法（1/2）

- 個人で制御できるリスクは自己の責任で！
  - 必要な知識と技能の取得は21世紀に生きる人の基本的素養：生き方／価値感に依存
  - 人生を生きるに値するものとすることも大事：**High Risk - High Return** も認める必要ある
- 専門家と非専門家の **moderator** が必要
- 有限の時間・資源をどう使い、リスクと便益をどう組み合わせるか？： リスクを考えるということは生き方を考えるということ

Kazuaki KATOH 981213　ISRE-98, Hayama, Japan　23

リスクへの対処法（2/2）

- 自己の意思で制御できないリスクの管理は社会に任せるしかない！
  - リスクの管理基準の整合性をどのようにとか？
    How much safe is safe enough?
  - 意思の集約法： 技術（方法論）の開発と判断材料としてのデータの収集 / 議論の公開 / 人的及び財的・資源の最適配分 が望まれる
  - NIMBYへの対応策：安全文化の薫育

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一般人に関わりのある放射線管理基準

- 放射線事業所敷地: 250 μSv/3月
- 放射線事業所管理区域境界: 1.3 mSv/3月
- 病院病室: 1.3 mSv/3月

- RI投与患者帰宅: 30 μSv/h (1m)
- 放射線発生装置規制除外: 0.6 μSv/h (0.1m)
- RI装備診療機器(骨塩/ガスクロ): 0.6 μSv/h (表面:非使用時)
  6 μSv/h (1m:使用時)
- 放射性物質運搬: 2 mSv/h (表面)
  100 μSv/h (1m)
- 放射性廃棄物: 現状では下限なし
- 同上[導入予定の clearance level]: 10 μSv/y

Typical misunderstandings よく見られる世間の誤解

- **Half Life:** "半減期"というものがあるので"放射能" は永遠にゼロにならない。
  未来は確率的だが過去は確定的!
- **Accident / Abnormality:** 事故と異常
  予想されている被曝や汚染は事故でも異常でもない!

Half Life 半減期
Future: Probabilistic
Past: Deterministic

放射能は永遠にゼロにならないというのは迷信

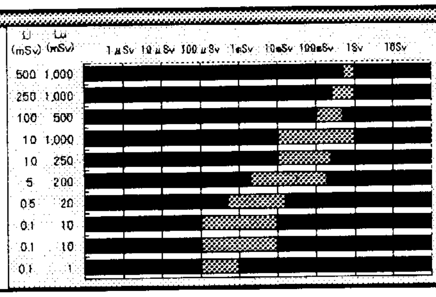
半減期:1年の放射性核種

	1年後	10年後 ($2^{-10}=10^{-3}$)
100万個	50万個	1,000個
2個	2個 (25%)	2個 (10(-6))
	1個 (50%)	1個 (10(-6))
	0個 (25%)	0個 (99.9998%)

An Example of Survey on Acceptable Levels to Radiation Exposure

>Lu: unbealable

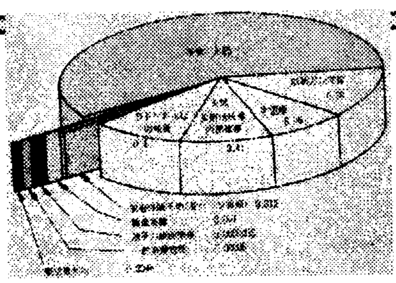
<Ll: not worring



Annual Population Dose in Japan 国民線量の値と内訳

一人当たりの線量 3.75mSv/年

日本人の環境放射線被曝線量 (mSv)
[「生活環境放射線」原安協-231, 1992より]



People's Comprehension of Population Dose
国民線量の内訳についての理解度

1. **Natural** 自然 ca 35%
2. **Medical** 医療 ca 65%
3. **Others** その他(原発・研究・教育、等) <<1%

981120:某看護系大学2年生 95人

3>1>2: 25/95	1>2>3: 10/95
3>2>1: 23/95	2>1>3: 10/95
1>3>2: 16/95	2>3>1: 9/95

[無回答 2]

JP0050117

JAERI-Conf 99-011

4.10 各種リスク要因の比較
Comparative View on Risk Factor of Human Death

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要約

リスクのない生涯は考えられない．リスクの要因を死亡に限ってみても，人類の歴史は太古から現在まで，それは無数といってよい．

自動車は移動に便利だが，事故死を増やしている．日本では，毎年約１万人が死亡するが，それは運転者だけではなく，跳ねられた歩行者と自転車乗車者とが全体の４０％を占めている。

高齢者では，歩行中の転倒による骨折の頻度が高い．このことは，自動車運転を諦めて事故を免れたはずの高齢者にとっては，歩行者としての別の危険が襲うことを示している．つまり，ある危険の可能性が減少すると，別の危険の可能性が出現してくる，このような「リスクの付け替え」は，随所にみられる．

いろいろな原因による死亡率について，一般に受け入れられているのは年間１０万分の１のレベルである．航空機事故は，年間１千万分の１であるが，その発生確率がきわめて微少であるにも拘らず，救命の可能性が小さいことや事故が苛酷であることから，大いに恐れられている．

航空機や原子炉では苛酷事故の可能性があるが，その確率は僅少である．年間死亡リスクの把握は，事故の大きさ（人／年）と生じる確率（回／年）の積についてなされるべきである．それによって，正しいリスク認知が得られ，確固たる「リスク受容」が達成される．

ABSTRACT

Human being, namely. "living" get involved in risk factor. Even if risk is limited to lethal danger, human history is coresponding with numberless risks from ancient up to today.

For example, there is increase in risk of death by car-crash owing to get high efficiency in transfer. In Japan, the death toll by car-accident is about ten thousands per year constantly. State of deaths by car-accident not only include driver itself but cyclist and pedestrian. Death rate of both the cyclist and pedestrian amounts to 40% of all.

In the aged, rate of fracture as result of fall-down while walking is very high. It shows that the aged who give up driving and get out of danger car-crush are attacked the another accident as walkers. On type of danger, the decrease in risk of one-side come to increase in risk of other side. That is "risk trade-off". Examples of risk trade-off as above are numerous in envaironment.

Acceptable death rate of various causes is about 10^{-4} per year in generally. Flight accident happens on rare occations(10^{-7} per year in Japan, usually). Spite of insignificant probalility, people fear by both reasons that the possibility of rescue is very few and the size of accident is enormous.

In the cases of flight and nucler power plant, estimated accidents is sever, but its probablity is very small. Therefore, risk of annual deaths by accident must be considered as multiplication of size of risk(deaths per year) by probability(frequency per year). Obtained result by such analysis shall conduct to right risk perception and stable "risk acceptance".

ヒトは300万年前といわれるその原始以来、展開してきた長い歴史の中で、さまざまな種類と程度の“危険の可能性＝リスク”に曝されてきた。地球上における弱者としての存在から、周辺のあらゆる動植物に生命を奪われる危険に直面していたし、また、多種類の微生物による攻撃により生命が奪われてきた。さらには、大きく変動する気象条件や地殻変動がもたらすさまざまな変化は、自然災害というかたちで攻撃を加えてくるいっぽうで、極度の慢性的食糧不足も生命を脅かす結果となった。

そして、ヒトの集団が形づくられるとともに文化が生まれ、文明社会が構成されるに伴って、集団内外におけるさまざまな抗争が大きな脅威となった。そのいっぽうで疫病の流行という微生物の多様な攻撃を受けることになった。そのような危険は、今日の便利な社会生活においても、その隅々にいたるまで、本質的にむかしと変わることなく、ヒトの24時間の生活の中に散りばめられている。

さらに、いまやこのような“危険の可能性”、すなわちリスクは、単に「生命」の喪失だけではなく、「健康」や「財産」など、“失いたくないもの”が増えるにしたがって広がりをみせ、その種類と度合いの理解について、関心が高まってきている。その中でも「死亡リスク」は一般の関心の集まるところであり、またそれはわが国などでは信頼度の高い統計として整理されているため、論議の対象となることが多い。

表１は、いろいろな死因による10万人あたりの年間死亡リスクの一覧である。疾病のうち、がんによる死亡数は、日本では全死亡数の1/3に近いが、諸外国においても、1/4～1/3　と高率である。ここには経年推移が示されていないが、臓器によりその傾向に若干の差異がみられるものの、全がんの死亡率は、各国とも増加を続けている。自然災害による犠牲者は、台風や地震など偶発的で回避や予測が困難なものが含まれるため、経年的にみて変動の幅が大きい。ところが水難やあ火災など、ヒトの日常活動におけるリスクの大きさには、不思議なほど毎年ほぼ一定の数値を示すものがある。

自動車の使用は移動に便利であるため発明以来発展をつづけているが、事故死を伴うことは避けられない。わが国の交通事故についてみると、この数年の年間死亡数は約１万人で、10万人あたり9.3人(１日あたり30人程度、毎時1.3人)に相当する。そして、この危険の可能性を示す数値に対しては、とくに抵抗なく受け入れられているといえよう。

これに対して、1985年の日航機墜落事故では、520人が死亡したが、10万人あたりでは0.43人(１日あたり2人程度)に過ぎず、阪神・淡路大震災(1995)では6,431人が死亡したが、10万人あたりでは5.0人(１日あたり20人弱)である。あとの2例では、人びとの受けた衝撃は大きかったが、実際には交通事故のそれぞれ1/15と1/2に相当する年間リスクであった。ここに、恒常的に発生しているリスクの大きさと、突発的で短時間に出現するそれとのあいだに、認識の違いのあることがわかる。つまり、観念的リスクと客観的リスクのあいだに不一致がみられる。

交通事故の考察にあたっては、得られる利便の故に課せられるリスクを受け入れているのかどうかについて、検討を加える必要がある。表２から、日本をはじめ各国・地域における歩行者と自転車乗車者の、交通事故死亡率が読み取れる。日本では、全交通事故死亡者数の約40％で、各国・地域でも15%～50%の数値となっている。この人びとは、自動車利用による利便とは関係がない存在である。

高齢者では、歩行中に転倒し骨折する頻度が高い。このことは、高齢者が自動車運転は運転技術の点から死亡事故につながる可能性が大きいと勧告され、これを容れて運転を諦めた高齢者に別のリスクが待ちかまえていることを示している。表３の中にに示した「転倒・骨折」は、路上歩行中の者だけを対象としていない(それを指示している統計数値はない)が、65歳を超えると全年齢平均値を上回るようになり、75歳以上で差異は急激に大きくなっている。このことは、事故死を恐れて運転を諦めた高齢者に、別のリスクが襲うことを示している。つまり、あるリスクを回避しても、その代わりに別のリスクが出現するわけで、このような「リスクの付け替え(risk trade-off)」は随所に見られる。このことが最初に提起されたときの例示は、アスピリンの服用についてであった。その場合、頭痛の症状を緩和するためにアスピリンを服用すると胃に副作用が現れるが、この場合、その可能性を勘案した上で服用を決行するかどうか、つまり、頭痛というリスクを回避する代わりに、服用によって生じる胃の障害という避けられないリスクを受け入れることについての判断に迫られることになる。日常行動において休みなく行われるさまざまな判断は、つねにこのrisk trade-offの評価に基づき、それを受容するための大切な手続きである。

一般に受け入れられている死亡リスクは、交通事故にみられるように年間10万分の1(10万人に1人)のレベルである。航空機や原子炉では苛酷事故の可能性があるが、その発生確率は僅少である。原

子炉事故については、10万年～100万年に1回などといわれているが、その苛酷さを1年間あたりに割り付ければ、決して大きなものではない。リスクの把握は、事故の大きさ(人／年)と発生確率(回／年)の積によるべきである。このような客観的立場が、リスクの正しい“認知”を導き、確固たるリスク“受容”の確立につながる。 ■

表1 いろいろな事項についての１０万人あたりの年間死亡数（１９９８年版）　Table 1 ANNUAL DEATHS BY VARIOUS CAUSES PER 10^5 PERSONS(1998)

〔収集・編集Collector and Editor：武田篤彦Atsuhiko TAKEDA(財)体質研究会Health Research Foundation) 1998.10.31.作表=暫定)〕

死亡リスクのめやす lead of death rate	10万人あたり死亡数(人) number of deaths per 10^5 persons	事項（末尾の数字は死亡数(人), *;推定値）（国名のないものは日本国） causes of death(figure of the end shows deaths, *:estimation) (lacked name of country indicates Japan)	1時間あたりの死亡数(人) number of deaths/hr
↑10^{-2}	1,431.5	ハンガリー国民の全死因Hungary, all causes(1994)[1] 146,889	16.8
	914.3	フランス国民の全死因France, all causes(1994)[2] 528×10^3	60.3
	834,7	アメリカ合衆国民の全死因USA, all causes(1994)[3] 2,175,613	248.4
	719.1	エジプト国民の全死因Egypt, all causes(1994)[4] 416×10^3	47.5
	712.0	日本国民の全死因all causes(1996)[5] 896,211	102.3
	318.7	ハンガリー国民のがんHungary, malignant neoplasums of all sites(1994) 32,702*	3.7
	247.5	フランス国民のがんFrance, malignant neoplasums of all sites(1993) 142,924*	16.3
	215.5	日本国民のがんmalignant neoplasums of all sites(1996) 271,183	31.0
	204.1	アメリカ合衆国民のがんUSA,malignant neoplasums of all sites(1992)[6] 520,495*	59.4
	111.5	脳血管疾患cerebrovascular disease(1996) 140,336	16.0
↑10^{-3}	109.8	心疾患disease of heart(1996) 138,229	15.8
	70.3	65歳以上の前立腺がんmalignant neoplasum of prostate(1996)[7] 5,516*	0.896
	58.8	鉱業の労働災害labor accident of minners(1995) 31 〔労働者数laboring population:52,763	0.0035
	56.4	肺炎pneumonia(1996) 70,971	8.10
	54.7	林業の労働災害labor accident of forestry(1995) 66 〔労働者数laboring population:120,676〕	0.0075
	54.0	コロンビア国民の銃器による殺人Columbia, homicide by small arms(1995)[8] 19,336	2.21
	39.9	胃がんmalignant neoplasum of stomach(1996) 50,165	5.73
	38.2	肺(気管、気管支及び肺)がんmalignant neoplasums of lung and others(1996) 48,041	5.48
	34.7	肝(肝と胆のう及び肝外胆管)がんmalignant neoplasums of liver, gallbradder and others(1996) 43,717	4.99
	31.1	不慮の事故accidents and adverse effects(1996) 39,184	4.47
	27.3	韓国国民の自動車交通事故<3日以内>R. Korea, road accidents<within 3 days>(1996)[9] 12,653	1.44
	26.9	65歳以上の子宮がんmalignant neoplasums of uterus over 65 years old(1995)[10] 2,894*	0.330
	25.9	大腸(結腸,直腸および直腸S状結腸移行部[11])がんmalignant neoplasums of colon(1996) 32,630	3.72
	22.3	ポルトガル国民の自動車交通事故Portugal, road accident(1994)[12] 2,192*	0.250
	22.0	エジプト国民のがんEgypt, malignant neoplasums of all sites(1987)[13] 9,016*	1.29
	19.3	自殺suicide8(1997[14]) 24,391	2.78
	16.6	老衰senility(1996) 20,878	2.38
	16.5	65歳以上の交通事故road accident over 65 years old(1996)[15] 3,145	0.359

表1(つづき) Table 1(continued)

	15.8	ｱﾒﾘｶ合衆国民の自動車交通事故<30日以内>USA, road accident<within 30 days>(1996)[16] 41,907	4.78
	13.9	フランス国民の自動車交通事故<6日以内>France, road accident<within 6 days>(1996)[17] 8,080	0.922
	13.8	台湾地域民の自動車交通事故<24時間以内>Taiwan, road accident<within 24 hr>(1996)[18] 2,990	0.341
	13.2	膵臓がんmalignant neoplasum of pancreas(1996) 16,613	1.90
	13.1	肝疾患liver disease and cirrhosis(1996) 16,517	1.89
	12.4	漁業の労働災害labor accident of fishery(1995) 7 〔労働者数laboring population:56,391〕	0.0008
	12.4	建設事業の労働災害labor accident of construction(1995) 745 〔労働者数laboring population:6,029,824〕	0.0850
	12.3	乳がん<女子>malignant neoplasum of breast<female>(1996) 7,900 〔当該人口:63,995,848〕[19]	0.902
	10.8	ｵｰｽﾄﾗﾘｱ国民の自動車交通事故<30日以内>Australia, road accident<within 30 days>(1996)[20] 1,977	0.226
	10.8	イタリア国民の自動車交通事故<7日以内>Italy,road accident<within 7 days>(1996)[21] 6,193	0.707
	10.7	ドイツ国民の自動車交通事故<30日以内>Germany, road accident<within 30 days>(1996)[22] 8,758	1.00
↑10^{-4}	10.2	糖尿病diabetes(1996) 12,838	1.46
	9.3	交通事故<30日以内>total of road accident<within 30 days>(1996) 11,674	1.33
	9.2	ｽｳｪｰﾃﾞﾝ国民の自動車交通事故<30日以内>Sweden, road accident<within 30 days>(1996)[23] 537	0.0613
	8.5	オランダ国民の自動車交通事故<30日以内>Netherlands, road accident<within 30 days>(1996)[24] 1,334	0.152
	7.7	交通事故<24時間以内>road accidents of all<within 24 hrs>(1997)[25] 9,640	1.10
	7.7	子宮がんmalignant neoplasum of uterus(1996) 4,963 〔当該人口:64,177×10^3〕	0.567
	7.3	食道がんmalignant neoplasum of esophagus(1996) 9,138	1.04
	7.0	運輸業の労働災害labor accident of transportation(1995) 167 〔労働者数laboring population:2,380,893〕	0.0191
	6.3	ノルウェー国民の自動車交通事故Norway, road accident(1993)[26] 272*	0.0311
	6.3	イギリス国民の自動車交通事故<30日以内>U.K., road accident<within 30 days>(1996)[27] 3,598	0.411
	6.3	アメリカ合衆国民の銃器による殺人USA, homicide by small arms(1994)[28] 16,524*	1.89
	6.0	中国国民の自動車交通事故<7日以内>R.China, road accident<within 7 days>(1996)[29] 73,655	8.41
	5.0	阪神・淡路大震災Hansin-Awaji earthqueke disaster(1995)[30] 6,431	0.734
	5.0	白血病leukemia(1996) 6,279	0.717
	4.7	自動車・二輪車乗車中の交通事故<24時間以内>road accident of car-drivers<within 24 hr>(1997) 5,913	0.675
	4.3	16-24歳の二輪車乗車中の事故<24時間以内>road accident of motor cyclist(17-24 years old)(1997)[31] 714	0.0935
	4.2	香港地域民の自動車交通事故<30日以内>Hongkong, road accident<within 24 hr>(1996)[32] 263	0.0300
	3.4	全業種の労働災害labor accident of all industries(1995)[33] 1,628	0.186
	3.4	自動車乗車中の交通事故<24時間以内>road accident of motor vehicle ocupants<24 hr>(1997) 4,251	0.485
	2.9	歩行者・自転車乗車中の交通事故<24時間以内>road accident of pedestrians and pedal cyclists(1996) 3,708	0.423
	2.7	製造業の労働災害labor accident of manufacturing(1995) 306 〔労働者数laboring population:11,401,190〕	0.0349
	2.4	先天奇形，変形及び染色体異常native malformation, deformation and chromosome abberation(1996) 3,021*	0.345

表1(つづき) Table 1(continued)

	2.3	結核tuberculosis(1996) 2,858	0.363
↑10⁻⁵	2.1	歩行者の交通事故<24時間以内>road accident of pedestrians<within 24 hr>(1997) 2,643	0.302
	0.96	水難drowning(1997) 1,213	0.138
	0.85	火災fire(1997) 1,070	0.122
	0.84	自転車乗車中の交通事故<24時間以内>road accident of pedal cyclists<within 24 hr>(1997) 1,065	0.122
	0.64	二輪車乗車中の交通事故<24時間以内>road accident of motor bicyclists<within 24 hr>(1997) 1,662	0.190
	0.56	殺人homicide(1997) 710	0.0810
	0.43	日航機墜落事故crash of the Nikko airliner (1985)3[3)] 520	0.0594
	0.28	魚とり・釣りfish catching and angling(1997) 349	0.0398
	0.16	水泳中swimming(1997) 203	0.0232
↑10⁻⁶	0.16	山岳遭難事故mountain climbing(1997) 197	0.0225
	0.09	船舶による事故shipping(1997) 111	0.0127
	0.08	自然災害natural phenomena(1997) 96	0.0110
	0.07	ｽｸｰﾊﾞﾀﾞｲﾋﾞﾝｸﾞなど水上ﾚｼﾞｬｰｽﾎﾟｰﾂaquatic leisure sports(1997) 91	0.0104
	0.04	台風・大雨・強風・高潮による事故typhoon, heavy rain. high gale and tide(1997) 50	0.0057
	0.02	航空機による事故aircraft accident(1997) 28	0.0032
↑10⁻⁷	0.01	ﾊﾟﾗｸﾞﾗｲﾀﾞｰなど空中ﾚｼﾞｬｰｽﾎﾟｰﾂflying leisure sports(1997) 16	0.0018
	0.007	爆発物による事故explosive(1997) 9	0.0010
↑10⁻⁸	0.004	落雷による事故thanderbolt(1997) 5	0.0006

【註】1) 人口population:10,261×10³, 2) 人口population:57,747×10³, 3) 人口population:260,651×10³, 4) 人口population:57,851×10³, 5) 人口population:125,864×10³, 6) 人口population:255,020×10³, 7) 当該人口concerned population:7,847×10³, 8) 人口population:3,290×10³ 9) 人口population:46,433×10³, 10) 当該人口concerned population:10,576,569, 11) colon, rectum and rectosigmoid junction, 12) 人口population:9,880×10³, 13) 人口population:40,983×10³(1979), 14) 人口population:126,166×10³, 15) 当該人口concerned population:19,016×10³, 16) 人口population:265,284×10³, 17) 人口population:58,265×10³, 18) 人口population:21,698×10³, 19) 当該人口concerned population;63,995,848, 20) 人口population:18,289×10³, 21) 人口po-pulation:57,333×10³, 22) 人口population:81,818×10³, 23) 人口population:5,844×10³, 24) 人口population:15,776×10³, 25) 人口population:4,325×10³, 26) 人口population:57,138×10³, 27) 人口population:260,651×10³, 28) 人口population:1,223,890×10³, 29) 人口population:125,570,246, 30) 人口population:16,071×10³, 31) 人口population:6,311×10³, 32) 労働者数laboring population:47,246,440, 33) 人口population:121,048,923.

〔出典〕国民衛生の動向(1998年), 警察白書(平成10年版), 交通安全白書(平成10年版), 平成８年・労働者災害補償保険労働災害統計年報)

表2 各国の状態別交通事故死亡者構成率(%)(1996年)

Table 2 Comparison with death-rate of road accident divided from situation(%)(1996)

事故の状態 situation	日本 Japan	アメリカ USA	カナダ Canada	イギリス UK	スウェーデン Swaden	フランス France	ドイツ Germany	オランダ Holland	イタリア Italy	オーストラリア Australia	韓国 Korea	中国 China	香港 Hongkong
①自動車乗車中 motor vehicle occupant	40.5	79.7	76.8	53.9	66.3	66.3	67.3	49.3	67.4	69.5	44.6	8.1	29.7
②二輪車乗車中 motor bicyclist	18.5	5.2	4.2	12.2	10.1	15.1	11.4	15.6	17.8	9.7	10.0	11.0	12.2
③自転車乗車中 pedal cyclist	12.5	1.8	1.9	5.6	9.1	3.7	6.8	20.0	-	2.9	2.2	19.9	4.2
④歩　行　中 pedestrian	28.3	12.0	15.0	27.7	13.8	12.2	13.5	10.6	-	17.8	37.8	26.3	54.0
(③　+　④)	40.8	13.8	16.9	33.3	22.9	15.9	20.3	30.6	14.8	20.7	40.0	46.2	58.2
⑤そ　の　他 others	0.2	0.4	2.1	0.3	0.7	2.7	1.1	4.5	0.0	0.1	4.3	34.6	0.0
集計期間(日) observation term(day)	30	30	30	30	30	6	30	30	7	30	3	7	30

[出典] 交通安全白書(平成10年版)

表3 高齢者の年齢階級別交通事故と転倒・転落による死亡率(/10^5)，骨折受療率(/10^5)と，その比較(1996年)

Table 3 Death-rate(/10^5) and treatment-rate(/10^5) of fracture and their ratio by age group of the aged(1996)

年齢階級 (歳) age (year)	総数(男性+女性) both sex				男　性 male				女　性 female				総　数 both sex	
	交通事故 road accident		転倒・転落 fall down·fall		交通事故 road accident		転倒・転落 fall down·fall		交通事故 road accident		転倒・転落 fall down·fall		骨折受療 fracture-treatment	
	死亡数/10^5 deaths/10^5	比 ratio	死亡数/10^5 deaths/10^5	比 ratio	死亡数/10^5 deaths/10^5	比 ratio	死亡数/10^5 deaths/10^5	比 ratio	死亡数/10^5 deaths/10^5	比 ratio	死亡数/10^5 deaths/10^5	比 ratio	受療数/10^5 patient/10^5	比 ratio
総数(all)	11.3	1	4.7	1	16.6	1	6.2	1	6.6	1	3.4	1	121	1
55～64	13.9	1.21	5.7	1.21	20.5	1.23	10.2	1.65	7.7	1.17	1.4	0.41	150	1.24
65～74	21.0	1.83	9.0	1.91	30.1	1.81	15.3	2.47	13.9	2.11	4.0	1.16	246	2.03
75<	33.8	2.94	37.4	7.96	50.8	3.06	46.2	7.45	24.4	3.70	32.6	9.59	561	4.64

[出典] 国民衛生の動向(1996年)

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4.11 Understanding Radiation and Risk: The Importance of Primary and Secondary Education †

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ABSTRACT :

In Japan's primary and secondary schools, radiation and radioactivity are taught as part of the curriculum dealing with social science subjects. Students learn much about the hazardous features of radiation, but lack the scientific understanding necessary to build a more balanced picture. Although the same point applies to education covering the harmful effects of volcanic eruptions, earthquakes, electrical storms and so on, public understanding of these events is relatively high and students are generally able to make informed judgments about the risks involved. By contrast, their limited understanding of radiation often contributes to fears that it is evil or even supernatural. To correct this distortion, it is important that primary and secondary education includes a scientific explanation of radiation. Like heat and light, radiation is fundamental to the history of the universe; and scientific education programs should give appropriate emphasis to this important subject. Students would then be able to make more objective judgments about the useful and hazardous aspects of radiation.

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1. Public understanding of risk

The general public tends to adopt extreme views about hazardous matters; sheer emotion all too often overrides a rational assessment of risk. A widespread prejudice against radiation illustrates the point. Radiation is frequently feared, but rarely understood.

The responsible use of radiation provides a powerful tool for enhancing social and economic welfare. Too much radiation is dangerous, but the same is true of an excessive consumption of salt. Although human life depends on a certain amount of salt, excessive doses lead to hypertension and renal damage; consuming more than 200g at one time would be life threatening. Japan's Chinaform incident also demonstrates the point about dose levels being more significant than notions of absolute safety. Some 10,000 Japanese patients, who received more than 1.2g of Chinaform, suffered from appalling "SUMON" (subacute myelo-optico-neuropathy) side-effects. The incident stands out as Japan's biggest pharmaceutical disaster; but global figures indicate that more than one-hundred-million people consumed lower doses of Chinaform without any problems.

Whereas the public can easily understand "zero risk," rational judgments about the degree of relative danger associated with a particular hazard are more problematic. There is a natural tendency to emphasize the element of danger in anything that is not "completely safe." Improved education is essential to promoting a more balanced public perception of risk and countering the effects of misleading or sensationalist reporting. The public should be able to make informed judgments on the basis of accurate and well-balanced information.

An example of public misunderstanding of risk occurred with early media coverage of AIDS (Acquired Immunodeficiency Syndrome). There were pictures of medical workers preparing to treat AIDS patients by putting protective clothing designed for working with biological weapons technology. Novels and movies depicted AIDS as a highly infectious threat to society. It was only later that people came to accept that AIDS is a weakly infectious virus (HIV: human immunodeficiency virus) but, notwithstanding pictures of celebrities shaking hands with AIDS victims, many people continue to believe that AIDS is highly infectious. Although campaigns have done much promote an improved understanding of AIDS transmission processes, it is difficult to overcome prejudices engendered by early reporting.

2. The treatment of radiation in Japan's compulsory education system

While the effectiveness of school education programs owe a great deal to the efforts of individual teachers, they also depend on the contents of textbooks. Japan's education ministry fixes the compulsory education syllabus for every school in the country and only allows the use of approved textbooks. By examining the contents of these ministry-approved textbooks, the author and his colleagues were able to build an insight into how the Japanese education system deals with radiation.

Japanese students first study radiation during their fifth year of primary school (11 years old) as part of their social science curriculum. The syllabus covers the dropping of atomic bombs on Hiroshima and Nagasaki, together with the Happy Dragon fishing boat (which was a casualty of the Bikini Atoll H-bomb test) and the catastrophe at the Chernobyl nuclear power plant. In each of these cases, significant numbers of people were exposed to massive doses of radiation. Moreover, explanations in these textbooks use emotive language, such as: "Many atomic bomb survivors are still tortured and killed by the effects of radioactivity(sic)." However, during the period 1947-1989, the total number of cancer deaths (including leukemia) amongst Hiroshima's atomic bomb survivors was only 340 more than would be expected in a normal population. It is important to separate the terrible human suffering caused by the bomb from an objective assessment of radiation hazards.

Emotive language can easily distort the picture. Social science school text books often use a negative prefix when referring to radiation (for example, with terms such as "harmful radiation" or "terrifying radioactivity"). Although natural science textbooks use more precise language, the author did not find a clear explanation of the nature of radiation and type of harmful effects that might be associated with different doses of radiation. (Physics options provided by senior high schools include a scientific treatment of radiation, but only 10 percent of students select these courses.)

Education often involves elements of propaganda. Nazism, Stalinism, and Japan's militarism have all demonstrated the effectiveness of promoting a one-sided representation of events. However, the public disapproval that stems from distorted views of religious, historical and racial matters is not evident in the case of radiation. Japan's compulsory education system instead produces graduates who might go on to propagate negative images of radiation. Careers in films, literature and other media can all provide influential vehicles for nurturing the idea that radiation is inherently dangerous, with evil and even supernatural associations.

3. The need for educational reform

There is a clear need to ensure that Japan's compulsory education system provides a more balanced treatment of radiation and related issues. Primary and secondary education syllabuses should include the treatment of radiation as a natural science subject. Modern science recognizes that radiation has been fundamental to the history of the universe. And there is no justification for maintaining nineteenth-century attitudes that pre-date the discovery of radiation.

The difficulties of teaching radiation are no excuse for leaving it out of the curriculum. We should rise to the challenge of explaining radiation and the health implications that can accompany different levels of exposure. Education should support a more objective understanding of radiation.

4. Techniques for teaching radiation as part of the natural science curriculum

Some scientists insist that it is impossible to teach radiation as a natural science subject to primary and secondary school students who do not understand atomic and nuclear structures. The argument might appear persuasive, but a moment's reflection reveals that primary school students can build a useful appreciation of the nature of electricity without knowing about the role of electrons. The issue is one of compromise and the author does not claim that there is any perfect solution to the problem.

Existing primary school education programs illustrate techniques for presenting complex subjects in comparatively simple terms. Let us briefly review the way a primary school textbook deals with electricity. In their third school year, students learn how to use a small lamp to confirm the flow of current from a dry battery. They learn about the difference between conductive and insulating materials. And use an electric motor to confirm that current has a direction. These are easy-to-appreciate demonstrations of what electricity can do: the lamp lights and the motor moves. Electricity is invisible, but simple experiments provide potent illustrations of its significance. A similar approach could be used to introduce the study of radiation.

It is possible to demonstrate radiation using a photographic plate or diazotype photosensitive paper, while real-time evidence of radiation can be shown on a fluorescent plate or the type of X-ray film sensitizer sheet used in diagnostic radiology. Such techniques have paved the way towards an improved understanding of radiation and provide a powerful tool for stimulating student interest in the subject. Students might use samples of uranium ore and photographic plates to learn about radiation's penetrative qualities, along with the principles of radiation shielding and quantitative analysis of the processes involved. Some enterprising high school teachers have achieved encouraging results by using home-made cloud chambers to demonstrate radiation tracks.

While commercially available sealed sources (having a radioactivity of less than 3.7 MBq) are suitable for school experiments and demonstrations, the author believes that it is preferable to use natural sources of radiation. These convey the message that radiation is part of the natural world; not something inherently evil nor supernatural. Radiation has always been an integral part of the universe. Education programs should present a comprehensive picture of radiation that counterbalances concern about hazards with an understanding of radiation science.

JP0050119

4.12 放射線のリスクに関する初等中等教育

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要旨：

我が国における現在の初等中等教育で、放射線は社会科の教材でのみ取扱われ、理科の教材で取扱われることが全くと言ってよいほどない。その結果、生徒達は著しい放射線の害が生じた事例だけを教えられ、その害をもたらしたものの本質は固より、その性質についてすら、正しい知識を与えられないまま、義務教育課程を終えることになる。このような状態で“放射線のリスク”を教育することなど、到底望むべくもない。

火山の噴火や、地震、落雷などは、過剰な放射線被曝同様に危険なものであるが、初等中等教育を終えた生徒達は、相応の知識を与えられているため、これらの自然現象について古代人達のような超自然的脅威を覚えることは稀である。これは、彼らの多くが、放射線や放射能に対して感じていることと対照的である。初等中等教育課程に必要なことは、放射線も電気や熱と同じ自然現象の一つでり、人類が誕生する遥か以前から存在していたものであることを理解させるための教育である。放射線を電気や熱と同様、客観的に語れるようになれば、“放射線のリスク”の理解への道は自ずと開かれる筈である。

1. リスク認識の形成について：

有害なものに関する一般の認識は、ともすれば極端に走りがちなものである。放射線や放射能に関する認識は、その典型であると言える。多くの人々にとって、放射線や放射能は、常に“嫌悪すべきもの”のリストの先頭近くにある。しかし、多くの人々が感じているこの主観的有害性は、科学的に検証された事実から大きく乖離している。

人の健康にとって有害な要因には、放射線以外にもさまざまなものがあるが、それらに共通した性質は、人体に対する負荷が“過剰である”場合にその有害性を発現することである。食塩は人の生命維持に必須のものであるが、代謝に必要な量以上を長期間摂取し続ければ高血圧や腎障害などを引き起こす可能性があり、一度に 200g 以上をを摂取すれば、生命にとって危険であることが知られている[1)]。キノホルム（Chinoform : 5-chloro-8-hydroxy-7-iodoquinoline）は、毎日 1.2g 以上を処方されていた人々約 1 万人がスモン病（SUMON : subacute myelo-optico-neuropathy）に罹患するという、我が国の医療史上最大の薬害をもたらしたが、1970 年にこの薬の使用が禁止されるまで、腸内殺菌や整腸を目的として、世界中で何億人もが少量の処方されたにも拘らず、それらの人々には危険な副作用が現れなかった。

しかしながら、多くの人々にとって、有害性や危険性を身体負荷量の函数として規定するという考え方は馴染みの薄いものである。寧ろ、“無害でないものは有害”であり、“安全でないものは危険”であるという二律背反的な思考法が一般的であろう。誰しも有害なものや危険なものは敬遠したいと考えるのは当然であるから、こうした二律背反的な思考法から脱却しない限り、ゼロリスク以外を受容するという結論は生まれようがない。この状況を救えるのは、若年期からの教育のみであろう。

リスクの認識には、また、対象となる事物の有害性に対する正しい知識が必要である。ここで“正しい”とは、単に科学的無謬正のみを言うのではなく、その事物に関連するさまざまな情報がバランスよく提供されていることをも意味する。例えば、エイズに関しては、当初、感染者の致死率の高さや、その死に至る過程の悲惨さのみが伝えらた。また、当時はエイズの原因が不明であったため、細菌戦用の防護衣を着用して診察に当る医師のようすなども報道された。そして、エイズをペスト以上に危険な伝染病として取り扱った小説や映画も作られ、人々にエイズに対する恐怖を振りまいた。今日では、エイズを引き起こすウイルス(HIV)の感染力は、極めて弱いことが分っている。しかし、さまざまなキャンペーンが精力的に行われているにも拘らず、HIV の感染力の弱さは容易に理解されず、エイズ患者に対する偏見は今なお完全には拭い切れてはいない。なぜならば、人々が注目し記憶に残す情報は、“危なくないこと”

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1) 経口投与による食塩の半致死負荷量（LD_{50}）は、動物実験によれば、体重 1 kg 当り 3 g 乃至 4 g である。 Material Safety Data Sheet

ではなく“危ないこと”に関するものだからである。

2．義務教育課程における放射線の扱い：

学校における教育が、教員の工夫と努力とに大きく負っていることは今更言及するまでもないが、その内容が教科書や学習指導要領から大きな影響を受けていることも、また動かし難い事実である。筆者等のグループは、文部省科学研究費補助金研究[2)]の一環として、義務教育過程で使用される教科書の中で、放射線や放射能がどのように取り扱われているかを調査してきた。以下に、その調査結果の概要を示す。

小学校の教科書で、放射線や放射能に関連するテーマが最初に現れるのは、小学校５年生の社会科である。社会科の教科書では、小・中学校を通じて、広島・長崎の原爆、第五福竜丸事件、およびチェルノブィリ原子力発電所の事故が、必ず取り上げられ、それに関連して放射線や放射能の危険性が言及されている。これらのテーマは、何れも放射線が人の健康や生活に大きな害を与えた事例である。そして例えば、“いまでも、このとき受けた放射能(ママ)による病気で苦しんでいる人や、なくなる人がおおぜいいます”などの、感傷的な記述がしばしば使われている。この例について言うならば、“放射線”とあるべきところを“放射能”と記している点は別にしても、“おおぜいいます”という表現は、広島の被爆者に過剰発生したがん（白血病を含む）による死者が 400 人足らずである事実を客観的に伝えるために適切なものではない。また、社会科の教科書に登場する放射線や放射能には、しばしば“有害な”とか“おそろしい”などの負のイメージを与える接頭語が付けられている。しかし、放射線がなぜ有害なのかという説明は、社会科の教科書の中にはどこにも見当たらない。それどころか、教科書の中には、小学生には理解しようのない“再生不良性貧血(anemia aplastica)”という医学用語を載せ、自ら恐怖を演出しているものすらあった。

放射線や放射能が何ものであるか、また、どうして人に害を与えるのかというテーマを扱うべき科目は、疑いもなく理科であるが、初頭·中等教育の全課程を通じて、理科の教科書には、放射線や放射能に関する自然科学的説明も、その有害性に関する客観的な説明も見出すことができない。その結果、生徒達は社会科の教科書の記述のみから、放射線のリスクを判断せざるをえない[3)]。

若し、人々に意図的にある事物を嫌悪させようとするならば、その事物について一切の科学的説明をすることなく、その最も悲惨な影響の事例を示し、且つ、“おそろしい”“危険な”など負のニュアンスを持つ接頭語を乱用して“教育”することほど効果的な手段はないだろう。そうした方法の“有効性”は、

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2) 平成９年度文部省科学研究費補助金研究“初等·中等教育における合理的な放射線·放射能の教育法に関する調査研究”，研究代表者：安齋育郎（立命館大学教授）

3) なお、放射線や放射能についてある程度纏まった自然科学情報は、高校の物理に取り上げられているが、物理を選択する生徒は、高校進学者の 10％程度に過ぎない。

ナチズムやスターリン主義、あるいは我国の軍国主義下で行われた教育で、充分過ぎるほど証明されている。若し、放射線の扱いに見られるような不均衡が、イデオロギーや宗教の問題、あるいは歴史や民族問題などに関する義務教育課程にあったならば、重大な社会問題を招いたはずである。

こうした教育を受けた人々が作り出した小説や映画、漫画やアニメーションでは、放射線や放射能は極めて危険なものとして扱われ、科学的にはあり得ないおぞましい“効果”が、極めて印象的な手法で表現される。これらの作品を通じて、放射線や放射能に関する凶々しいイメージが更に増幅され、固定観念となるのを防ぐことは、更に困難であると言わざるを得ない。

3．いま学校で何を教えることが必要か：

疑いもなく、いま学校がなすべきことは、放射線や放射能を自然科学の対象として教えることである。宇宙の原初からその主要な構成要素の一つであった放射線に全く言及することのなく、19 世紀的自然科学だけを教えることは、現代人の教育としてもはや適切ではない。教授法の困難さは、それを“教えないこと”の正当な理由とはなり得ない。

また、放射線被曝の影響に関しても、その著しい害についてのみ取り上げるのではなく、害のさまざまなレベルについて客観的な事実を説明する必要がある。そうした情報が与えられ、初めて、放射線のリスクについて客観的な判断力を育てることが可能になる。

4．小中学生に放射線をどのように教えたらよいか：

原子や原子核の構造を知らない生徒達を相手に、放射線について教えることは不可能であるという主張がある。自然科学の成り立ちを考えれば、一応尤もな意見であるが、学校では“電子”を知らない生徒達に電気について教えることが現に行われ、成功を収めている。してみると、原子や原子核の構造を知らない生徒達に、放射線について教える何らかの方法が存在するはずである。残念ながら、筆者はこの問題に関する完全な答えを用意していない。しかし、現在義務教育過程で行われている電気や磁気、熱や光に関する教育方法が、一つのヒントを与えてくれるはずである。

試みに小学校における電気の教え方を見てみよう。先ず、三年生では、乾電池と豆電球を用いて直流回路の構成法や物質に導体と絶縁体があることを体験的に学び、４年生では、乾電池とモーターを用いて直流電流に向きがあること、複数の乾電池や光電池を用いて電流と仕事率の関係を体験する…。

ここで用いられている手法は、不可視な電気を五感で感知可能な他の形態（光や運動）に変換し、生徒達にその量的関係を体験させるというものである。放射線についても、同様の手法が有効であることは疑いない。特に、放射線の作

用を視覚化する教具の導入は、最も大きな効果を持つものと期待できる。例えば、初期の放射線研究で広く用いられていた写真乾板や蛍光板を用いた放射線の観察は、生徒達に印象的な“発見的体験”となるに違いない[4)]。鉱物標本として手に入るウラン鉱石と写真乾板とを用れば、生徒達は放射線の透過と遮蔽や、放射線の量について経験的に知ることができるだろう。もちろん、積極的な高校教師達が手作りの装置で試みている霧箱による放射線飛跡の観察も、生徒達が放射線の性質を理解する上で有力な方法である。これらの“実験”には、法令で規制されない放射能量 3.7MBq 以下の線源を用いることも可能ではあるが、筆者はむしろ天然の放射線源を積極的に利用すべきであると考えている。なぜならば、天然の放射線源を利用すれば、観察し体験した放射線の性質が自然の法則の一部であり、放射線そのものも“ありふれた”ものであることを印象づけられるからである。そして、放射線が宇宙の主要な構成要素の一つであり、生物はその自然放射線に曝されながら進化してきたこと、それゆえ、人にとって少量の放射線被曝が本当に危険であるとすれば、人はその進化の過程を生き残れなかったはずであることを教えるべきである。

4) 写真乾板の代わりにジアゾ感光紙、蛍光版の代わりにX線撮影で用いられる増感紙を用いてもよい。

JP0050120

4.13 Investigation on the Acceptance Level of Radiation Exposure

- Comparison of Chinese and Japanese

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Abstract

Radiation has helped to develop our culture and civilization, both of material and of spiritual, and without doubt it is useful to develop our civilization further and to enrich our future life. On the other hand, we cannot help avoiding to live with some by-product radiation of "advanced civilization" in addition. Thus we must associate with radiation even if we like it or not.

To our understanding, safety standard or criteria of safety control is nothing but a contract of the body concerned with the society. In order to make this contract rigorously, it is required for both sides to have adequately enough knowledge and data on the methodology of treating the matter. In such societies, people's acceptable levels to radiation exposure would not be widely distributed. Unification of the wills of the society is absolutely necessary to establish such a contact or develop the philosophy on radiation safety. Hence, we have tried to investigate the acceptable levels of people to radiation exposure. Two kinds of levels, upper limit of the acceptable dose for instantaneous whole body exposure, Lu, and lowest of the dose caring in mind, Ll, were set for inquiry. In this presentation, some results of our survey to both Chinese and Japanese professionals in the fields of science-technology and medical science are reported.

Similarly to the previous study by Katoh, in 1989 or so, the distribution of these two levels were very broard and the band widths between the two levels, Lu and Ll, were quite narrow. The former seems reveal the variety of individual's sense of value. Moreover, it was found that, two levels, Lu and Ll, were significantly higher ($p<0.05$, $p<0.005$) in Japanese to in Chinese in science/engineering group, while in medical group, the two levels were higher apparently in Japanese than in Chinese, but no statistically significant difference was observed. Moreover, in medical group, Lu and Ll showed higher values than those in science-technology group for the Chinese ($p<0.05$, $p<0.01$). Similar tendency was observed for the Japanese, however, there was also no statistically significant difference.

JP0050121

4.14 放射線被曝の受容レベルについての調査
－中国人と日本人の比較

Investigation on the Acceptance Level of Radiation Exposure
- Comparison of Chinese and Japanese

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要旨

安全の基準は社会と当事者との契約、すなわち社会の合意で決められねばならない。それには、人々の放射線安全に対する正しい理解が必要であり、個人個人の理解の程度が十分で揃っていることが望まれる。その意味で、社会の構成員の個人的放射線受容レベルが今日どのように分布しているかを知ることは、放射線の合理的管理方策の在り方や一部公衆に見られる radiofobia（放射線嫌悪症もしくは過敏症）に対する対応の方策を検討する上で極めて重要である。このようなことから、我々は、社会を構成する色々の人たちを対象に放射線被曝についての受容レベルの調査を行ってきた。今回、中日両国のそれぞれにおける医学系と理工系の２グループについて調査を行った。

中日両国の学者ともに、受容レベルの値は個人差が大きく、広い分布を示している。また、各グループとも、個人レベルでの２受容レベル間の間隔は狭かった。さらに、理工系の学者においては、日本人学者の受容レベルは、Lu および Ll ともに在日中国人学者の受容レベルより有意に高い値を示した（$p<0.05$、$p<0.005$）。医系学者グループについては、中国人学者グループの方は、Lu および Ll ともに理工系学者グループのそれらより有意に高い値を示した（$p<0.05$、$p<0.01$）。一方、日本人学者グループでは、在日中国人学者および日本人理工系学者グループより高値である傾向は見られたものの、統計的な有意差はなかった。

知的水準の高い人達の間にあっても、放射線被曝のリスクや安全に対する考え方は、個人によって異なっており、受容レベルは予想以上のばらつきを見せた。また、こういった事情は中日両国の国境に関わらないものであることが明らかとなった。

はじめに

「安全」と「危険」とは、相互対立しかも相互依存している一対の言葉である。多くの辞書に書かれているように、危険でないことは安全、安全でないものは危険とされており［1］、この二つの言葉が一つはないと別の一つは成立が不可能と思われる。実際には、この世の中絶対的安全あるいは絶対的危険は存在しない。両者の間には無数の状態があり、それらを通してこの対立している二つの言葉は繋がっている［2］。特に、高度に発展している現代文明の時代においては、技術の開発や発明により、新たな危険がそれらの副産物として不可避的に付随している。例えば、いわゆる“環境ホルモン”が現在話題となっており、詳細な研究から、ゴミ処分による大気の汚染や、環境ホルモンの影響など一連的危害が分かってきた。ここで、この一連の危害に対し、どのような対応をとるべきかが問題になっている。もし全てのゴミ処分工場が停業とすると、人間の生存する場はいつの間にかゴミに埋められてしまうだろう。さらに、各種の発電所からの危害もよく検討されてきた。これらの危険を避けるため発電所を閉め、電気のない原始時代に戻るというのは、我々現代人として受け入れられるでしょうか。

また、放射線は現代の生活、文化、文明を発展させるための重要な手段であり、学問研究・産業・医療に広く利用されているうえに、今も変わらず大きな未知の可能性を秘めている。しかしながら、結果として放射線あるいは放射線の発生を伴う機器の使用が積極的に進められている一方、放射線や放射性物質の使用が副産物として不可避的に付き合いを強いられることも増えつつあることは、医療の現状を見るまでもなく明らかである。その上に、原爆による被災、原発の事故、動燃での不手際などもあって、放射線・放射能・原子力は危険なものであるという概念が国民に広く植え付けられている。日本国だけではなく、世の中大勢の人々が放射線・放射能・原子力に対し恐怖感を持ち、「望而生畏、聞之失色」と言っても言い過ぎないのは現状である。これは、放射線の使用を積極的に進めていく上での大きな障害になっている。

以上のことから、「安全」と「危険」についてどのように考えるかという問題は今日非常に重要であると思われる。安全の基準は社会と当事者との契約、すなわち社会の合意で決められねばならない［3］。新たな技術を推進するには政治家、研究者そして経営者だけでなく、一般の人々のこの問題についての意識が高まり、社会として意志が集約され、合意が形成されるよう努力すべきと思う。それには、人々の放射線安全に対する正しい理解が必要であり、個人個人の理解の程度が十分で揃っていることが望まれる。

それなくしては、合理的な契約ができないからである。その意味で、社会の構成員の個人的放射線受容レベルが今日どのように分布しているかを知ることは、放射線の合理的管理方策の在り方や一部公衆に見られる radiofobia（放射線嫌悪症もしくは過敏症）に対する対応の方策を検討する上で極めて重要である。

このようなことから、我々は、現在の社会が放射線の危険性の受け入れについてどのような状態にあるのかを知ることを目的として、社会を構成する色々の人たちを対象に放射線被曝についての受容レベルのアンケート調査を行なった。

アンケート対象及び方法

在中日国学者（内訳：大学院在学生、訪問学者、大学教師）および同等学歴をもつ日本人学者計 75 人を対象とし、次のレベルについて調査を行なった。

レベル 1 （Lu）：身体に一度に放射線を受ける場合（全身均等、外部被曝）、これ以上なら怖くていやだという線量。

レベル 2 （Ll）：同じく、これ以下なら特に被曝が気にならないという線量。

アンケート調査は関東地区にある 3 箇所の大学で教官に通して行い、具体的には、面談や郵便、電子メール等による聞き取り（アンケート調査）であった。回収したアンケートは中日別、理工系医系別の 4 つのグループに分けて分析した。

A. 在中日国人学者理工系（30 人、男：女＝18：12）

B. 日本人学者理工系（15 人、男：女＝10：5）

C. 在中日国人学者医系（15 人、男：女＝9：6）

D. 日本人学者医系（15 人、男：女＝7：8）

統計学的検討は t-検定を用いた。p 値が 0.05 より小さい場合を有意とした。

線量というものを正しく理解していないことによる意味のない回答を排除するため、人類が自然界から受けている年間の線量値などを紙面で解説した。

結果と考察

安全の定義

アンケート用紙には放射線についての「安全」をどのように捉えているか簡潔に答えてもらった。整理すると大体次の 7 つに分けられる：

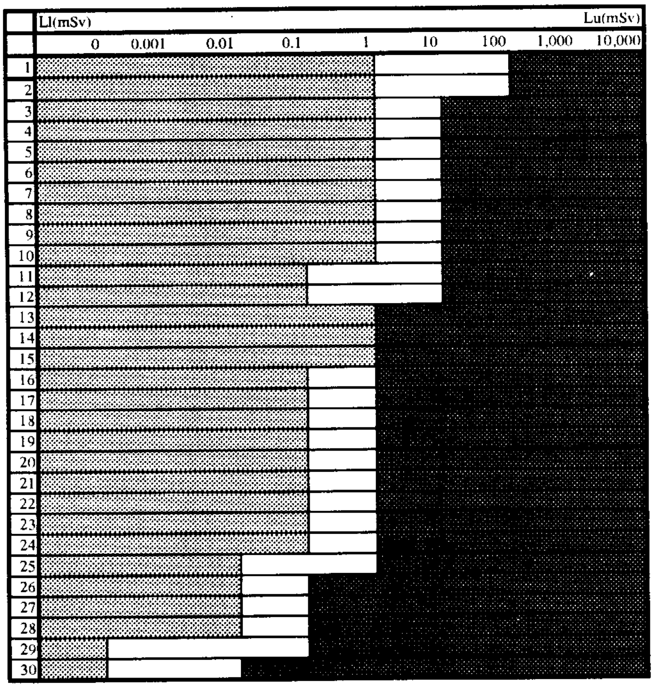
1. 人体に対し、既知の障害（現代科学で認識された障害）および未知の障害を引き起

こさない状態。

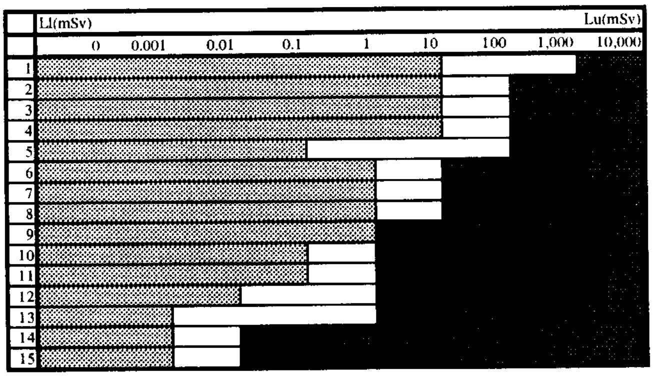
2. 組織や細胞レベルだけでなく分子レベルでの影響もないような環境。
3. 生理的および心身的な影響のない、また短期だけでなく長時間に渡っても障害を起こさないような状態。
4. 自分自身への影響だけでなく、子孫への影響もないという環境。
5. 生命維持する活動を妨げず、天寿を全うできること。
6. 絶対的な安全は存在しない。従って、リスクをできる限り低く抑えることが相対的に安全ということになる。
7. ICRP の勧告に従い、各指標の限度値を超えない環境。

放射線被曝に対する受容レベル

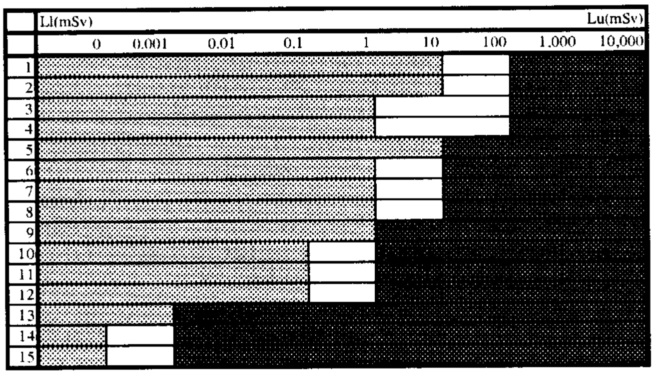
A group. (Science-Technology of Chinese)



B group. (Science-Technology of Japanese)



C group. (Medical science of Chinese)



D group. (Medical science of Japanese)

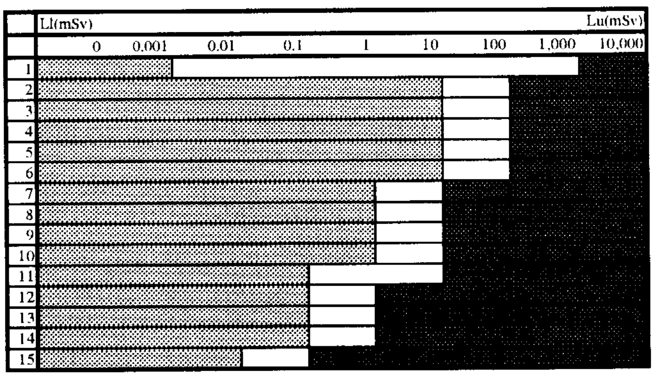


図１. 各グループにおける放射線の被曝に対する受容レベル

単一被曝で「怖いと感じる最低のレベル（Lu）」と「気にならない最高のレベル（Ll）」について聞いたものであり、回答をまとめると図１の通りとなった。中日両国の学者ともに、発表者の一人加藤が以前報告した調査結果［４］と同様な傾向を示した。すなわち、受容レベルの値は個人差が大きく、分布は広かった。ばらつきの幅も大きく見られた。また、各グループとも、個人レベルでの 2 受容レベル間の間隔が狭かった。このことも以前の調査結果に一致している［４］。

表１．各グループの放射線受容レベルの比較　　（単位：mSv）

項　目	A	B	C	D
怖いと感じる最低レベル（Lu）の平均値	10.3±4.5†	95.7±65.6	31.7±12.1*	100.3±65.1
気にならない最高レベル（Ll）の平均値	0.5±0.1†††	2.9±1.0	2.4±1.1**	3.6±1.2*
Lu の最低値と最高値	0.001〜100	0.01〜1,000	0.001〜100	1〜1,000
Ll の最低値と最高値	0.001〜1	0.001〜10	0〜10	0.001〜10

†：中日両国のグループ間の比較 $P<0.05$、†† $P<0.01$、††† $P<0.005$

*：中日両国における、理工系と医系との間の比較、$P<0.05$、** $P<0.01$

さらに、各グループ間の比較を行ない（表１）、次のことが知られた。１）日本人理工系学者の受容レベルは、Lu および Ll ともに在中日国人理工系学者の受容レベルより有意に高い値を示した（$P<0.05$、$P<0.005$）。２）日本人医系学者の Ll および Lu は、在中日国人医系学者のそれより高い傾向が見られるものの、統計的有意差は認められなかった。３）中国人学者グループでは、医系グループの Lu および Ll ともに理工系グループより有意な高値を示した（$p<0.05$、$p<0.01$）。４）日本人学者グループでは、医系グループのそれらが理工系学者グループより高値である傾向は見られたものの、統計的な有意差はなかった。医系の学者に比べ、理工系は放射線被曝に対しやや敏感であることが示唆された。

今回の調査は範囲が狭くデータも少ないため、これらの結果についての理由付けは困難であるが、一つとして考えられるのは、日本国は自然資源が少ないため、原子力の開発をより早い段階から発展させているのに対し、中国では化石燃料が豊富で今でも重要なエネルギー源となっており、原子力の利用開始がやや遅れたことにあるものではないかと思われる。さらに、放射線に関する教育が、急速に発展してきた放射線学および放射線応用学への対応の遅れもあり、放射線の利用価値より、むしろその危険性と危険性を避けるための防護規則の重要性を強調しているきらいがある。一方、周知のように、

放射線の医学への応用が中日両国を含み世界中でかなり進んできている。放射線診療機器の開発利用に伴い、放射線・放射能の医療への応用が、現在臨床上、診断及び治療に重要不可欠な手段として人の命に係わっている。そのため、放射線に関する知識が医系学者に対し必須うのものとして特に求められていることから医系学者の受容レベルが高いことが解釈できると思われる。

本調査は、放射線についての安全文化の国際比較の第一歩として行なったものである。放射線問題に関し、すべての面は含んではいないが、人々の被曝に対する受容レベルが大きくばらついていることを明らかにできた。こういう状況の下では、放射線技術の推進について社会的な合意を形成するのは困難である。この問題をどう解決するのが良いは、今後の課題である。おそらく、放射線および放射線防護に関する基礎的な知識の普及教育が「当務之急」であろう。また、この課題を解決するため、このような意識調査を国際協力により、量的にも質的にもより高いレベルで、より多くの国について行なっていくことが望まれる。

まとめ

本調査の結果より以下のような知見が得られた。

1. 知的水準の高い人達の間でも、放射線被曝のリスクや安全に対する考え方は個人によって異なり、受容レベルは予想以上のばらつきを見た。この傾向は中日両国に共通している。
2. 放射線及び放射線防護に関する基礎的知識の十分でない人達が予想以上に多く存在している。
3. 放射線被曝の受容レベルについては、中日いずれの国においても、現状では定量的に社会的コンセンサスを得ることは困難である。

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5. International Advisory Committee Report

(国際諮問委員会報告)

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REPORT ON THE MEETING OF THE INTERNATIONAL ADVISORY COMMITTEE FOR THE INTERNATIONAL SYMPOSIUM ON RADIATION EDUCATION(ISRE98)

Mitio Inokuti

Argonne National Laboratory
9700 S. Cass Avenue, Bldg. 203 Argonne, Illinois 60439-4843, U. S. A.

The meeting was held on 12 December 1998, 15:45-19:20, in the form of a business supper between an oral session and a poster session of the ISRE98 in a conference room at the Productivity Center. The participants are shown in an attachment.

Mitio Inokuti (U. S. A.) chaired the meeting, and proposed the following two points for deliberations:

1) Should there be a next international meeting on a scope of topics similar to the ISRE98?

2) Should there be a standing committee, or a council, for planning such a meeting, or for liaison among activities for radiation education in different counties?

The proposal was unanimously agreed upon.

After self-introduction by the participants, free discussion was made on matters including the following:

1) The meaning of the term "radiation education."

2) The scope of the present meeting (ISRE98). Although the present meeting was highly significant, it may be desirable to explore the possibility of a broader range of topics. At the same time, it was also said that a meeting with a more focused scope might be more effective. The two-day period of the present meeting might have been too short to discuss in depth some of the key issues.

3) A broader contact with the general public might have made the present meeting more effective. It was a pity that the present meeting does not seem to have been covered by the journalism, even though the Minister of Education participated.

Inokuti pressed on a response to the two initial questions. The response by the participants were unanimously affirmative. In particular, George Marx (Hungary) pointed out a meeting on science education scheduled to be held in June 1999 in Hungary, and urged others to participate. Yet, the discussion fell short of definitely scheduling a follow-up meeting of the ISRE98. Issues raised with the response include the following:

1) Should a follow-up meeting be organized in collaboration with an international body such as the IAEA, with scientific societies or academies, or with governments? There was considerable discussion on this question. An advantage of such a collaboration might be the possibility of some financial support. A disadvantage is that there may be excessive constraints in organization and management often found in an international body or governments.

2) A standing international committee or council may be formed as a non-governmental generalization of the present International Advisory Committee. It is then necessary to include representatives of countries such as Germany, Russia, and the United Kingdom, who happened to be absent from the present meeting. It is also appropriate to reconsider the membership from the countries represented in the ISRE98. (It is recommended that The Secretariat of the ISRE98 follow up the idea of the standing committee, although this item was not voted on.)

3) In addition to planning for a follow-up meeting, the standing committee may set up ways for continuing communications on activities related to radiation education, including the initiation of a news letter or a home page on the Internet.

The International Advisory Committee :

Jean-Pierre Adloff, France	Manoon Aramrattana, Thailand
Bum-Jin Chung, Korea	V. G. Dedgaonkar, India
Azhar Djaloeis, Indonesia	Toyojiro Fuketa, Japan
Wieslaw Goraczko, Poland	Kodi Husimi, Japan
Chin-Wan Hung, Taiwan	Mitio Inokuti, U. S. A.
Kazuaki Katoh, Japan	George Marx, Hungary
Matteo Merzagora, Italy	Ayab Mir, Pakistan
Sana Ullah, Bangladesh	Turan Ünak, Turkey

The Secretariat

Kunihiko Hasegawa, Japan	Masahiro Kotaka, Japan

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