JAERI-Conf 99-011

ISRE98
PROCEEDINGS OF INTERNATIONAL SYMPOSIUM ON RADIATION EDUCATION

International productivity Center
Shonan International Village, Hayama, Kanagawa, Japan
December 11-14, 1998

September 1999

日 本 原 子 力 研 究 所
Japan Atomic Energy Research Institute

本レポートは，日本原子力研究所が不定期に公刊している研究報告書です。
入手の問合わせは，日本原子力研究所研究情報部研究情報課（〒319-1195　茨城県那珂郡東海村）あて，お申し越しください。なお，このほかに財団法人原子力弘済会資料センター（〒319-1195　茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

This report is issued irregularly.
Inquiries about availability of the reports should be addressed to Research Information Division, Department of Intellectual Resources, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken, 319-1195, Japan.

編集兼発行　　日本原子力研究所

Hosted by:

Organizing Committee of International Symposium on Radiation Education (Chairperson: Prof. HUSIMI Kodi) and Radiation Education Forum

In cooperation with:

Applied Physics Society of Japan
Atomic Energy Society of Japan
Japan Atomic Energy Relations Organization
Japan Atomic Energy Research Institute
Japan Atomic Industrial Forum
The Japan Federation of Engineering Societies
Japan Health Physics Society
Japan Isotopes Association
Japan Nuclear Cycle Development Institute
Japan Polymer Society
Japan Society for Science Education
Japan Society of Radiation Research
Japanese Society of Radiation Chemistry
Physics Education Society of Japan

Supported by:

International Atomic Energy Agency
Japan National Tourist Organization
Ministry of Education, Science, Sports and Culture
OECD Nuclear Energy Agency
Science and Technology Agency

Organizing Committee

HUSIMI Kodi (Chairperson) FUKETA Toyojiro (Vice chairperson)* IIRI Yuichi (Vice chairperson)
EDA Minoru GOTOH Michio HATANO Yoshihiko
IKEDA Masamichi* ISHIGURE Kenkichi ISHIGURO Ryouji
KATOH Kazuaki KIKUCHI Tohru KUBODERA Akiko*
KUDO Kazuhiko KUROKUI Seiji MURAO Yoshio*
MURATA Takashi NAKAHARA Hiromichi NAKAZAWA Masaharu
NISHIHARA Hideaki NISHINA Kojiro SHIMADA Toshirou
SHIMONO Hiroshi SUZUKI Atsuyuki TACHIKAWA Enzoh
TAKASHIMA Yoshimasa TAKEDA Atsuhiko TANOOKA Hiroshi
TSUJIMOTO Tadashi YAMAGUCHI Hikoyuki YOSHIKAWA Hideo

* In charge of treasury and accounting

Advisory Board

ANN Shigehiro AOKI Yoshiroh HARA Reinosuke
IMAMURA Masashi KANEKO Kumao KONDOH Souhei
KUMATORI Toshiyuki MATSUDAIRA Hiromichi MIKI Ryouta
MORI Kazuhisa NAGAI Teruo NAITOH Keiji
OKADA Shigefumi SAITO Nobufusa SAKANOUE Masanobu
SHIBATA Shun-ichi SHIMIZU Sakae SHINOZAKI Yoshiharu
SUGAWARA Tsutomu SUGURI Susumu SUMITA Kenji
TABATA Yoneho

International Advisory Committee

INOKUTI Mitio (Chairperson; U.S.A.)
ADLOFF Jean-Pierre (France) AHMAD Sobri Bin Haji Hashim (Malaysia),
ALSOP Roger (Australia) BERNIDO Corazon C. (Philippines) DEDGAONKAR V. G. (India)
DJALOEIS Azhar (Indonesia) FEINENDEGEN L. E. (U.S.A.) FUKETA Toyojiro (Japan)
GORACZKO Wieslaw (Poland) HASIBULLAH (Pakistan) HODGSON Peter E. (U. K.)
HUNG Chin Wan (Taiwan) KEARFOTT B. (U. S. A.) KRIENGSAK Bhadrakom(Thailand)
LEE Byong-Whi (Korea) MACHI Sueo (Austria) MARX George (Hungary)
MERZAGORA Matteo (Italy) NISHINA Kojiro (Japan) PAREZKE Herwig G. (Germany)
PHAT Tran Hun (Vietnam) SUN Zuxun (China) ULLAH Sana (Bangladesh)
UNAK Turan (Turkey)

Local committee

YAMAGUCHI Hikoyuki (Chairperson) OHNO Shin-ichi (Vice chairperson) *

ASANO Takeyoshi*	HASEGAWA Kunihiko	HARIMA Yoshiko
HASHIMOTO Tetsuo*	HIROI Tadashi*	HIROTANI Yoshiaki*
HORIUCHI Kimiko	IMAI Kiyoko*	ITOH Yasuo
KAMATA Masahiro	KAWAMURA Shouichi*	KIKUCHI Bunsei
KOTAKA Masahiro*	KUDOH Hiroshi	MATSUZURU Hideo*
MINEGISHI Atsuko*	MIYAZAWA Koji	MORI Yuji
MURAISHI Yukimasa*	NAKANISHI Takashi	NAKANISHI Tomoko
NOZAKI Tadashi*	OOHASHI Kunio	RYU Tae
SAEKI Kuniko	SATO Tadashi	SEGAWA Yoshiyuki
SHIMODA Yoshio	SUDA Satoru	SUGI Teruo
TAKAGI Shinji	TAKAHATA Chuzo	TAKEDA Masuo*
TOMINAGA Hiroshi*	TOONOKI Hirosh*	TSURUTA Takao
YAMAMOTO Michioki	YAMANA Yasuhiro	WATARI Kazuo

*Program committee

Secretariat

MATSUURA Tatsuo (Secretary General)	HASEGAWA Kunihiko
KOTAKA Masahiro	SUDA Satoru

Editorial Committee

HASHIMOTO Tetsuo	IMAI Kiyoko	KAWAMURA Shouichi
KOTAKA Masahiro	MATSUZURU Hideo	MINEGISHI Atsuko
OHNO Shin-ichi	TAKEDA Masuo	

Radiation Education Forum
Sanwa Daiichi Bdg., 1-17-2 Nishi-shimbashi, Minato-ku, Tokyo
105-0003 Japan
Phone and Fax: +81-3-3591-5366
E-mail: mt01-ref@kt.rim.or.jp

Symposium Registration List

Name	Organization	Country
ADLOFF, Jean-Pierre	University Louis Pasteur	France
ADLOFF, Jean-Pierre, Mrs.		France
ALSOP, Roger	Australian Nuclear Association	Australia
AOKI, Hiroko	Japan Atomic Industrial Forum	Japan
AOKI, Yoshiro	Nuclear Safety Commission	Japan
ARAMRATTANA, Manoon	Office of Atomic Energy for Peace	Thailand
ARATANI, Michi	Institute for Environmental Sciences	Japan
ARIMA, Akito	Ministry of Education, Science, Sports and Culture	Japan
ASANO, Takeyoshi	Osaka Prefecture University	Japan
BAKHT, Delawar	Titas Gas Transmission & Distribution Co., Ltd.	Bangladesh
BAN-NAI, Tadaaki	Institute for Environmental Sciences	Japan
BERNIDO, Corazon C.	Philippine Nuclear Research Institute	Philippines
CHIBA, Naoto	Motomiya High School	Japan
CHUNG, Bum-Jing	Ministry of Science & Technology	Korea
DEDGAONKAR, V.G.	University of Pune	India
DJALOEIS, Azhar	National Atomic Energy Agency - BATAN	Indonesia
FUJII, Haruo	Japan Electric Power Information Center	Japan
FUJII, Kiyoshi	Wako Gakuen	Japan
FUJII, Yasuhiko	Tokyo Institute of Technology	Japan
FUKETA, Toyojiro	Institute for Environmental Sciences	Japan
FUNADA, Masaru	Funabashi High School	Japan
FUNYU, Takeshi	Institute of Radiation Measurements	Japan
FURUTA, Masakazu	Osaka Prefecture University	Japan
FUWA, Keiichirou	Japan Chemical Analysis Center	Japan
GORACZKO, Wieslaw	Technical University Poznan	Poland
GOTOU, Chiharu	Radiation Application Development Association	Japan
HARA, Kiyoshi	Shizuoka Prefectual Hamamatsu Koto Senior High School	Japan
HARA, Reinosuke	Seiko Electronic Industry	Japan
HARADA, Tadanori	Naruto University of Education	Japan
HARASAWA, Susumu	Rikkyo University, Emeritus Professor	Japan
HARIMA, Yoshiko	CRC Research Institute. Inc.	Japan
HASEGAWA, Kunihiko	Shizuoka University, Emeritus Professor	Japan
HASHIMOTO, Tetsuo	Niigata University	Japan
HATAKEYAMA, Masatsune	Seiko Gakuin High School	Japan
HATANO, Yoshihiko	Tokyo Institute of Technology	Japan
HAYASHI, Syu A.	Rikkyo University	Japan
HIROI, Tadashi	Tsukuba University High School	Japan
HIROTANI, Toshiaki	Japan Atomic Industrial Forum	Japan
HODGSON, Peter E.	University of Oxford	U.K.
HORIUCHI, Kimiko	Otsuma Women's University	Japan
HUANG, Chin-Wang	Chung Yuan Christian University	Taiwan
HULBER, Eric	77 Electronica, Ltd.	Hungary
HURUKAWA, Michiaki	Yokkaichi University	Japan
HUSHIMI, Kodi	Osaka University, Nagoya University, Emeritus Professor	Japan
IIRI, Yuichi	Japan Atomic Industrial Forum	Japan
IMAI, Kiyoko	National Institute of Radiological Sciences	Japan
INOKUTI, Mitio	Argonne National Laboratory	America

ISHIGURO, Ryoji	Hokkaido Electoric Power Co., Inc.	Japan
ISHIKAWA, Tokuji	Sophia University	Japan
ITO, Yasuo	University of Tokyo	Japan
KABUKI, Hidekatsu	Ferris Girls Junior & Senior High School	Japan
KAMATA, Masahiro	Tokyo Gakugei University	Japan
KANEKI, Yuji	Japan Atomic Industrial Forum, Inc.	Japan
KANO, Shuji	Kaminoyama Meishinkan High School	Japan
KATO, Yukihiro	Nagoya Nishi Clinic Hospital	Japan
KATOH, Kazuaki	Ibaraki Prefectual University of Health Sciences	Japan
KAWAKATU, Hiroshi	Kagawa University	Japan
KAWAMURA, Syoichi	Kanagawa University	Japan
KAWANO, Kazuya	Kobe University	Japan
KAYANUMA, Tokushige	Yamanashi Prefecutual Kitafuji Technical High School	Japan
KIKUCHI, Bunsei	Tokai University	Japan
KOBAYASHI, Mitsue	Osaka City University	Japan
KODERA, Yoshie	Nagoya University	Japan
KON-NO, Toshiharu	Japan Atomic Energy Relations Organization	Japan
KOTAKA, Masahiro	Tokyo Institute of Technology	Japan
KUBOTA, Nobuo	Tachibana Gakuen Senior High School	Japan
KUDO, Hiroshi	Tohoku University	Japan
KUDO, Kazuhiko	Kyushu University	Japan
KUDO, Misuzu	Takanabe Senior High School	Japan
KURODA, Paul K.	University of Arkansas	U.S.A.
KURODA, Paul K., Mrs.		U.S.A.
MARUYAMA, Haruo	Plasma Research Committee of Toki-city	Japan
MARX, George	Eotvos University	Hungary
MASUDA, Hideo	Ohizumi High School	Japan
MATSUDA, Teruo	Hikarigaoka Daiyon Primary School	Japan
MATSUURA, Shojiro	Japan Atomic Energy Research Institute	Japan
MATSUURA, Tatsuo	Rikkyo University, Emeritus Professor	Japan
MATSUZAWA, Takao	Ibaraki College of Technology	Japan
MATSUZURU, Hideo	Japan Atomic Energy Research Institute	Japan
MEGUMI, Tomoki	Self Defence Force, Central Hospital	Japan
MERZAGORA, Matteo	Universita di Milano	Italy
MIKADO, Syogo	Chiba Prefectual Kamagaya-nishi High School	Japan
MINAI, Yoshitaka	Musashi University	Japan
MINE, Mariko	Nagasaki University	Japan
MINEGISHI, Atsuko	Kanagawa University	Japan
MIR, Muhammad Ayab	Pakistan Nuclear Regulatory Board	Pakistan
MIYAZAWA, Kouji	Tokyo Kasei University Fuzoku Girls' High School	Japan
MORI, Chizuo	Aichi Institute of Technology	Japan
MORI, Yuji	Showa Senior High School	Japan
MORISHIMA, Koichi	Ujina Junior High School	Japan
MURAISHI, Yukimasa	The Upper and Lower Secondary Schools Attached to the Faculty of Education of the Univ. of Tokyo	Japan
MURATA, Takashi	Central Research Institute of Electric Power Industry	Japan
NAITO, Keiji	Nagoya University, Emeritus Professor	Japan
NAKAGAWA, Sei-ichi	Okayama University of Science	Japan
NAKAGAWA, Takayuki	Ibaraki Prefectual Institute of Education	Japan
NAKAHARA, Hiromichi	Tokyo Metropolitan University	Japan
NAKAMURA, Mariko	Tottori University	Japan

NAKANISHI, Takashi	Kanazawa University	Japan
NAKANO, Katsuyoshi	Tokishi School Board	Japan
NAKANO, Shojiro	Chiyoda Technol. Cooperation	Japan
NAKAO, Yuji	Nagano Prefectural Inakita High School	Japan
NISHI, Tatsuo	Institute of Radiation Measurements	Japan
NISHIHARA, Hideaki	Kyoto University	Japan
NISHINA, Kojiro	Aichi Shukutoku University	Japan
OHMORI, Sayoko	Otsuma Women's University	Japan
OHNO, Shin-ichi	Tokai University	Japan
OHTAKE, Shigehiro	Hikarigaoka Daiyon Primary School	Japan
OKUMURA, Yutaka	Nagasaki University	Japan
OOHASHI, Kunio	Chiba University	Japan
OTSUKA, Akiyoshi	Yamaguchi University	Japan
RYU, Tae	Sophia University	Japan
SAEKI, Kuniko	Senior High School Attached to Akita Keizai Hoka University	Japan
SAEKI, Masakatsu	Japan Atomic Energy Research Institute	Japan
SAKAI, Kazuo	University of Tokyo	Japan
SAKAMOTO, Koh	Kanazawa University	Japan
SAKANOUE, Masanobu	Kanazawa University, Emeritus Professor	Japan
SASAGAWA, Sumiko	Institute for Environmental Sciences	Japan
SASAKI, Akira	NESCO, Co., Ltd.	Japan
SASAKI, Yasuhito	National Institute of Radiological Sciences	Japan
SATO, Mutsuhiro	Nihon University Tohoku High School	Japan
SATSUTANI, Taisuke	Kobe Dempa Co., Ltd.	Japan
SCHOESSE, Tomas	Tokyo Institute of Technology	Germany
SEKIMOTO, Junko	Cramming School	Japan
SENSUI, Kazuko	Kanto International Senior High School	Japan
SHIBA, Koreyuki	Radiation Application Development Association	Japan
SHIBASAKI, Kenji	Tokyo Metropolitan Kodaira-Minami High School	Japan
SHIBATA, Seiichi	Kyoto University	Japan
SHINOZAKI, Yoshiharu	Radiation Education Forum	Japan
SHIRAKATA, Hirofumi	Japan Expert Clone Corporation	Japan
SHIRASAKA, Katsuhiro	Japan Atomic Energy Relations Organization	Japan
SHIRASUNA, Toru	Japan Science Foundation	Japan
SUDA, Satoru	The Japan Federation of Engineering Societies	Japan
SUGI, Teruo	Japan Atomic Energy Research Institute	Japan
SUNAYASHIKI, Tadashi	Hiroshima Prefectural College of Health and Welfare	Japan
SUZUKI, Toru	University of Tsukuba High School	Japan
TABATA, Yoneho	University of Tokyo, Emeritus Professor	Japan
TADA, Jun-ichiro	Japan Synchrotron Radiation Research Institute	Japan
TAKAGI, Shinji	Kanagawa University	Japan
TAKAHASHI, Tadayoshi	Ehime Prefecture Educational Research Center	Japan
TAKAHATA, Chuzou	Seiko EG and G, Co., Ltd.	Japan
TAKASHIMA, Yoshimasa	Kyushu Environmental Evaluation Association	Japan
TAKEDA, Atsuhiko	Health Research Foundation	Japan
TAKEDA, Masuo	Toho University	Japan
TANAKA, Ryuichi	Japan Atomic Energy Research Institute	Japan
TANIGUCHI, Sukenobu	Radiation Application Development Association	Japan
TANIMOTO, Seishiro	Radiation Educational Forum	Japan
TANO-OKA, Hiroshi	National Cancer Center	Japan
TOKUNAGA, Okihiro	Radiation Application Development Association	Japan

TORIKAI, Yuji	Institute of Environmental Sciences	Japan
TOTH, Esther	Lauder School, RAD Lauder Laboratory	Hungary
TSUZUKI, Teruhisa	Kyushu University	Japan
TURUOKA, Moriaki	Hokkaido Sapporo Kaisei Senior High School	Japan
TURUTA, Takao	Kinki University	Japan
UEHARA, Toshio	Osaka Nuclear Science Association	Japan
ULLAH, Sana	Atomic Energy Centre	Bangladesh
UNAK, Turan	Ege University	Turkey
WAKASA, Yuji	Nanyou Technical High School	Japan
WANITSUKSOMBUT, Warapon	Office of Atomic Energy for Peace	Thailand
WATANABE, Tomohiro	Rikkyo High School	Japan
WATARI, Kazuo	National Institute of Radiological Sciences	Japan
WU, Jin	Ibaraki Prefectural University of Health Sciences	Japan
YAMADA, Takeshi	Toho University	Japan
YASUOKA, Hisashi	Hyogo Prefectural Mikage High School	Japan
YATAGAI, Hideo	Bunkyo Women's University Junior & Senior High School	Japan
YOKOI, Ryo	Seikei High School	Japan
YOKOTA, Ken-ichi	Nagasaki University	Japan
YOSHIDA, Shigeo	Osaka University	Japan
YOSHIKAWA, Hideo	Secretary of Minister, Ministry of Education, Science, Sports and Culture	Japan

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

Proceedings of International Symposium on Radiation Education (ISRE 98)

Division of Planning and Analysis

Nuclear Safety Research Center
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

(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

JAERI-Conf 99-011

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。

東海研究所：〒319-1195　茨城県那珂郡東海村白方白根2-4

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。

1. Lectures

（招待講演及び依頼講演）

1.1 理科教育の問題点に関する考察

有馬　朗人

文部大臣・参議院議員、100-8962　千代田区永田町２－１－１、参議院議員会館２２３号室

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

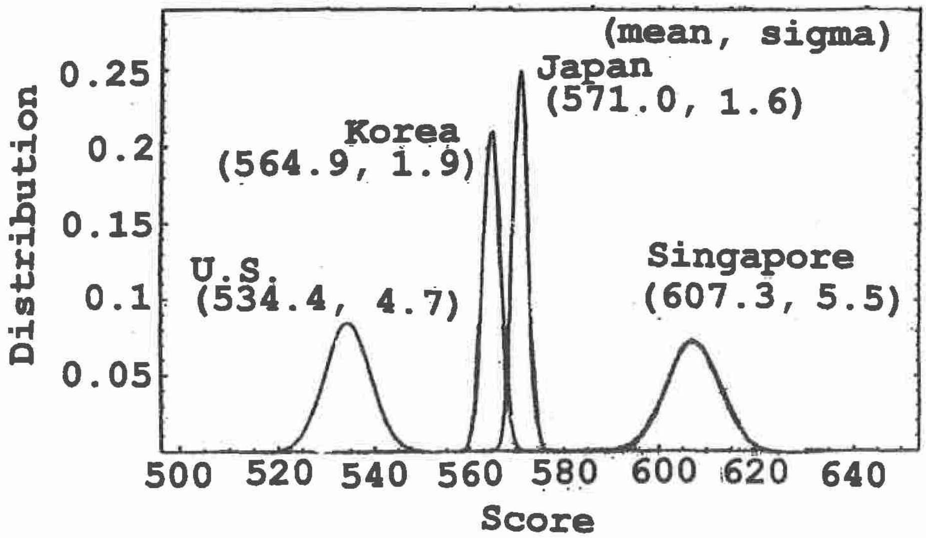
化学の領域　(1995)

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
	:	:	:

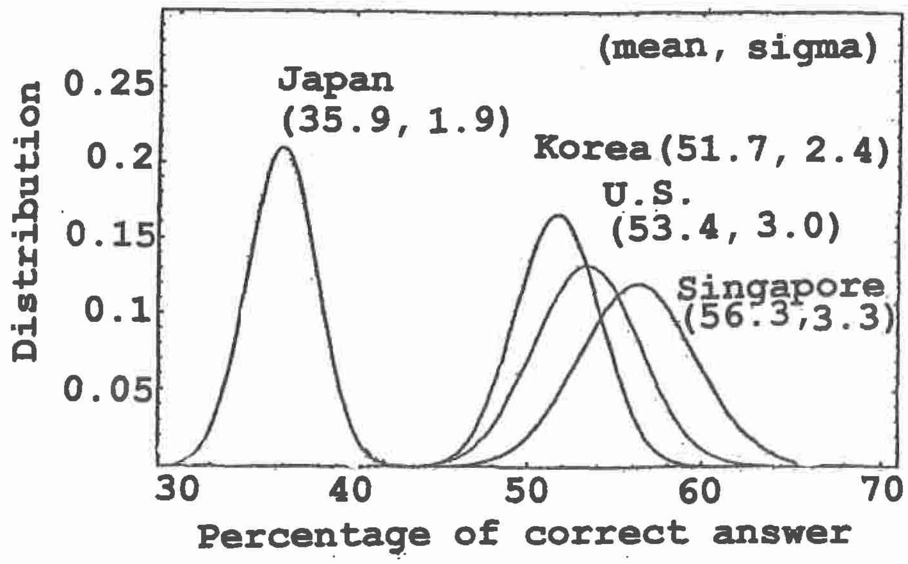
第３表　一般成人の科学知識

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

Jean-Pierre Adloff

Honorary Professor, University Louis Pasteur, 63 Rue Saint Urbain 67100 Strasbourg, France.

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.

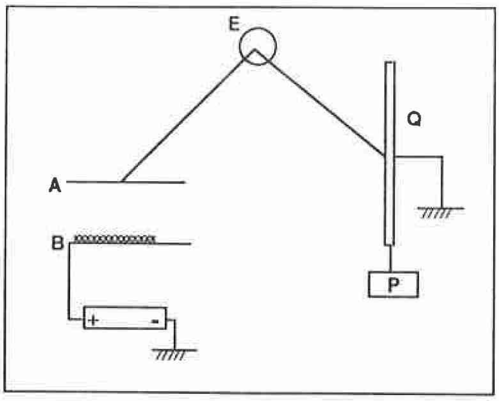


Fig.1. The charges produced in the ionization chamber AB by the active substance laid on the plate B are compensated by opposite charges calculated from the weight P applied to the piezoelectric quartz Q and the time of application. The compensation is controlled with the electrometer E.

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.

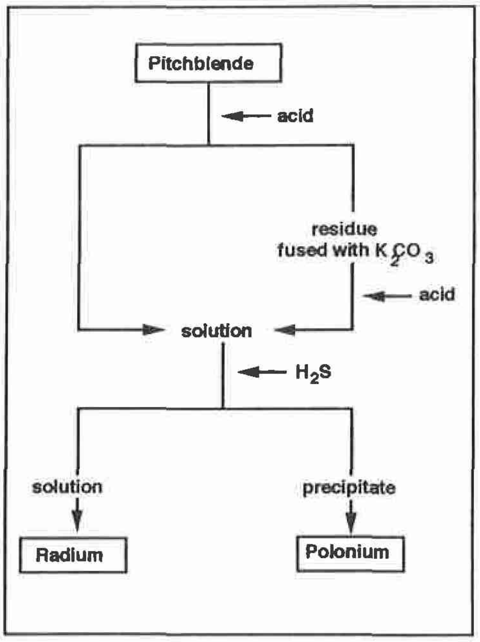
Research on uranic rays now turned from physics to chemistry. The obstacles were immense: separate and identify a substance whose chemical properties were completely unknown. The Curies who were not much familiar with chemistry were helped by Gustave Bémont, an analytical chemist at the Parisian School 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.



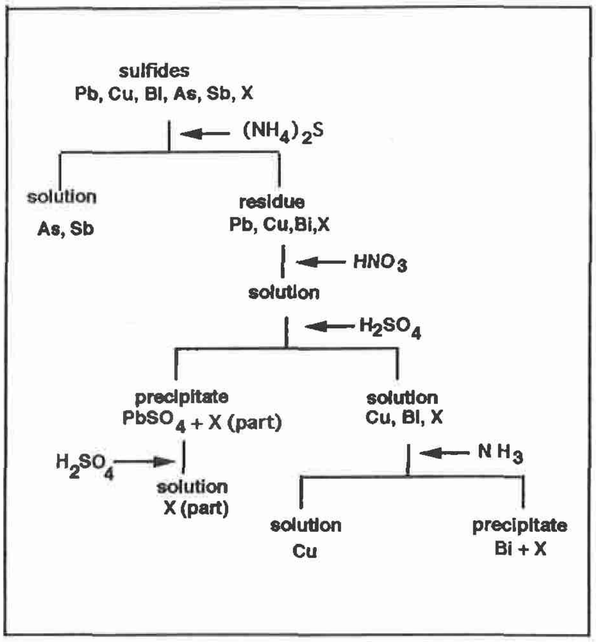


Fig.2 (left): Simplified scheme of the first treatment of pitchblende.

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.

References

1) J.P. Adloff, *Comptes Rendus Acad. Sci. Paris*, **1, Sér. II c**, 217-228 (1998); ibid. 457-464 (1998).

2) M. Sklodowska Curie, *Comptes Rendus Acad. Sci. Paris* , **126**, 1101- 1103 (1898).

3) J.P. Adloff and H.J. MacCordick, *Radiochimica Acta*, **70/71**, 13-22 (1995).

4) P. Curie and M. Curie, *Comptes Rendus Acad. Sci. Paris*, **127**, 175-178 (1898)

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

P.K.Kuroda

4191 Del Rosa Court, Las Vegas, Nevada 89121 USA

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:

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

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.

---

1. P.Curie, "Radioactive substances, especially radium", Nobel Lecture, June 6, 1905, "Nobel Lectures, Physics 1901-1921", Nobel Foundation(1967) Elsevier Publishing Company, Amsterdam, London, New York pp.73-78.
2. P.K.Kuroda, Science and Technology: A radiochemist' view, J. Radioanalyt. Nucl. Chem. 197,29-40(1995).
3. J.F.Joliot, "Artificial production of radioactive elements", Nobel Lecture, December 12, 1935, "Nobel Lectures, Chemistry, 1922-1941, Nobel Foundation(1966) , Elsevier Publishing Co., Amsterdam, London, New York, pp.369-373.
4. P.K.Kuroda, On the nuclear physical stability of the uranium minerals, J. Chem. Phys. 25, 781(1956).

5. P.K.Kuroda, "The origin of the chemical elements and the Oklo phenomenon, Springer-Verlag, Berlin, Heidelberg, New York, pp.1 -167(1982).
6. G.T.Seaborg, "The transuranium elements", Yale University Press, pp. 1-328(1958).
7. J.H.Reynolds, Determination of the age of the elements, Pys.Rev. Lett.4, 8 - 10(1960).
8. P.K.Kuroda, Nuclear fission in the early history pf the earth, Nature 187, 36-38(1960).
9. J.H.Reynolds, Xenology, J. Geophys. Res. 68, 2939-2956(1963).
10. E.M.Burbidge, G.R.Burbidge, W.A.Fowler, F.Hoyle,"Synthesis of the elements in stars,"Rev. Mod. Phys. 29, 547-650(1957).
11. A.G.W.Cameron, Nuclear astrophysics, Ann. Rev. Nucl. Sci. 8, 299(1958).
12. A.G.W.Cameron, The formation of the sun and planets, Icarus 1, 13(1962).
13. P.K.Kuroda, Temperature of the sun, Nature Phys. Sci. 230, 40-42(1971).
14. O.K.Manuel, E.W.Hennecke and D.D.Sabu, Xenon in carbonaceous chondrites, Nature Phys. Sci.240, 99-101(1972).
15. B.Srinivasan and E.Anders, Noble gases in the Murchison meteorite: Possible relics of the s-process nucleosynthesis, Science 201, 51-56(1978).
16. E.Anders and E.Zinner, Interstellar grains in primitive meteorites: Diamond, silicon carbide and graphite, Meteoritics 28, 490-514 (1993).

1.4 放射能に関するキュリー夫妻の仮説と元素の起源

黒田　和夫
4191 Del Rosa Court, Las Vegas, Nevada 89121 U.S.A.

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。

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

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ー過程と pー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ー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ー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ー過程と pー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ー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ー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ー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。

1. P. Curie, Radioactive substances, especially radium", Nobel Lecture, June 6, 1905, Nobel Lectures, Physics 1901-1921", Nobel Foundation(1967) Elsevier Publishing Elsevier Publishing Company, Amsterdam, London, New York pp. 73-78.
2. P. K. Kuroda, Science and Technology: A radiochemist' view, *J. Radioanalyt. Nucl. Chem.* 197, 29-40(1995).
3. J. F. Joliot, Artificial production of radioactive elements", Nobel Lecture, December 12, 1935, Nobel Lectures, Chemistry, 1922-1941, Nobel Foundation(1966), Elsevier Publishing Co., Amsterdam, London, New York, pp.369-373.
4. P. K. Kuroda, On the nuclear physical stability of the uranium minerals, *J. Chem. Phys.* 25, 781(1956).
5. P. K. Kuroda, The origin of the chemical elements and the Oklo phenomenon, Springer-Verlag, Berlin, Heidelberg, New York, pp.1-167(1982).
6. G. T. Seaborg, The transuranium elements", Yale University Press, pp.1-328(1958).
7. J. H. Reynolds, Determination of the age of the elements, *Phys. Rev. Lett.* 4, 8-10(1960).
8. P. K. Kuroda, Nuclear fission in the early history of the earth, *Nature* 187, 36-38(1960).
9. J. H. Reynolds, Xenology, *J. Geophys. Res.* 68, 2939-2956(1963).
10. E. M. Buridge, G.R.Burbidge, W.A.Fowler, F.Hoyle, Synthesis of the elements in stars, *Rev.. Mod.Phys.* 29, 547-650(1957).
11. A. G. W. Cameron, Nuclear astrophysics, *Ann. Rev. Nucl. Sci.* 8, 299(1958).
12. A. G. W. Cameron, THE formation of the sun and planets, *Icarus* 1, 13(1962).
13. P. K. Kuroda, Temperature of the sun, *Nature Phys. Sci.* 230, 40-42(1971).
14. O. K. Manuel, E. W. Hennecke and D. D. Sabu, Xenon in carbonaceous chondrites, *Nature Phys. Sci.* 240, 99-101(1972).
15. B. Srinivasan and E. Anders. Noble gases in the Murchison meteorite: Possible relics of the *s*-process nucleosynthesis, *Science* 201, 51-56(1978).
16. E. Anders and E. Zinner, Interstellar grains in primitive meteorites: Diamond, silicon carbide and graphite, *Meteoritics* 28, 490-514(1993).

1.5 NATURAL RADIATION AND RADIOACTIVITY IN EDUCATION

Masanobu Sakanoue

Professor Emiritus, Kanazawa University,
Miyano-chô 14-20, Takarazuka, 665-0843, Japan

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.

1895 | 1900 | 05 | 10 | 15 | 20 | 25 | 30 | 1933

X U Th.Tn. RaA.RaTh ・Atomic Nucleus ・Auger Effect ⇩
Ra. Rn. "B.C. Io. ・Isotope. Diplacement law Neutron
R R Po.Ac. RaD. MsTh. UY. ・Artificial trans. of element
a a UX.ThX "F. UX 2. Pa. UZ. Sm.
y d. 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.,
So lvent 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 | 1970 | 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" ϕ ×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

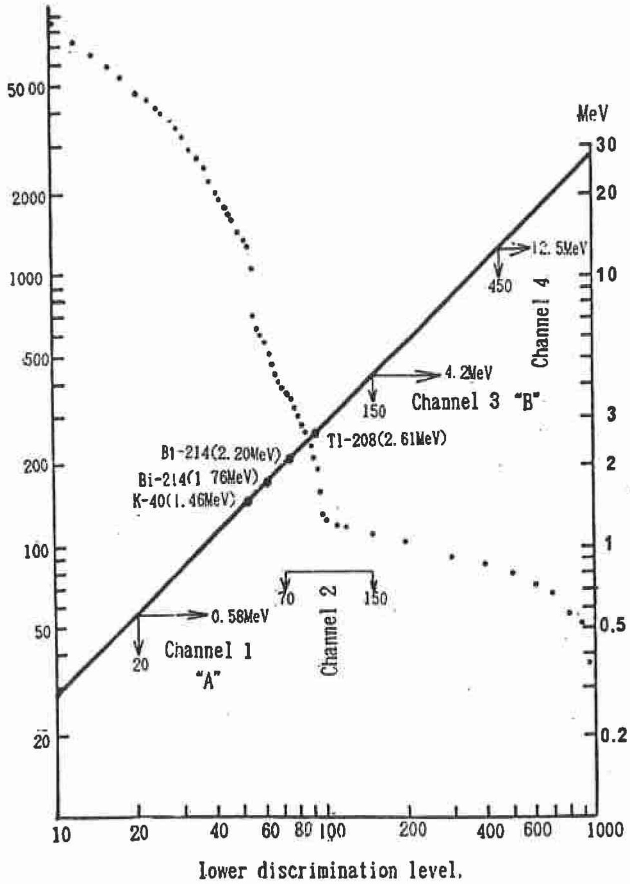


Figure 1:
Integral curve obtained by changing lower discrimination level, and relationship between pulse height discrimination level and gamma ray energy

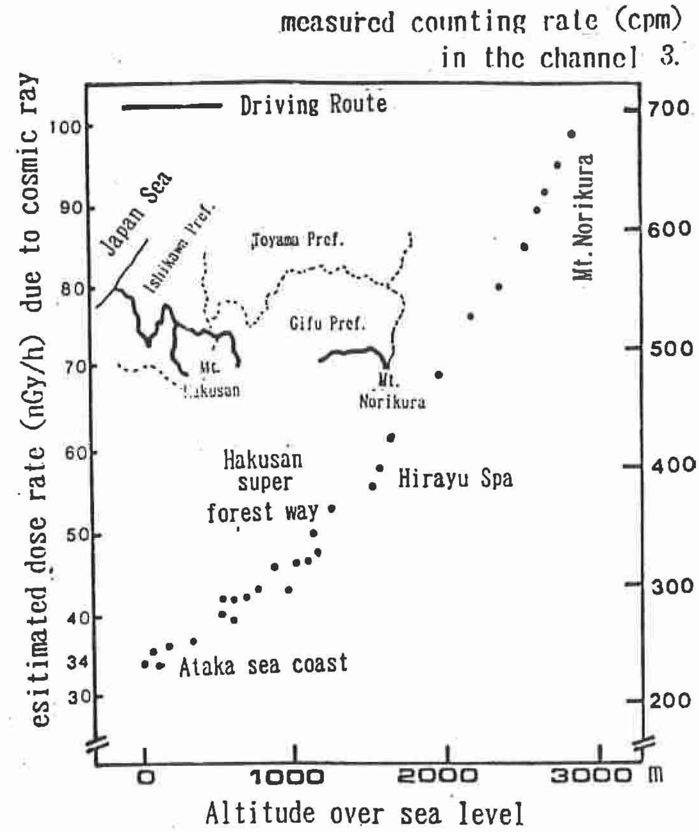


Figure 2:
Variation of counting rate due to cosmic ray with altitude during carborne survey

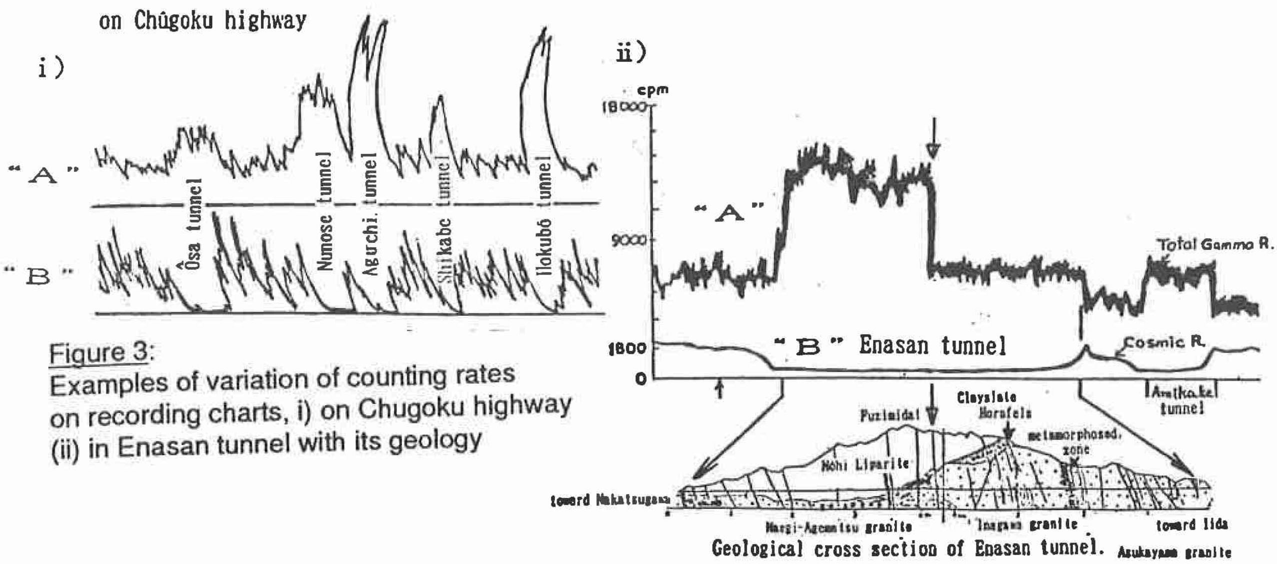


Figure 3:
Examples of variation of counting rates on recording charts, i) on Chugoku highway (ii) in Enasan tunnel with its geology

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 different 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 (×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.

REFERNCES

1)J.Elster,"Messung der elektrischen Zerstreuung in der freien atomosphärisch Luft an geographish weit voneinander entfert liegenden Orten," Phys. Zs. 2, 113-116(1900).

2)J.Elster,"Luftelektrische Messungen während der totalen Sonnenfinsternis zu Algier am 28.Mai 1990," Phys. Zs. 2, 66-67(1900).

3)J.Elster,H.Geitel,"Weitere Versuch über die Elektrizitätszerstreuung in abgeschlossenen Luftmengen," Phys. Zs. 2, 560-563(1901).

4)J.Elster,H.Geitel,"Beschreibung des Verfahrens zur Gewinnung vorübergehend Stoffe aus der atomosphärisch Luft," Phys. Zs. 3, 305-310(1901).

5)E.Rutherford,"Radioaktive Substanzen und ihre Strahlung," 『Handbuch der Radiologie』 BandⅡ, XIX, Die Radioaktivität der Erde und Atomosphäre, 243 Radioaktive Materie in der Luft, (1901).

6)M.Sakanoue,"Comparison of Radiation Level in Japan by Carborne Monitoring," (in Japanese) Radioisotopes,44, 459-463(1995); (in English) M. & F.Sakanoue, "Continuous Carborne Radiation Level Measurements by 4" $\phi\times$4" NaI Detector with 4 Channel Discriminators," Intern. Environ. Consult. Newsletter,Vol3,No1, 6-12(1997).

7)M.Sakanoue,H.Yonehara,Ma Jizeng, "Measurement of environmental natural radiation level using 4 channel pulse height discriminator with 4"$\phi\times$4" NaI (Tl) detector,"(in Chinese) Radiation Protection (China), 12,413-420(1992); M.Sakanoue,H.Yonehara,Ma Jizeng,Li Yuanxin,Xhen Zhitu,"Continuous measurements of radiation levels along Guangzhou-Yangjian and Hong Kong area using carborne 4 channel pulse height discriminator with 4"$\phi\times$4" NaI(Tl) detector," (in Chinese) Radiation Protection (China),12,421-430(1992).

8)A.A.Tajuddin,S.J.Hu,M.Sakanoue, "Continuous measurements of radiation levels along the west coast highway of Peninsular Malaysia," Appl.Radiat.Isot., 45, 1117-1119(1994).

9)M.& F.Sakanoue, "Radiation level monitoring in Europe during our travels," Intern. Environ. Consult. Newsletter, Vol1994,issue2, B56-59(1994).

1.6 医学における放射線・放射能の最近の利用

佐々木康人
放射線医学総合研究所
263-8555 千葉市稲毛区穴川 4-9-1

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イソトープで、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絨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絨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。

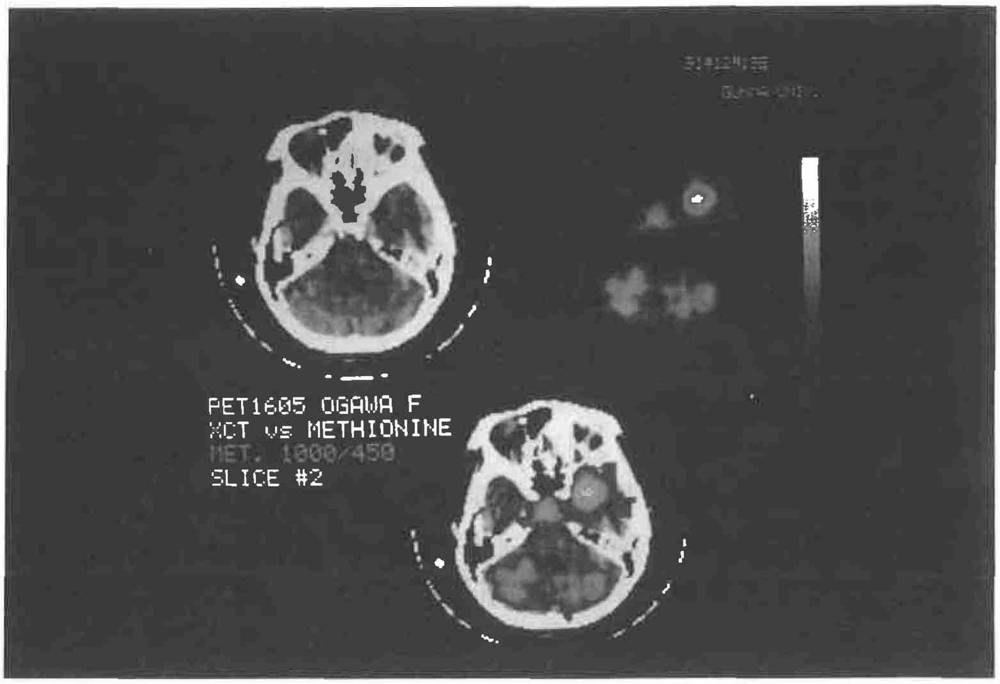


図 1　蝶形骨翼部の脳腫瘍（矢印）、CT(左上)
^{11}C-メチオニン PET(右上)、
CT と PET の複合画像(下段)

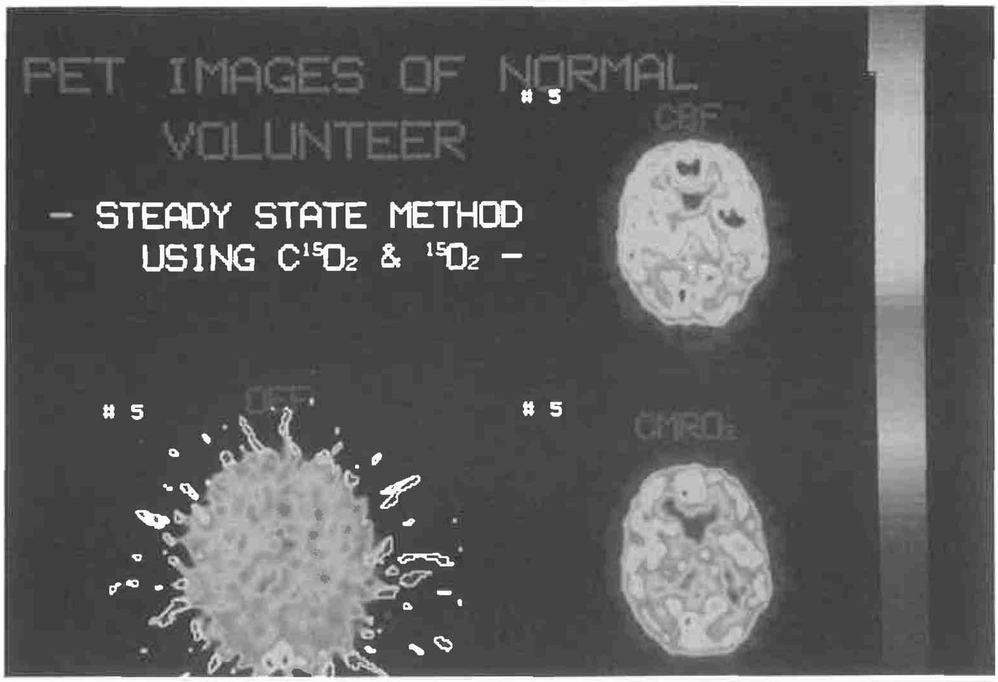


図 2　^{15}O－炭酸ガス吸入後の PET 局所脳血流量(rCBF)を示す機能図 (functional image)(右上)と ^{15}O-酸素ガス吸入後の PET 局所酸素代謝率 (rCMRO$_2$)を示す機能図(右下)

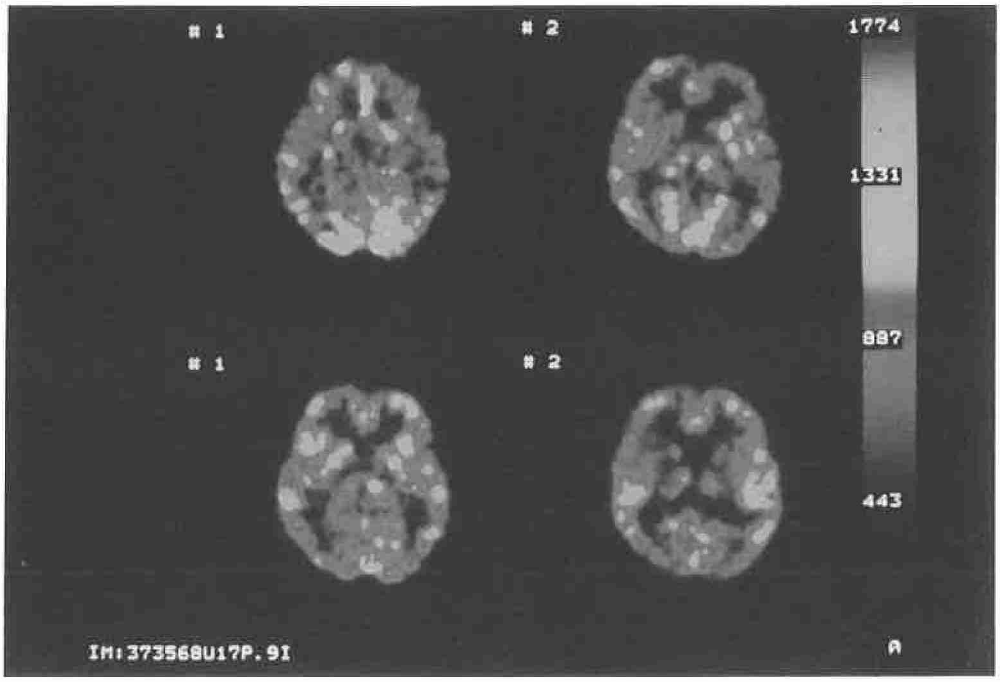


図3　^{15}O水PETによる脳賦活試験

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）。

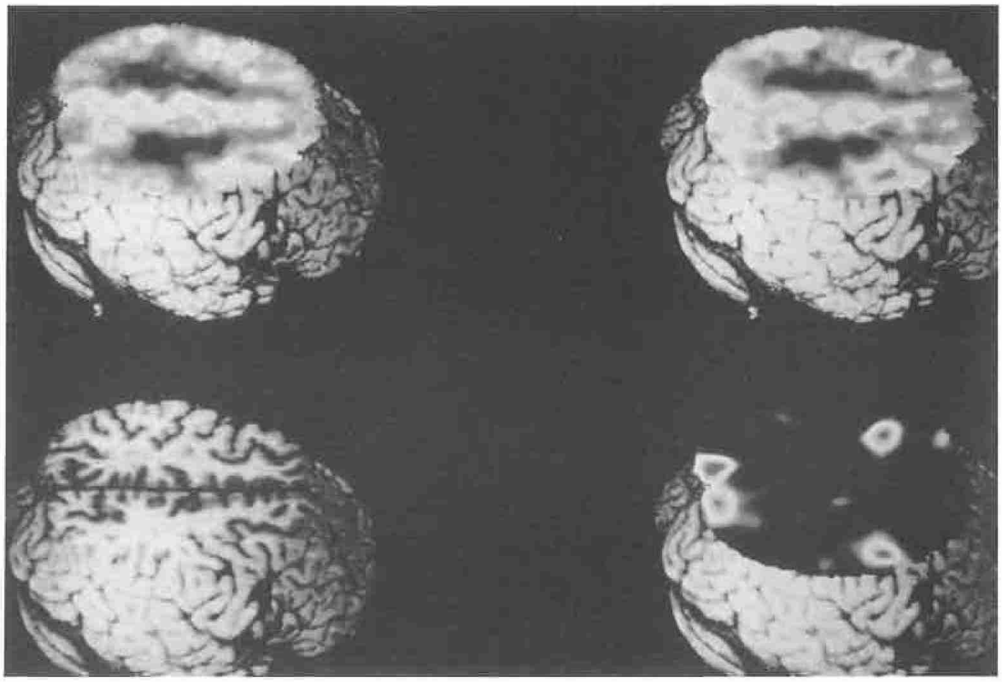


図4　脳賦活試験中の^{15}O水PET(右上)から安静時脳血流PET(左上)を引き算したサブトラクションイメージ(右下)。後頭部視覚領野（矢印）と前頭眼野（矢頭）が活性化している。PET画像は3次元MRI(左下)に重ね合わせてある。

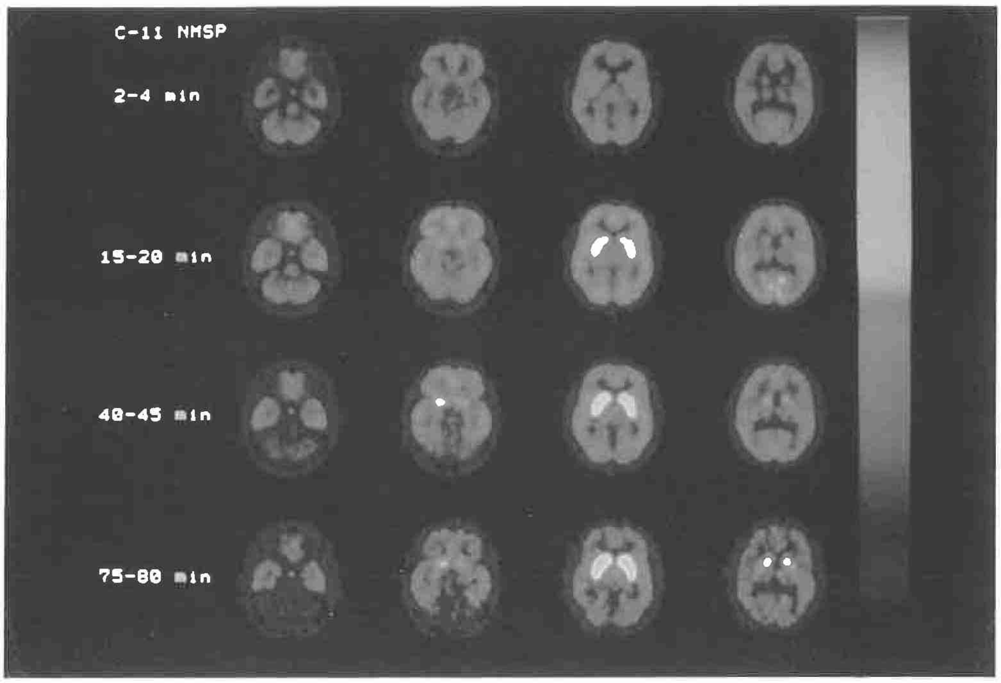


図５　^{11}C-N-メチルスピペロンとPETを用いたドーパミンD2受容体画像、75分後に線状体の受容体部位が描出されている(矢印)。

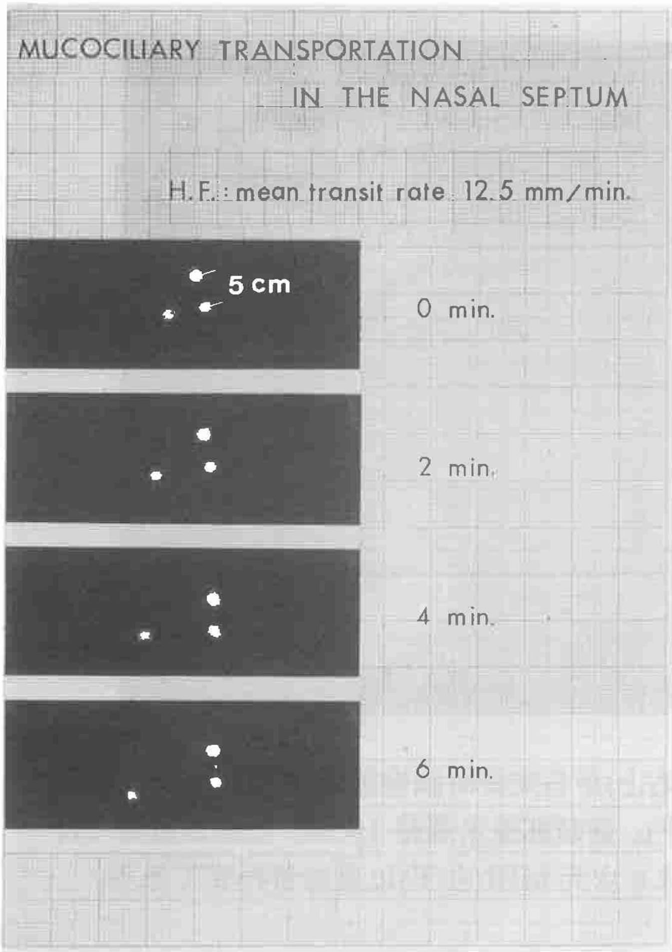


図６　シンチカメラによる
鼻粘膜線毛機能の測定

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。

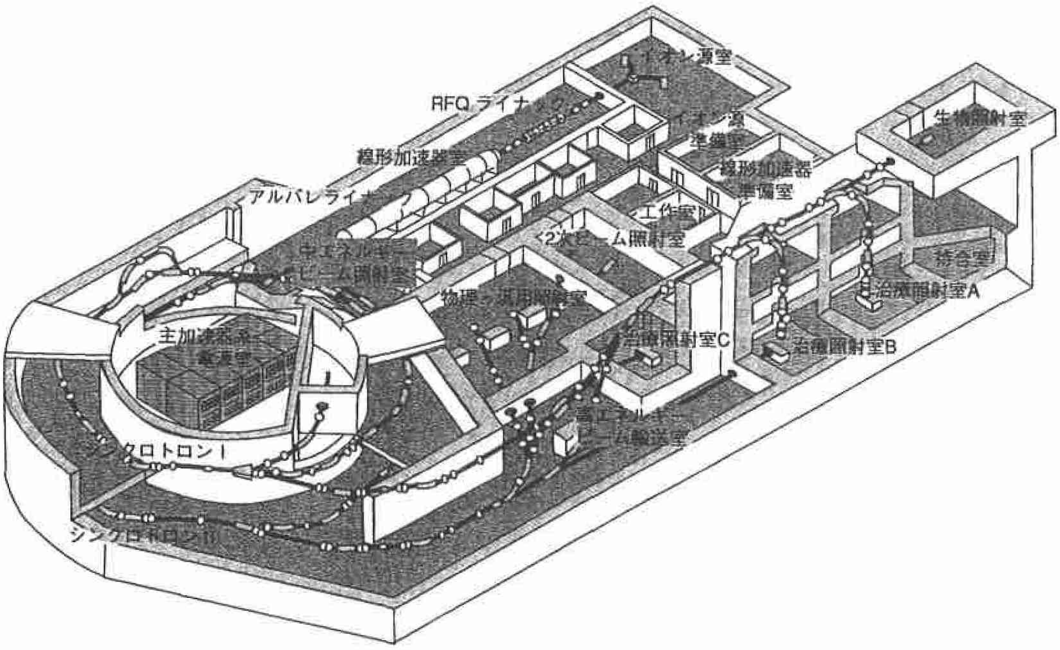


図 7　HIMAC(Heavy Ion Medical Accelerator in Chiba)の模式図

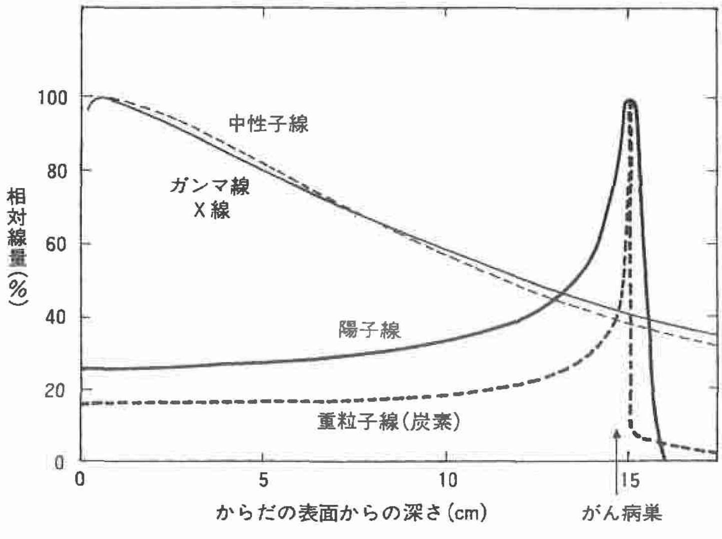


図 8　光子（X 線、ガンマ線)、中性子線、陽子線、重イオン（炭素）線の体内線量分布を示す模式図

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

日本原子力研究所
松浦祥次郎
Shojiro MATSUURA
Japan Atomic Energy Research Institute

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。

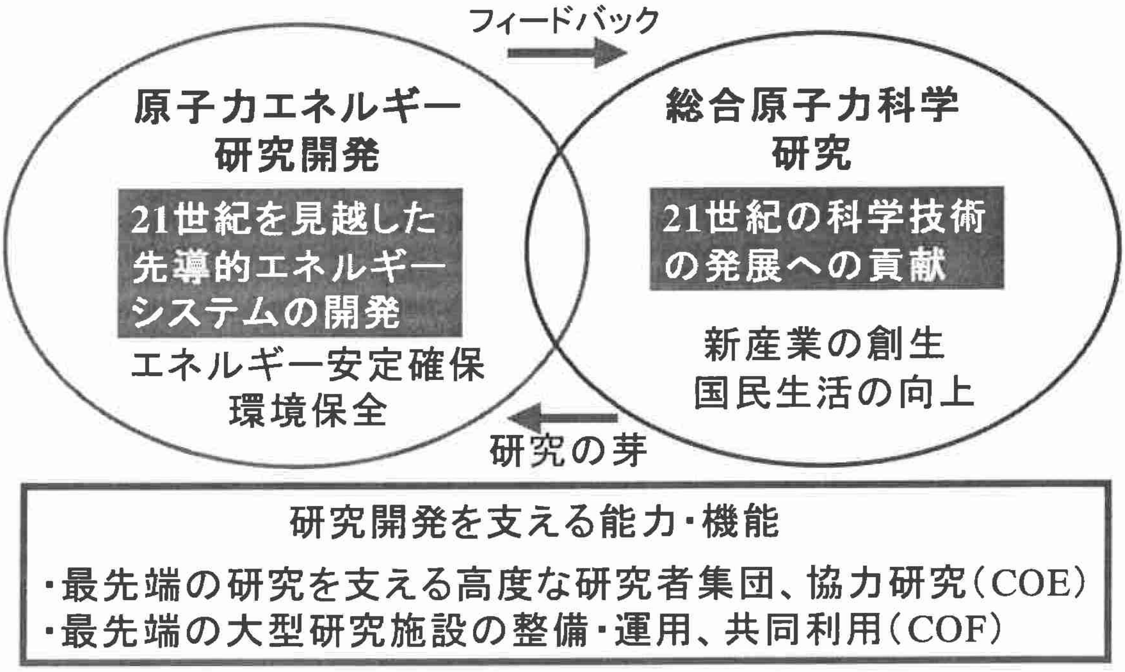


図1　原研の研究開発の方向

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。

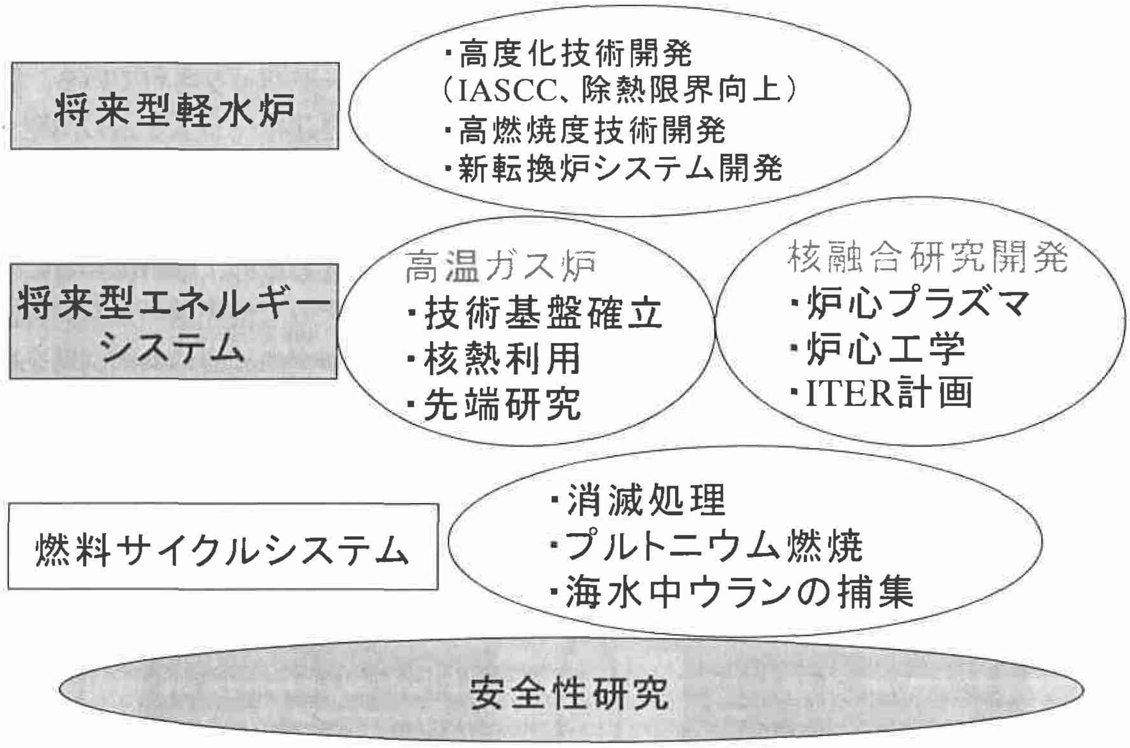


図2 原子力エネルギー研究開発

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。

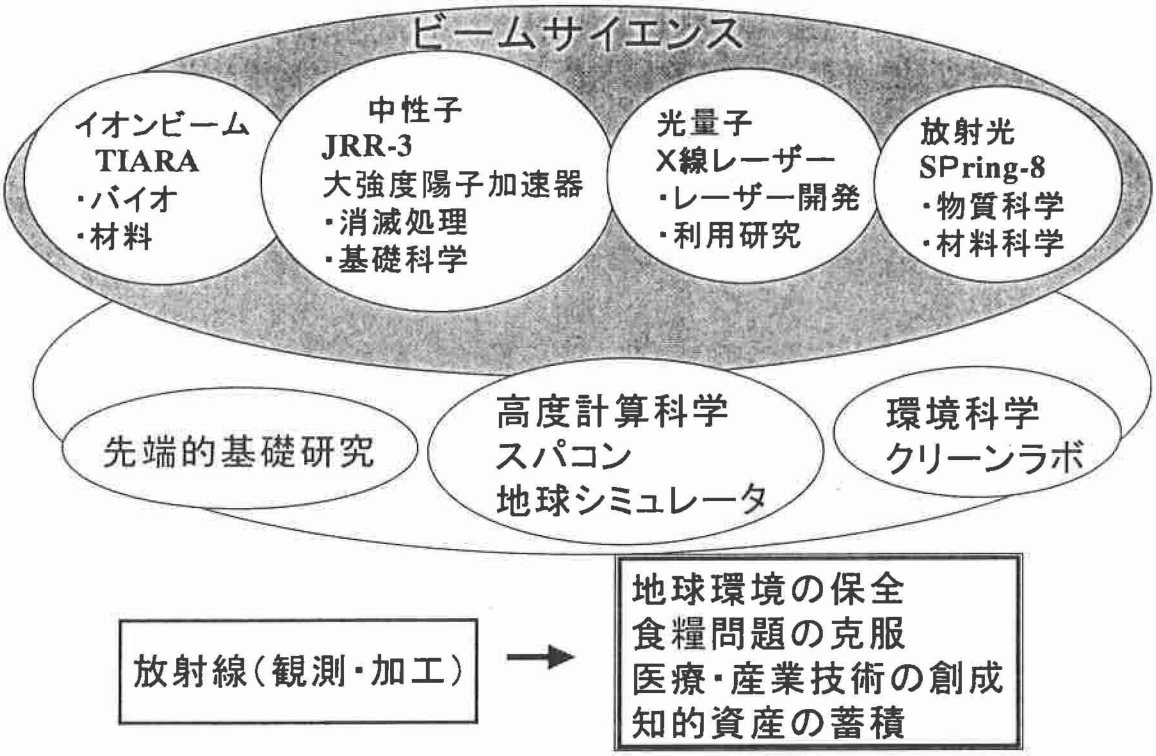


図3 総合的原子力科学研究

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。

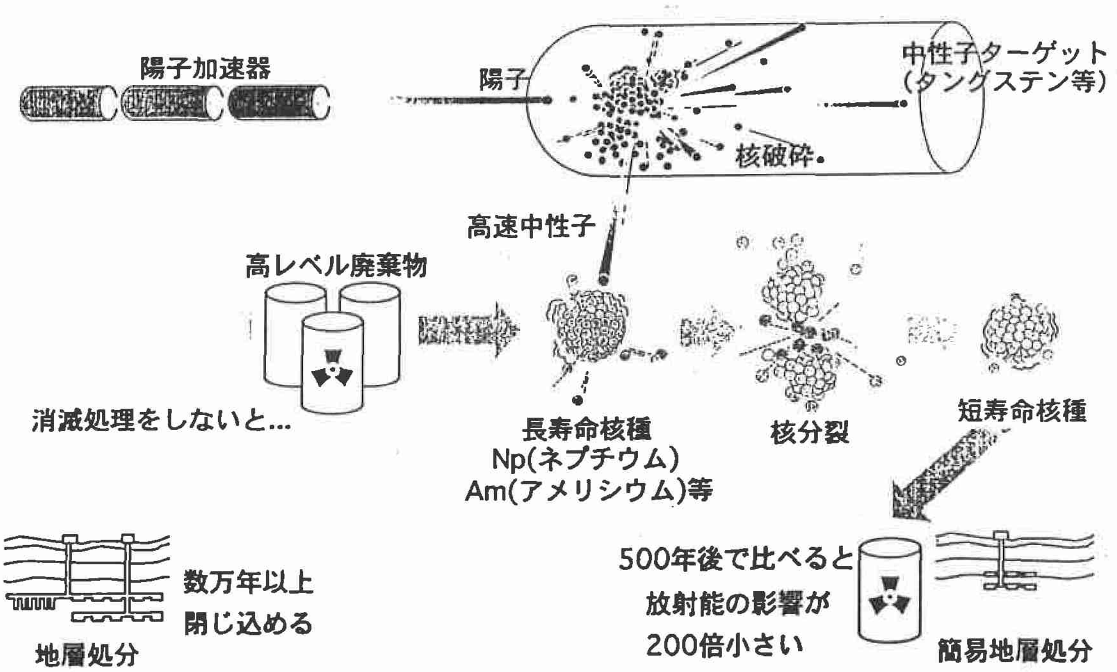


図５　消滅処理の概念

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ﾎﾞﾙﾄ）からGeV（ｷﾞｶﾞｴﾚｸﾄﾛﾝﾎﾞﾙﾄ）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
  - ー橋掛け重合：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
  - ーグラフト重合：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
  - ー環境保全：排煙処理、汚泥処理
  - ー資源利用：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

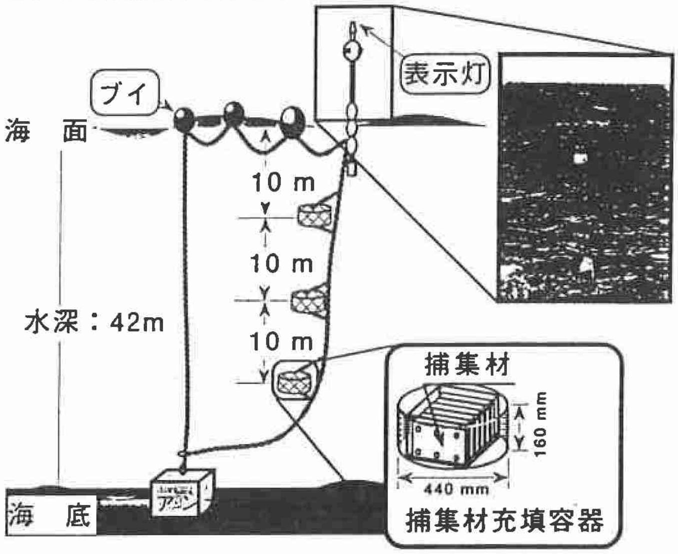
高分子の機能材料については、放射線を利用した橋かけ重合（直鎖状の高分子の間に橋を架けて安定な高分子材料を製造するプロセス）を用いて、耐熱性、難燃性の材料の合成、天然ゴムラテックスの改良、ハイドロゲル状の絆創膏材料の合成などの技術を開発してきた。放射線を利用したグラフト重合（ある種の高分子に異なる高分子等を結合させるプロセスで、接ぎ木の概念に類似している）を用いて、電池用の隔膜、空気清浄用のフィルター、海水中金属イオンの捕集材等の合成技術を開発してきた。電池用の隔膜を例にすると、広く使われているボタン型電池の隔膜は殆どが放射線重合で作られた材料で作られている。さらに、将来の宇宙利用に役立つと考え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。

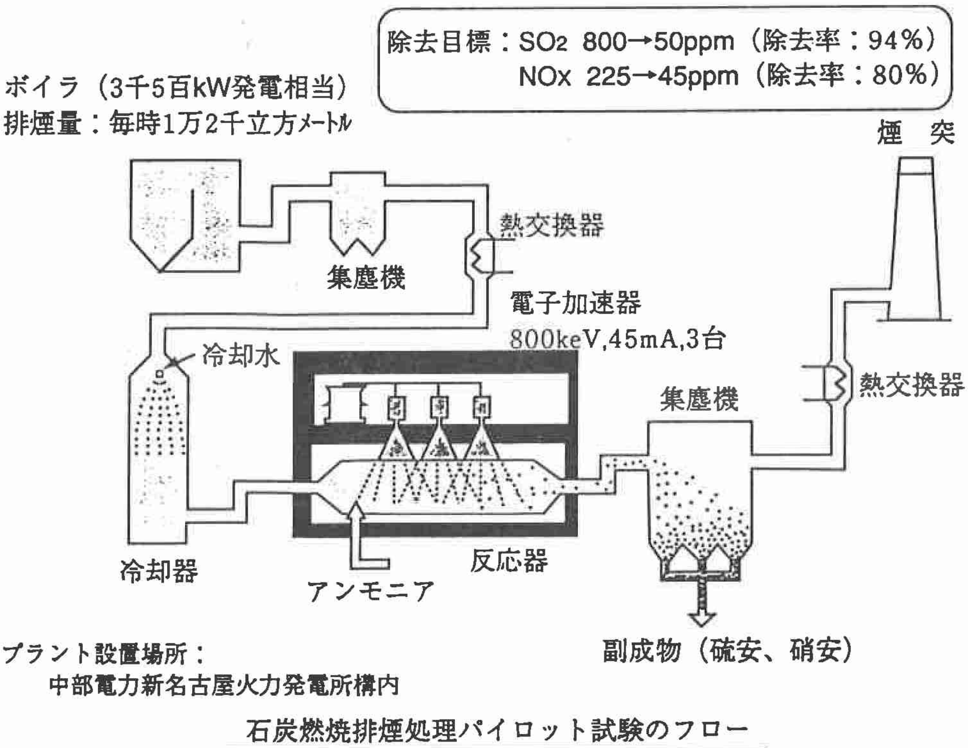
放射線グラフト重合法を用いて合成した捕集材を用いて、海水中に極微量溶解しているウラン、バナジウムなどの希少金属を選択捕集するシステムを開発

- 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。

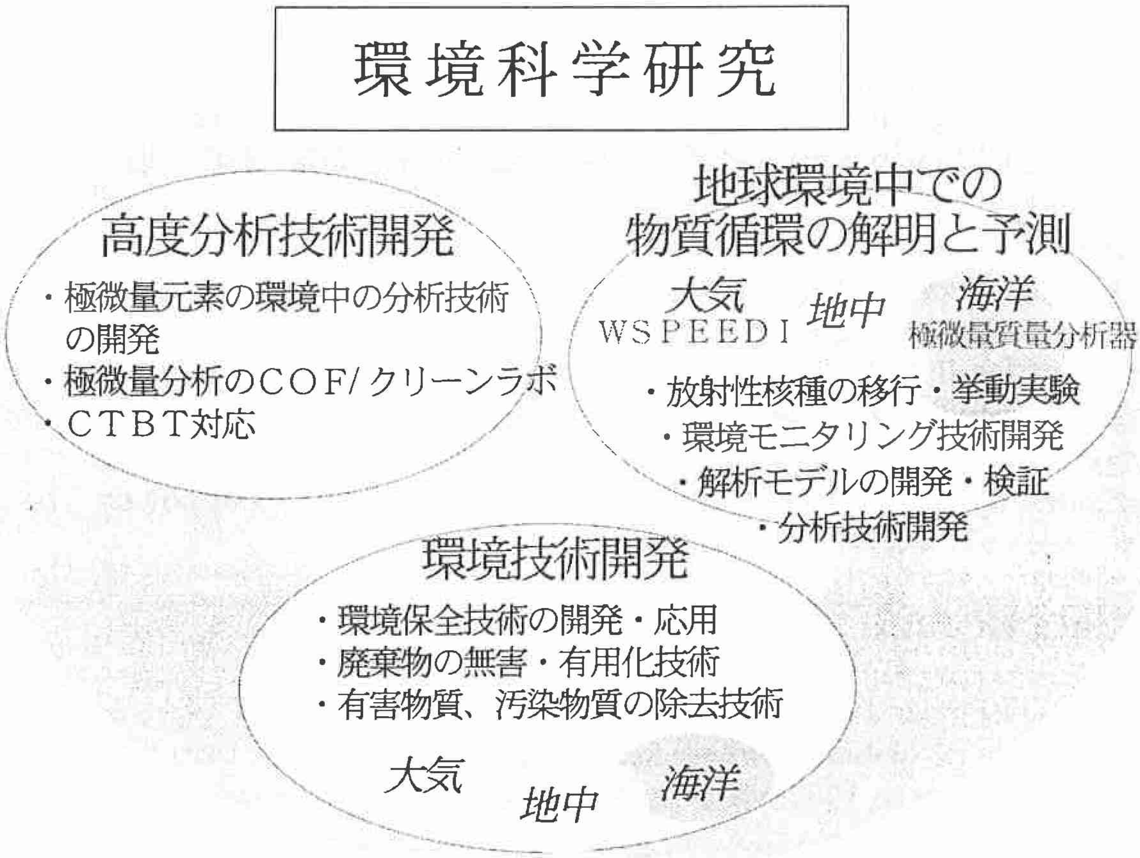


図８　環境科学研究計画

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

Peter E.Hodgson

Nuclear and Particle Physics Laboratory,

Department of Physics, University of Oxford.

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.

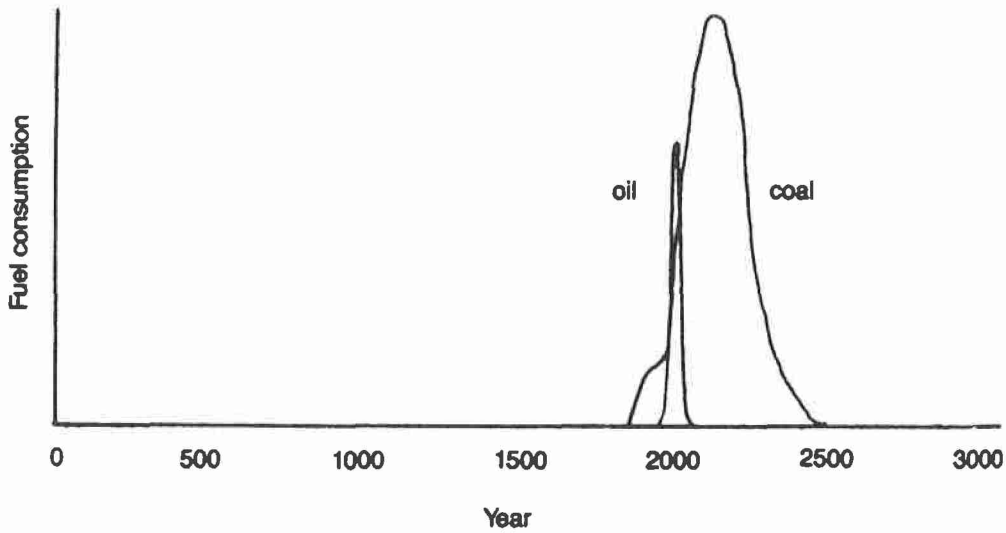
The importance of nuclear power in reducing carbon dioxide emissions has been admitted by a recent report of the parliamentary Select Committee on Trade and Industry which says that "without a significant component of nuclear power generation the plant mix achievement - or maintenance - of the Government 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?

1.9 低線量影響研究最近の話題

山田武[1]、大山ハルミ[2]
[1]東邦大学医学部、現　電力中央研究所生物科学部狛江分室
[2]放医研障害基盤研究部

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間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、照射した細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。

文献

放射線ホルミシス一般

1) 山田武：Isotope News 1991年3月号. 2-5. 1991.
2) 石田健二：日経サイエンス. 1991年4月号. 82-90. 1991.
3) Luckey TD著、松平寛通監訳：放射線ホルミシス. ソフトサイエンス社. 東京. 1990.
4) Luckey TD著、松平寛通監訳：放射線ホルミシスII. ソフトサイエンス社. 東京. 1993.
5) エネルギーレビュー1994年4月号、特集「低レベル放射線の生体への刺激効果」
6) 大山ハルミ、山田武：低線量放射線の健康影響-放射線ホルミシス. RADIO ISOTOPES.vol. 46, 360-370 (1997)

米沢先生と佐々木先生その他らの放射線適応応答の関係論文は下記のMutation Research集号にまとめられている。

7)Mutation Research, Special Issue: The adaptive response to very low doses of ionizing radiation. Vol. 358. No.2. (1996)

低線量の神経系への影響に関する論文

8) Miyachi Y., Ogawa N. and Mori A. : Rapid decrease in brain enkephalin content after low-dose X-irradiation of the rat. Journal of Radiation Research, 33: 11-15, 1992
9) Miyachi Y., Kasai H., Ohyama H. and Yamada T. : Depression of mouse aggressive behavior by very low-dose X-irradiation and its unusual dose-effect relationship. In "Low-dose Irradiation and Biological Defense Mechanisms" (Eds. Sugahara T. et al) Elsevier Sci. Pub. Amsterdam, 171-174, 1992
10) Miyachi Y., Kasai H., Ohyama H. and Yamada T. : Changes of aggressive behavior and brain serotonin turnover after very low-dose X-irradiation in mice. Neuroscience Letters, 175: 92-94, 1994
11) Miyachi Y., Koizumi T. and Yamada T.: Immediate arousal response and adaptation to low-dose X-rays in mouse and its disappearance by bulbectomy and nitric oxide inhibitor. Neuroscience Letters, 177: 32-34, 1994
12) Miyachi Y. and Yamada T.: Low-dose X-ray-induced depression of sexual behavior in mice. Behavioural Brain Research, 65: 113-115, 1994
13) Miyachi Y.: Head-up behavior induced by low-dose X-rays and its disappearance by zinc sulfate perfusion in the nasal passage. Behavioural Processes, 36: 297-301, 1996
14) Miyachi Y.: Marked decreased radiation-induced emesis by olfactory bulbectomy or pre-exposure using low-doses. Experientia, 52: 230-233, 1996
15) Miyachi Y. and Yamada T.: Head-portion exposure to low-level X-rays reduces isolated-induced aggression of mouse, and involvement of the olfactory carnosine in modulation of the radiation effects. Behavioural Brain Research, in press

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

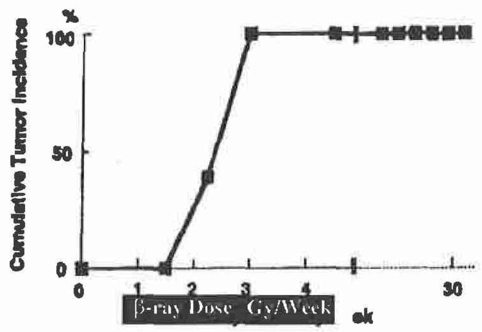


図1

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

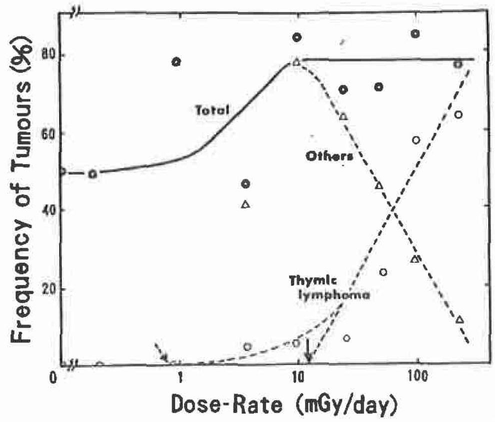


図2

1.10 MORTALITY OF ATOMIC BOMB SURVIVORS IN NAGASAKI

Mariko Mine, Sumihisa Honda ,Hisayoshi Kondo, Kenichi Yokota, Masao Tomonaga and Yutaka Okumura

Atomic Bomb Disease Institute Nagasaki University School of Medicine, Sakamoto1-12-4, Nagasaki 852-8523, Japan

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.

REFERENCES

1) Beebe, G.W. et al., “Studies of the mortality of A-bomb survivors. 6. Mortality and radiation dose, 1950-74”, Radiat. Res., 75, 138-201(1978)

2) Y.Shimizu et al.,“Studies of the mortality of A-bomb survivors. 9. Mortality . 1950-85:Part 1. Comparison of Risk Coefficients for Site-specific Cancer Mortality Based ob the DS86 and T65DR Shielded Kerma and Organ dose”, Radiat. Res., 118, 502-

524(1989)

3) Donald A. Pierce et al., "Studies of the mortality of A-bomb survivors. Report 12, Part 1 Cancer: 1950-1990", Radiat. Res., 146, 1-27(1996)

4) H.Mori et al., "Medical Database for the Atomic-Bomb Survivors at Nagasaki University", Acta Medica Nagasaki, 37, 52-65(1992)

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

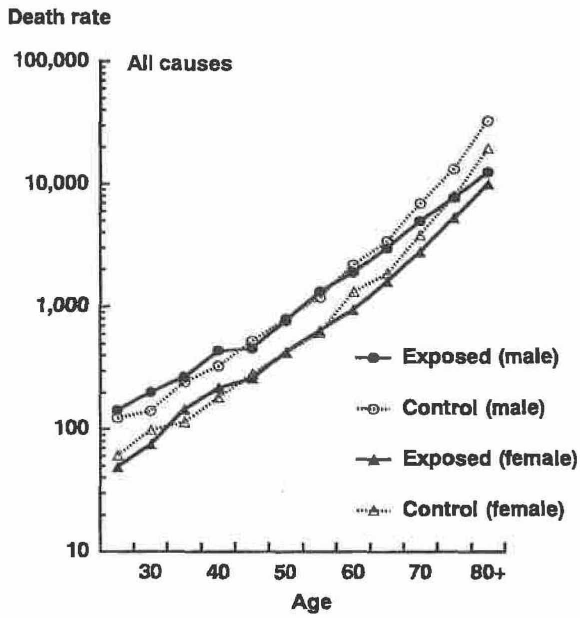


Fig. 1 Compare the mortality of exposed and control

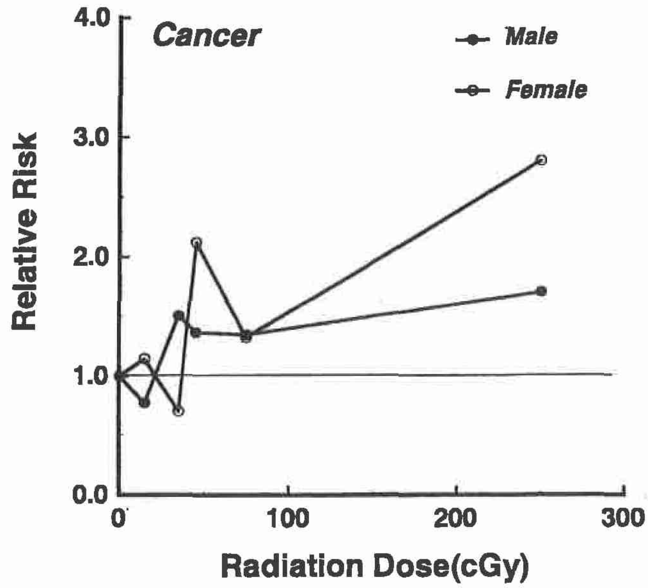


Fig.2 Relative Risk by radiation dose and sex (Cancer)

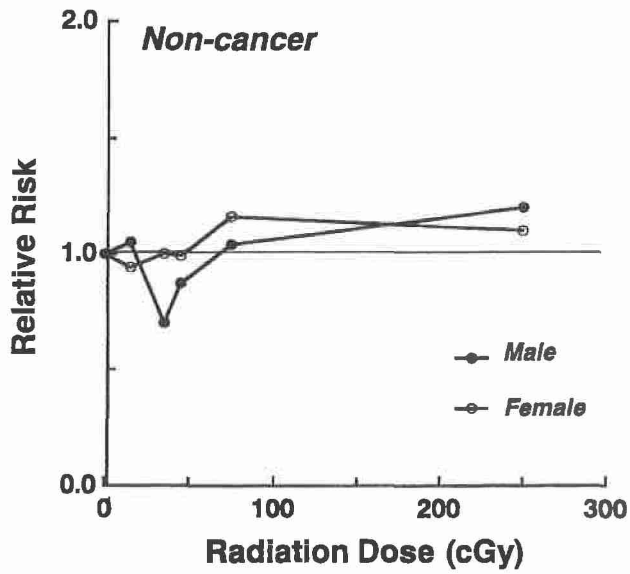


Fig.3 Relative Risk by radiation dose and sex (Non-Cancerous disease)

1.11 UNDERSTANDING NUCLEAR ISSUES

George Marx
Department of Atomic Physics, Eötvös University
Pazmany setany 1A, Budapest H-1117, fax 36-1-3722753

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 Kármán discovered the Kármán 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: $n+{}^{14}N \quad {}^{14}C+H$.

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: $H+H \quad {}^2H+e^+$, $H+{}^2H \quad {}^3He$, $2{}^3He \quad {}^4He+2H$, but reactions like $^2H+{}^4He \quad {}^3H+{}^3He$ 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: $n+{}^{87}Sr \quad {}^{87}Rb+H$, $n+{}^{40}Ca \quad {}^{40}K+H$. 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 $(5500/75)\cdot(0.2\ pJ/3)=5$ 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**