JAERI-M
93-160

PROCEEDINGS OF THE WORKSHOPS ON THE UTILIZATION OF ELECTRON BEAMS

July 9 and 13, 1992, Bangkok and Jakarta

September 1993

(Ed.) Shoichi SATO

日本原子力研究所
Japan Atomic Energy Research Institute

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Proceedings of the Workshops on the Utilization of Electron Beams
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Takasaki Radiation Chemistry Research Establishment
Japan Atomic Energy Research Institute
Watanuki-cho, Takasaki-shi, Gunma-ken

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Workshops organized by JAERI in cooperation with OAEP, BATAN and JAIF on the utilization of electron beam (EB) were held in Bangkok and Jakarta on 9 and 13 July 1992, respectively. The proceedings contain 13 papers presented at the Workshops. Welcome remarks, opening address and closing remarks are also recorded. At the first part of the Workshops, general view on the application of electron accelerators and introduction of electron accelerators were made. Potential applications of electron accelerators to polymer processing, sterilization of medical products, flue gas purification, treatment of wastewater and sewage sludge and bio-resources were introduced from Japanese participants. Potential application of electron accelerators to polymer processing and food irradiation in Thailand and Indonesia were also discussed.

Keywords: Electron Accelerator, Electron Beam, Industrial Application, Polymer, Curing, Economical Aspects, Food Irradiation, Flue Gas, Wastewater, Sludge, Bioresources, Sterilization

電子線の利用に関するワークショップ論文集
1992年7月9，13日　バンコク，ジャカルタ

日本原子力研究所高崎研究所
（編）佐藤　章一

（1993年7月20日受理）

電子線の利用に関するワークショップが，原研とタイ原子力庁（ＯＡＥＰ），インドネシア原子力庁（ＢＡＴＡＮ）ならびに日本原子力産業会議の協力のもとに，バンコクで平成4年7月9日およびジャカルタで13日に開催された。本論文集はワークショップにおいて発表された13の論文を収録したものである。さらに，開会の挨拶，閉会の辞なども併せて収録した。ワークショップの最初の部分では電子加速器利用の概要，電子加速器の紹介が行われた。さらに，高分子工業への電子加速器の利用，医療用具の滅殺菌，排ガスの浄化，廃水ならびに汚泥の処理，および生物資源への電子線の利用が述べられた。また，タイならびにインドネシアにおける高分子工業や食品照射への電子加速器の利用の可能性についても議論された。

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PREFACE

The Workshops on the utilization of electron beam (EB), organized by JAERI in cooperation with OAEP, BATAN and JAIF, were held in Thailand and Indonesia on 9 and 13 July 1992, respectively following to the First Workshops in 1990.

Dr. S Sato, Dr. W. Kawakami, Dr. K. Makuuchi, Dr. S. Hashimoto and Dr. T. Kume of JAERI, Mr. S. Takahashi of JAIF, Mr. K. Tomita and Dr. M. Takehisa of Radia Ind. Co. Ltd., Dr. Y. Sasaki of Yazaki Co., Mr. A. Kuroyanagi of Nisshin Electric Co. Ltd., Mr. M. Suzuki of Nisshin-High Voltage Co. Ltd. and Mr. T. Doi of NKK Corporation participated from Japan.

The Workshop in Thailand entitled "Workshop on Industrial Utilization of Electron Accelerators" was held in the Central Plaza Hotel, Bangkok. About 140 persons participated from OAEP and other government offices, universities and companies. It was mentioned from Mr. Suchat Mongkolpantha that the information exchange through the cooperation between Thailand and Japan is very meaningful to promote research and development in Thailand and potential for the application of electron accelerators in Thailand were discussed.

The Workshop in Indonesia entitled "Second Workshop on Industrial Utilization of Electron Accelerators" was held in the

Hotel Indonesia, Jakarta. About 90 persons participated from BATAN and other government offices, universities and companies. It was mentioned from Dr. Nazir Abdulla that National Atomic Energy Agency concerns very much with the radiation technology into industrial line in Indonesia and BATAN going to built an EB machine with a medium energy of 2 MeV. A low energy electron accelerator was already installed in Indonesia and strong interest was shown from many participants. Many questions and discussions were made about the possibility of the utilization of electron accelerators in Indonesia.

S. Sato
Editor in Chief
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JAERI

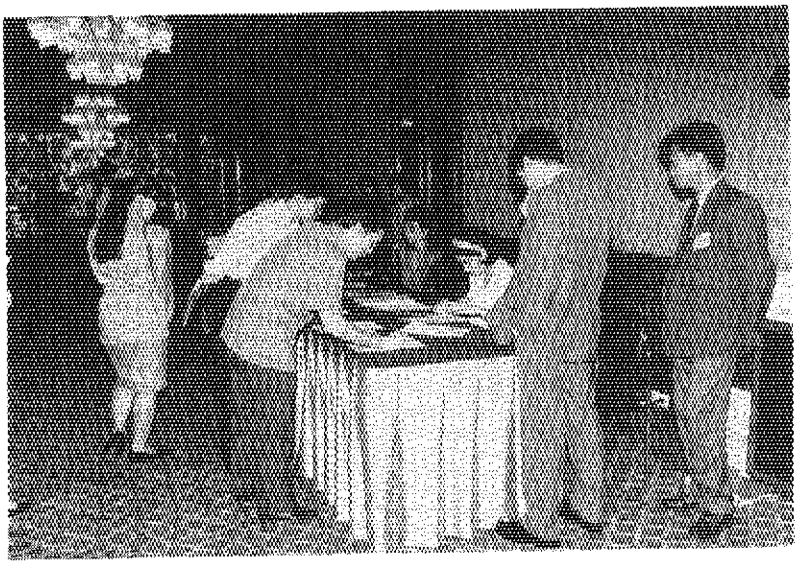

Photo. 1 Registration at the Central Plaza Hotel, Bangkok

Photo. 2 Secretary-General of OAEP delivering his welcome remarks

Photo. 3 A view of workshop participants in Thailand

Photo. 4 A snapshot at lunch break

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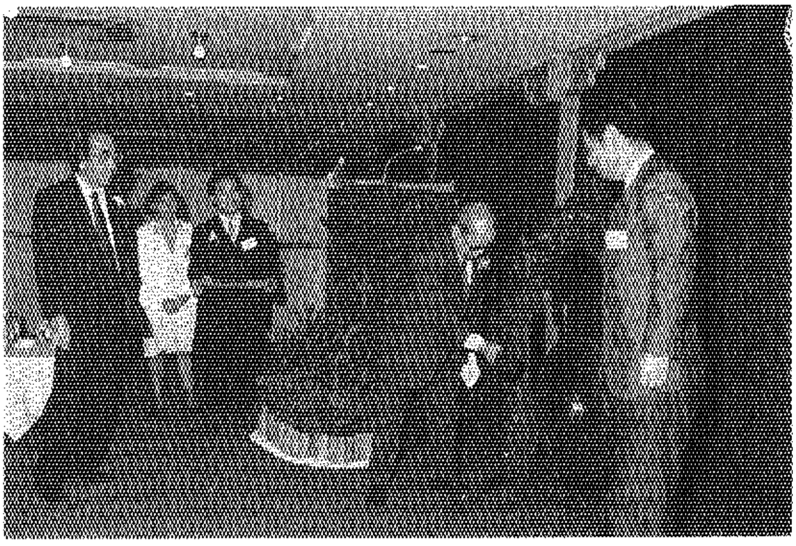

Photo. 6 Director Generals of BATAN and TRCRE jointly opening the Workshop

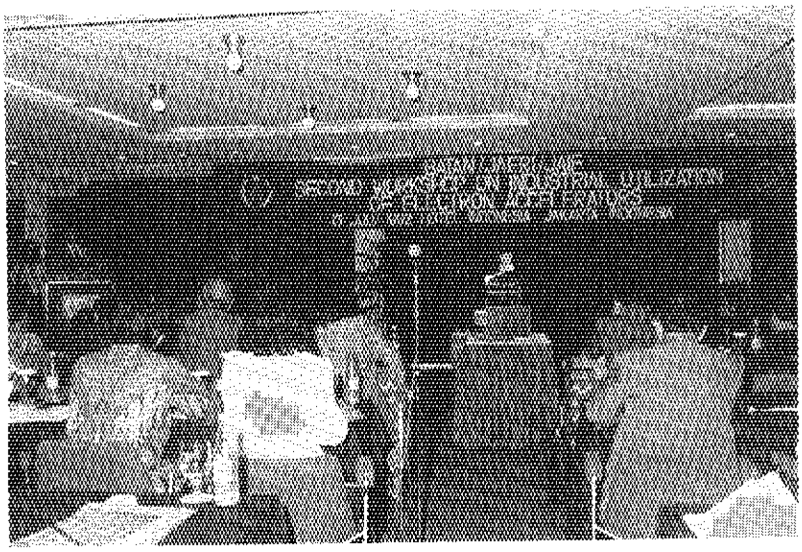

Photo. 7 A staff of BATAN delivering the Organization Committee Report

Photo. 8 A view of Workshop participants in Indonesia

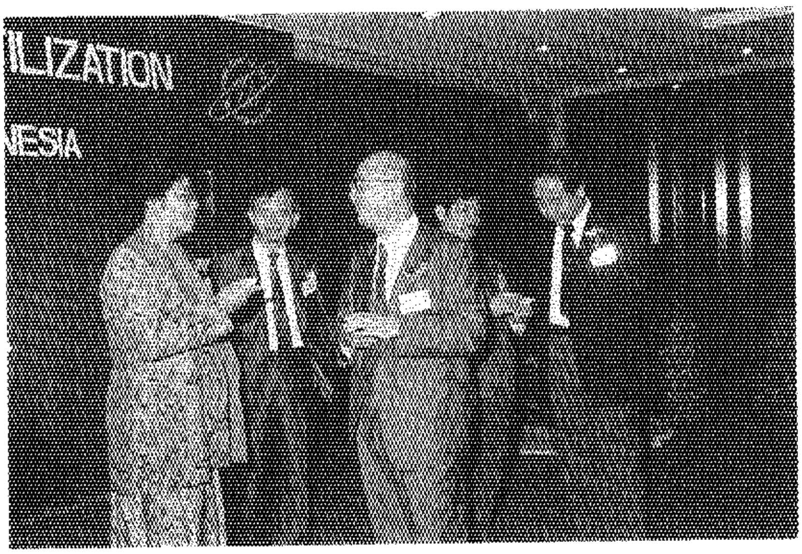

Photo. 9 Discussions during coffee break

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1.1. Welcome Remarks

Suchat Mongkolphantha

Secretary-General

Office of Atomic Energy for Peace, Thailand

Dr. Sato,

Dr. Sasaki,

Honored Guests,

Ladies and Gentlemen,

The Government of Thailand has indeed good reason to welcome the holding of this Workshop on Industrial Utilization of Electron Accelerators. Before I go any further, please let me extend a warm welcome to those who come a long way to join us here, the distinguished group of experts and scientists as well as decision makers from the governmental institutes and private sectors from Japan. I also wish to welcome all of distinguished participants, who are present here to assess and exchange views on electron accelerator utilization and its future direction.

As for Thailand has given high priority to industrial development. Emphasis is placed on study and research of modern and advance technologies to achieve considerably impressive industrial growth. The utilization of electron accelerators, which has been developed and proven beneficial in the developed countries, has been introduced into Thailand and generally accepted for its importance to the development in a wide range of industries, namely plastic products, radiation curing of surface coating, radiation cross-linking of wires and cables, sterilization of medical products, vulcanization of natural rubber, food irradiation, flue gas purification, and radiation treatment of wastewater and sewage sludge.

Considering that industry and technology have become inseparably related, and considering also that we live in a time of such rapid technological changes, the Office of Atomic Energy for Peace (OAEP), in cooperation with the Japan Atomic Energy Research Institute (JAERI) and Japan Atomic Industrial Forum (JAIF), organizing this workshop to welcome the proven awareness and demonstration of electron accelerator advantages. This is also to promote the transfer of the technology encouraging maximum benefits from its utilization in the future.

Ladies and Gentlemen,

Bilateral cooperations are playing increasingly significant roles. Apart from the Implementing Arrangement between OAEP and JAERI on the research cooperation in the field of radiation processing which has made significant progress satisfactorily, this workshop is a good case in point. With a network of information and experience, Japan has the capabilities to assist neighboring countries in numerous areas and range of circumstances and Thailand is not as exception.

On this auspicious occasion, I would like to compliment the Government of Japan, JAERI and JAIF who have contributed their time, resources and energies to make the workshop a reality. I wish you a very pleasant and fruitful stay in Thailand. And I wish all of you a great success.

Thank you.

1.2. Welcome Remarks

Nazir Abdullah

Acting Director General

National Atomic Energy Agency, Indonesia

Dr. Sato,

Mr. Takahashi,

Ladies and gentlemen,

I was very happy today to have all of you in this conference room. This is the second joint Workshop BATAN/JAERI/JAIF on the Industrial Utilization of Electron Accelerators. Since the first workshop two years ago, there are many progress had been achieved.

First of all, I would like to inform you that Indonesian government has paid a great attention on the development of radiation technology in Indonesia. At present, National Atomic Energy Agency has two pilot scale gamma rays irradiators with total power of 225 kCi Cobalt-60 gamma ray source and one pilot scale Electron Beam Machine of 300 keV.

The gamma rays irradiators were used mainly for research and development of sterilization technique and for food preservation as well as for modification of natural rubber latex.

We have known that the radiation sterilization technique is very helpful for our medical and pharmaceutical industries. One private company, INDOGAMA, has operated a new gamma ray irradiator at Bekasi area and ready tried to take over the former BATAN's service actively in the field of radiation sterilization. The new gamma ray irradiation facilities with an initial of power 400 kCi Cobalt-60 gamma ray source have been commissioned last month and its ready to be operated commercially.

An electron accelerator is another type of irradiation source which is very important for the production of polymer cross-linked products such as wire and cable insulation, heat shrinkable film and tube, polyethylene foam and rubber tire.

The electron accelerators or in more familiar we called electron beam machine is also useful for flue gas and sludge treatment. The two application are very important to demonstrate the contribution of radiation technology in environmental pollution control program.

I believe, this workshop will be capable to open our interest and even create a new idea about the application of EB machine as a new tools in our industrial line. A mutual interaction among the participants and of course the useful discussion between participants and speakers will make everything understandable and be more benefit each other.

Today we have our friends from Japan and China who will energize your idea about radiation technology. In addition, the speakers from BATAN will also give you some information about their activities in this field. BATAN is ready to cooperate with all of you to gain a benefit of the irradiation technology.

I would like to convince you that BATAN is not only made effort to introduce the application of Nuclear Power Plant in Indonesia as an alternative to overcome the shortage in electrical energy, but also made effort to introduce appropriate radiation technology in our modern industrial sector.

National Atomic Energy Agency concerns very much with the radiation technology into industrial line in Indonesia. In order to accelerate the technology transfer in appropriate manner, we are going to built an EB machine with a medium energy of 2 MeV later this year. The EB machine will be located at the Center for the Application of Isotopes and Radiation, Psar Jumat, Jakarta.

The EB machine is purchased from China and it is planned to be used as the research & development as well as a demonstration plant and to produce heat resistant cross-linked wire & cable insulation, sterilization, heat shrinkable film for packing material etc. man power training facility. In this opportunity, I would like to invite all of you, scientists, engineers, entrepreneur to joint us in the development of radiation technology in Indonesia and therefore makes significant profit for our country.

Ladies and Gentlemen,

I appreciate very much for a nice cooperation of our colleagues from Japan to jointly organize this workshop and I do hope the workshop will be useful and radiation technology will be developed in our industrial line in the near future.

Also, I appreciate for China's delegation to participate in this workshop. I hope during your brief stay here in Indonesia, all of our colleagues from Japan and China will be a pleasant, enjoyable and fruitful one.

I now have much pleasure in declaring open the BATAN/JAERI/JAIF Second Workshop on the industrial utilization of electron accelerator and wish you all every success.

Thank you.

1.3. Opening Address

S. Sato

Director General

Takasaki Radiation Chemistry Research Establishment

Japan Atomic Energy Research Institute

Mr. Suchat Mongkolpantha, Secretary-General of OAEP,
Distinguished Guests,
Ladies and Gentlemen,

On behalf of JAERI, JAIF and members of Japanese delegation, I would like to express our gratitude to OAEP for their excellent preparation and hosting of this Workshop on Industrial Utilization of Electron Accelerators. This Workshop was organized jointly by OAEP, JAIF and JAERI to exchange information on the status of research and development in the field of industrial application of radiation, mainly from electron accelerators. By the combined presentations from industries and research institutes, as is realized in the program of this workshop, I believe the mutual understanding in both countries will be promoted further, to the progress of radiation chemical industry.

As we observe the situation in many countries, the use of radiation as an important and very characteristic energy form in industries has been increasing. In Japan, there are about 200 electron accelerators for use in commercial processing and research.

We recognize that the application of atomic energy in general can be promoted efficiently, only by international cooperation. Today, the progress of nuclear industry in one country is strongly linked with the development in other countries. It's also the policy of the Atomic Energy Commission of Japan and our institute to promote the international cooperation with Asian countries. The cooperation between OAEP and JAERI in the field of radiation processing in the sewage sludge treatment technology will be reported in this meeting, resulting from the OAEP-JAERI cooperation. And it is our common understanding that JAIF has been contributing very much to the exchange of information from the industrial standpoint, including organization of this workshop.

I am convinced that the significance of this workshop will be understood by all the participants, as an effective and meaningful opportunity for the advancement of technology transfer to industry.

Thank you very much for your attention.

1.4. Opening Remark

M. Takehisa

Executive Director, Radia Ind. Co. Ltd.

Dr. Nazir Abudllah, Acting Director General of BATAN,
Distinguished Guests,
Ladies and Gentlemen,

It is a great honor and pleasure for me to deliver a brief opening remark on behalf of JAIF mission to the second workshop on industrial utilization of electron accelerators.

Firstly, I would like to refer a recommendation adopted at the panel discussion chaired by Mrs. Nazly Hilmy held in the first electron beam workshop in 1990.

There are 4 items, among which "there is a need to establish and maintain cooperation between Japanese industrial society and Indonesian industrial society" and "needs of workshop at regular intervals" were taken note for me, in addition to BATAN industry interaction and public education of atomic energy. I fully agree the recommendation for effective evolution of the radiation technology in industry.

I found that many attendants from Indonesian industries are in this second workshop on a series of electron beam application based on the recommendation. I appreciate efforts of BATAN and JAERI people who are committing to realize the 2nd workshop.

The one of significance of this workshop is that Japanese mission consists of both governmental, JAERI, and industrial, JAIF, sectors. For Indonesian side, I appreciate BATAN's effort for excellent preparation publicize the potential application of electron beams in various fields to industries which resulted in many attendants from the sector.

I would like to point out that there are some differences for information evaluation in governmental and in industrial sectors. I myself spent a long time in the former sector, now I am in the latter sector for almost 4 years. I am planning to talk electron beam sterilization not only from technical points but also from broad view points based on my experience in industry, and I expect all JAIF member will present a talk with industrial sense.

I really expect that the BATAN/JAERI/JAIF organized workshop will be useful for profitable evolution of industrial electron beam utilization in Indonesia. I also expect more commitment of Indonesian industrial sector to the workshop in the future.

Ladies and Gentlemen,

I hope this workshop would be not only effective means for long lasting cooperation in radiation application between both countries but also this workshop is effective for strength a mutual understanding and friendship for both countries.

Thank you very much for your attention.

1.5. Organization Committee Report

Mirzan T. Razzak

Head, Radiation Processing Division

Centre for Application of Isotopes and Radiation

National Atomic Energy Agency, Indonesia

Yang terhormat Dr. Nazir Abdullah, Acting Director general BATAN

Dr. Shoichi Sato, Director General Takasaki Radiation Chemistry Research Establishment, JAERI

Dr. Takehisa, JAIF

Mr. Takahashi, Manager International Nuclear Cooperation Centre, JAIF

Honorable Deputy Director General BATAN

Distinguished guests,

Ladies and Gentlemen, Good Morning,

As chairman of Organizing Committee of this function, it is my pleasant duty to welcome all of you to this second joint BATAN/JAERI/JAIF workshop on industrial application of electron accelerator.

First of all, let me report about the composition of the participants:

1. 16 Participant from Japan,
2. 30 Participant from Indonesian Companies,
3. 16 Participant from Research Institute, Universities and government officials,
4. 43 Participant from BATAN

Total becomes 105 participants.

Todays workshop will have 10 speakers i.e. 7 speakers from Japan and 3 speakers from Indonesia.

It is divided into 3 session. In session 1, we have 3 speakers from Japan who will talk about general view and economical aspect of industrial accelerator. In session 2, we have one speaker from Japan and 2 speakers from Indonesia. They will talk about the potential and the real industrial applications of EB processing. In session 3, we are going to have two speakers from Japan and one speaker from Indonesia. In this session we may have information about the emerging application or the most promising application of EB accelerator.

I do hope, all participants could get some idea about the future application of EB accelerator in Indonesia and I would like to invite all of you to be active in discussions.

It is my duty to acknowledge the support given by the JAIF, JAERI, CAIR-BATAN and several other to realize this workshop. Since the Honorable Director General BATAN, Mr. Djali Ahimsa is still in Vienna, it is also my duty to express my appreciation to the Honorable Acting Director General BATAN, Dr. Nazir Abdullah to take time off to officially open the function and give us the benefit of his advice.

Thank you and have a nice workshop.

1.6. Progress and Development of EB–irradiation in Japan

Y. Sasaki

Advisor, Yazaki Co., JAIF Representative

Mr. Chairman,

Ladies and Gentlemen,

Thank you very much for your kind greeting and warm welcome. It is a pleasure to be here to have the workshop on the Utilization of Electron Beams. On behalf of Japan Atomic Industrial Forum, I would like to speak some remarks.

Allow me, I would like to introduce myself in short.

I am a member of Yazaki Corporation, a commercial company in Japan, which mainly manufactures automobile parts such as electric wires and also meters for that.

I feel good familiarity with you and your country, because now our corporation has five factories in around of Bangkok since establishment of the first factory in 1962 and about 7,500 Thai peoples are working with us there, and also they contribute your country by exporting some of their products.

Since the famous finding of cross-linking reaction of polyethylene by Professor A. Charlesby in 1950, wide research works in this field have been deployed in the world ambitiously. These researches have given us much important information on the progress of radiation utilization in science and industries.

In Japan, the study-group in this field was organized in 1955 and development researches were initiated in 1957. Since then, various research works have been deployed looking for many kinds of the application year by year steadily.

Since the first EB-machine used in Japanese industry, it has passed about 30 years. So far, many researchers and engineers have grappled to overcome with the many difficulties and troubles encountered in the development process.

Nowadays, the total number of EB-machine for radiation processing including researches and developments in Japan are estimated over 180 sets.

Meanwhile, along with the progress or the development of fundamental and industrial researches, EB-machine and irradiation facilities have been improved very much year by year through mutual collaboration among researchers and engineers and we can now have the excellent EB-machine and irradiation facilities.

Nowadays, we can enjoy new high quality materials such as cross-linked urethane and fluoro elastmer produced by a high technology as a radiation irradiation in every day life. In future, EB-machines will be more and more necessitated according to the excellent performance of cross-linked products and for many potential applications.

I believe that these accumulated knowledge and techniques will explode into the big leading industry someday in future.

I hope these our accumulated knowledge, experiences and technologies will be transferred to your country successfully through this workshop and benefit each other.

It is our pleasure to have this kind of meeting.

Thank you.

2. PRESENTED PAPERS

2.1. General View of Electron Accelerator Utilization

S. Sato

Takasaki Radiation Chemistry Research Establishment
Japan Atomic Energy Research Institute

As radiation sources, electron accelerators have become widely used for processing of polymer products and other materials, along with cobalt-60 gamma sources which are used mainly for sterilization of medical products. With increasing reliability and availability of the electron accelerators (EB machines), their merits over gamma sources are recognized: variable energy ranges, high energy utilization efficiency, high outputs and no generation of radiation when switched off.

EB machines are used industrially for manufacturing of heat-resistant wires and cables, foamed polyolefins, heat-shrinkable tubes and sheets, for pre-vulcanization of tire rubber components, and also for a few kinds of surface curing (hardening of surface coatings). It is noted that the major chemical reactions involved are all crosslinking reactions of polymers. There are of course other radiation chemical reactions applied: polymerization, grafting reaction, and decomposition of polymers.

By absorption of radiation energy, active species are formed in materials. Selective reactions of these active species can be applied practically for a number of processes. The removal of sulfur and nitrogen oxides in flue gases from coal-burners, heavy oil-burners and municipal garbage incinerators have been under process development recently in Japan and some other countries. Sterilization or pasteurization of medical products and other organic materials may also be considered decomposition or modification of biological polymers such as DNA, protein or enzyme.

New radiation chemical products are in the process of industrial application, including radiation vulcanization and grafting of natural rubber latex, production of selective adsorbent materials for uranium in sea water, and those for deodorant use, and battery separator membrane by grafting technique, and several others.

Development of efficient X-ray conversion techniques of high energy electrons will further stimulate wider uses of the EB machines.

2.2. Introduction to Industrial Electron Acceleratrors

M. Suzuki

Nissin-High Voltage Co., Ltd.

I. INTRODUCTION

It was in 1960's that radiation was industrially irradiated to improve materials. For twenty and several years from then till now, an electron accelerator (hereinafter referred to as "EB system") which is a principal radiation source has been making rapid progress as principal part of large scale industrial installations capable of economically and stably producing a large quantity of products. Nissin-High Voltage Co., Ltd. (NHV) is a worldwide collective manufacturer of EB systems covering all energy regions ranging from low energy to high energy in industrial uses. Hereinafter, both current status of utilization of EB's in the world and that of EB systems of NHV are introduced.

II. UTILIZATION OF ELECTRON BEAM

1. Utilization of low-energy electron beam

Fields utilizing low-energy EB systems for production or for research and development are as shown in Fig.1. Low-energy electron beam has a energy of 150 to 300 keV in general. As a result, the utilization there-of is centralized to processing, i.e., what is called converting on the surface of thin layers, such as improvements of films and surface of sheets and curing of liquid resins on base materials, e.g., films, papers, metallic plates, etc.

In particular, it is fields of products obtained by utilizing curing of so-called liquid resins such as top coats produced for the purpose of obtaining gloss and protection on the surface of base materials, printing inks, adhesives for lamination and binders for magnetic media, and fields of products obtained by utilizing graft polymerization techniques such as super absorbent non-woven fabrics and flame retardant cloths that have made rapid progress in recent years.

2. Utilization of medium-and high-energy electron beams

Medium and high-energy electron beams (350 to 5,000 keV herein) are utilized on a large scale as means indispensable to crosslinking of thin wire insulating materials, foamed polyethylene, heat-shrinkable tubings, rubber for tires, and the like. On the other hand, as means for sterilization of foods, medical supplies, packaging materials, and the like they are beginning to counteract gamma rays from cobalt 60 which is unstable in view of supply and price. Furthermore, in the field of desulfurization and denitrification of exhaust gases contributory to protection of global environment which has often been proposed in recent years, researches and developments for realization of EB process are being performed extensively in Japan, U.S.A., Europe, etc.

As is apparent from Fig.1, approximately 580 EB systems in all belonging to the above energy region have already been supplied to markets covering Japan, North America and Europe since 1960. And in case that EB process on a full scale is realized in the fields of the above described sterilization, desulfurization and denitrification of exhaust gases, and in view of effective utilization of resources, sterilization and conversion to fertilizer of sewage sludges, decomposition and conversion to alcohol of biomass resources such as starch and cellulose, and the like, there can be further expected substantial rise in demands for EB systems.

III. RELATIONS AMONG ACCELERATION VOLTAGE, DEPTH-DOSE AND APPLICATION FIELDS OF EB

Fig.2 shows the Depth-dose curves for accelerated electrons. The energy of accelerated electrons diminishes after they penetrate a certain depth of the irradiated material. In order to present a penetration capability of electrons, Depth-dose curves are widely used. These determine the relationship between the penetration depth in a material of unit specific gravity and the relative dose given to the material. Regarding the maximum thickness of a treated material, in many cases a thickness which corresponds to 60% of the relative dose on a Depth-dose curve is chosen. In the case of curing, 80% is selected. When the material has a density of ρ, measurement in the horizontal axis of the Depth-dose curve should be devided by ρ.

Fig.3 shows the optimum thickness for double bombardment (both sides irradiation) . Thicker materials can be treated by lower acceleration voltage irradiation from both sides.

Fig.4 shows the relation between acceleration voltage and application, and the relation between dose and application.

Ⅳ. EB SYSTEMS

1. Low-energy EB system

The low-energy EB system(commercial name of NHV : Area beam type EB system "CURETRON") is a processing system that accelerates thermal electrons which are emitted from an electron gun having a filament arrangement of the length appropriate for the width of irradiated articles by applying a high DC voltage and then irradiates a flat electron beam taken out of a thin metal foil into air. It is principally composed of DC power supply unit, acceleration unit, conveyance unit, control unit, and the like.

Shielding against bremsstrahlung X-rays which are generated upon irradiation of electron beam is easily done since the energy of electron beam is as low as not more than 300 keV. Accordingly, self-shielding method where the acceleration unit and irradiation chamber are shielded from X-rays with lead plates and steel plates is employed. Therefore, this system is small-sized and compact.

Fig.5 and 6 show Area Beam Type EB systems, "CURETRON". The total number of the systems supplied is shown in the parts, where symbols, "CURE" and "R & D", are noted, of Fig.7.

2.Medium-and high-energy EB systems

EB systems belonging to this energy region ranging from 350 to 5,000 kV are what is called scanning type where spot-like electron current that are accelerated in an acceleration tube is scanned within the width of irradiated articles. In the same manner as the low-energy EB system, these systems are principally composed of DC power supply unit, acceleration tube unit, conveyance unit, control unit, and the like.

(1) Principle and construction

Fig.8 and Fig.9 show a principle and construction of the EB system (also called EPS : Electron Processing System). This system produces thermal electrons from cathode in a high vacuum, accelerates (give energy to) them in an acceleration tube by means of a high voltage electric field into a beam of high energy electrons, and this electron beam which is taken out in the open air after passing through a titanium foil is irradiated to a material. As a result, the irradiated material undergoes a chemical reaction.

Fig.10 ~ 14 show the main components of the EB system.

(2) Shielding against X-rays

X-rays generated as bremsstrahlung when electrons collide with material are quite high in penetrating power and harmful to the human body. Therefore, the shielding against X-rays is necessary.

Fig.15 shows an example of concrete-shielded type X-ray shielding room for the EB system of 800kV and higher energy.

Fig.16 shows 800kV 35mA selfshielded type EB system for the crosslinking of wire and cable insulations. This EB system is designed for reduced floor space and is able to be readily relocated to meet the needs of changing production lines. NHV has succeeded in producing such selfshielded EB system up to 800kV.

(3) Electric power efficiency of the EB system

The DC power supply of NHV's EB system adopts a Cockcroft-Walton circuit and the high frequency power supply applies the solid state inverters. The frequencies of the inverters are 1kHz or 3kHz. 1kHz is for system up to 1.5MV and 3kHz is for above 1.5MV. Therefore, this system produces good electric power efficiency. The electric power conversion efficiency from the wall (commercial 50 or 60Hz) to the beam power is 85% for the system up to 1.5MV and 75% above 2MV as shown in Fig.17.

(4) 5MV EB system

Fig.18 shows a 5MV 30mA EB system delivered to Radia Industry Co., Ltd. in Japan for the sterilization of the medical supplies. The DC power supply uses a Cockcroft-Walton circuit with pressurized SF_6 gas in the vessel using a relatively low frequency which provides low loss and stable operation. Therefore, this EB system has a high electric power conversion efficiency and a high reliability.

This 5MV 30mA EB system can also generate intense X-rays equivalent to a 2.5 million curie cobalt 60 source by using X-rays target.

The total number of the EB systems of this energy region supplied is shown in the parts, where symbols except "CURE" and "R & D", are noted, of Fig.7. It shows remarkable increases in the fields of wires, tires and foams.

V. POSTSCRIPT

The application field of electron beam irradiation is expected to expand and develop toward 21 st century, because of its many merits which other sources such as thermal rays, ultraviolet rays, gamma rays, etc. do not have.

(July, 1992)

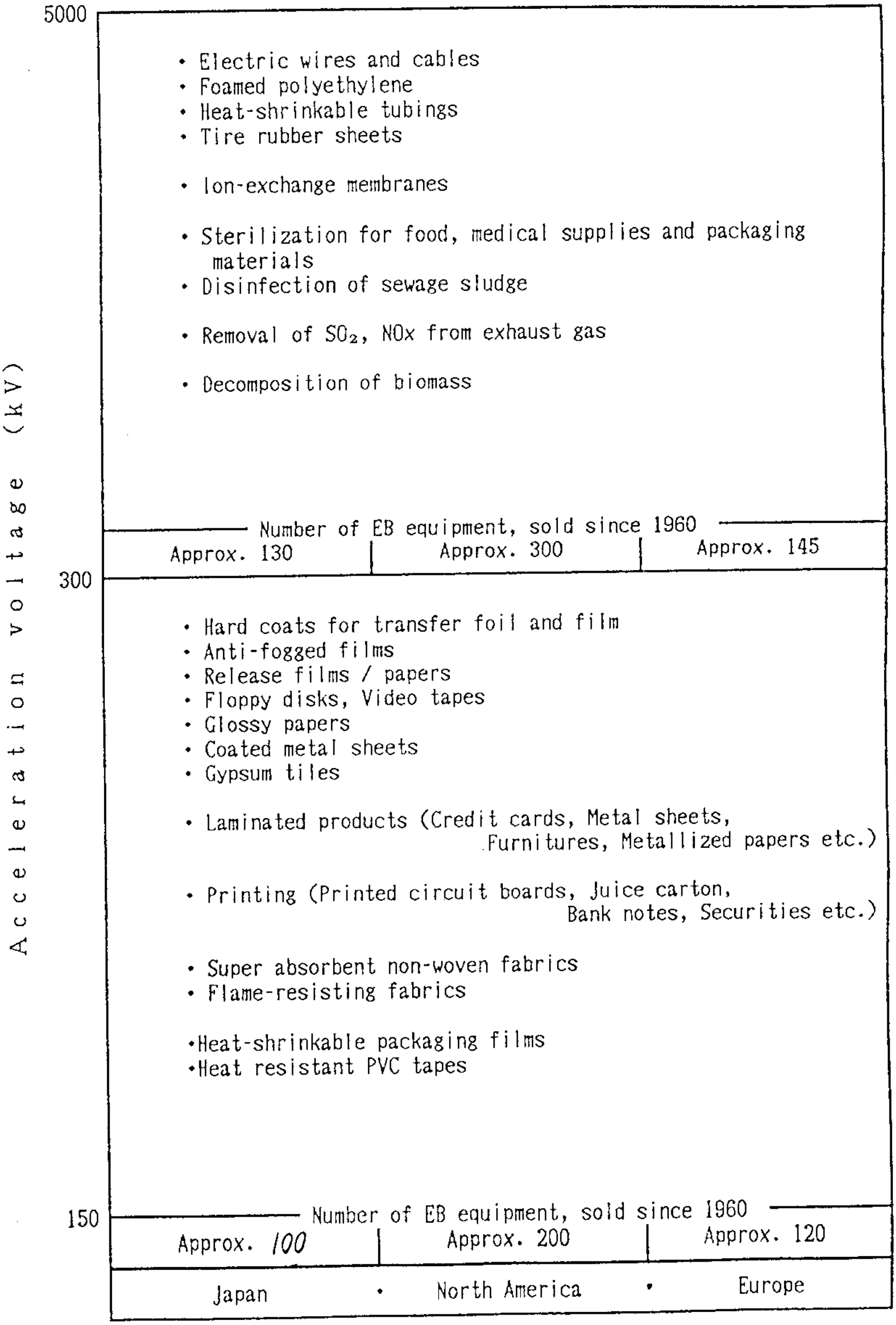


Fig. 1 Relation between EB energy and application fields (including R & D)

Depth Dose Curve

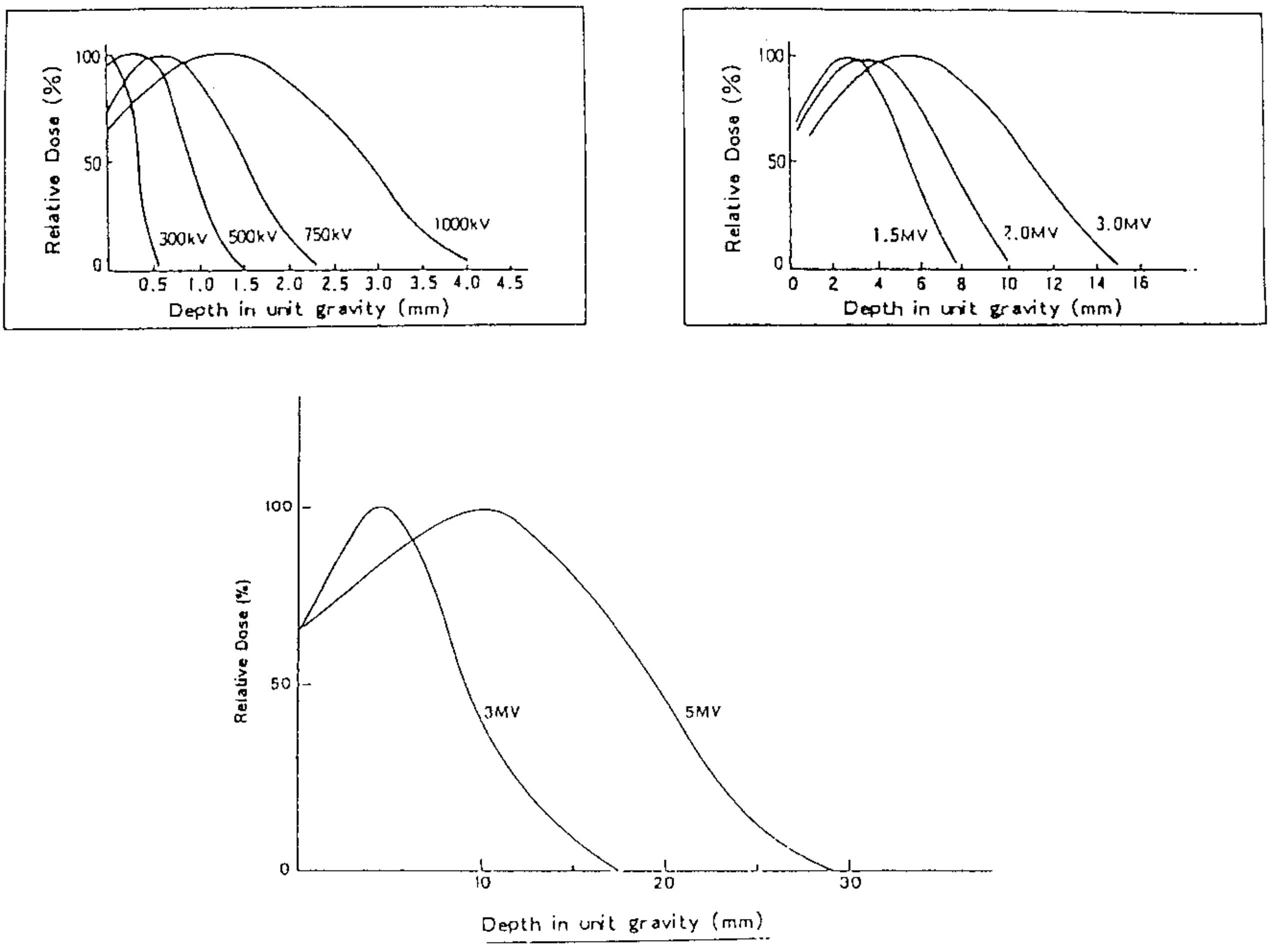


Fig. 2

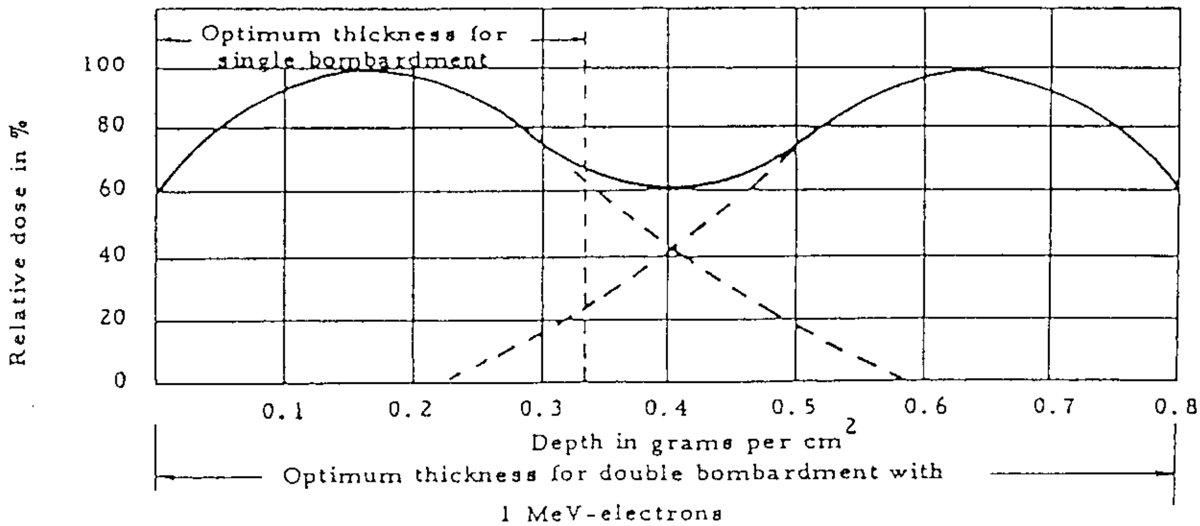


Fig. 3

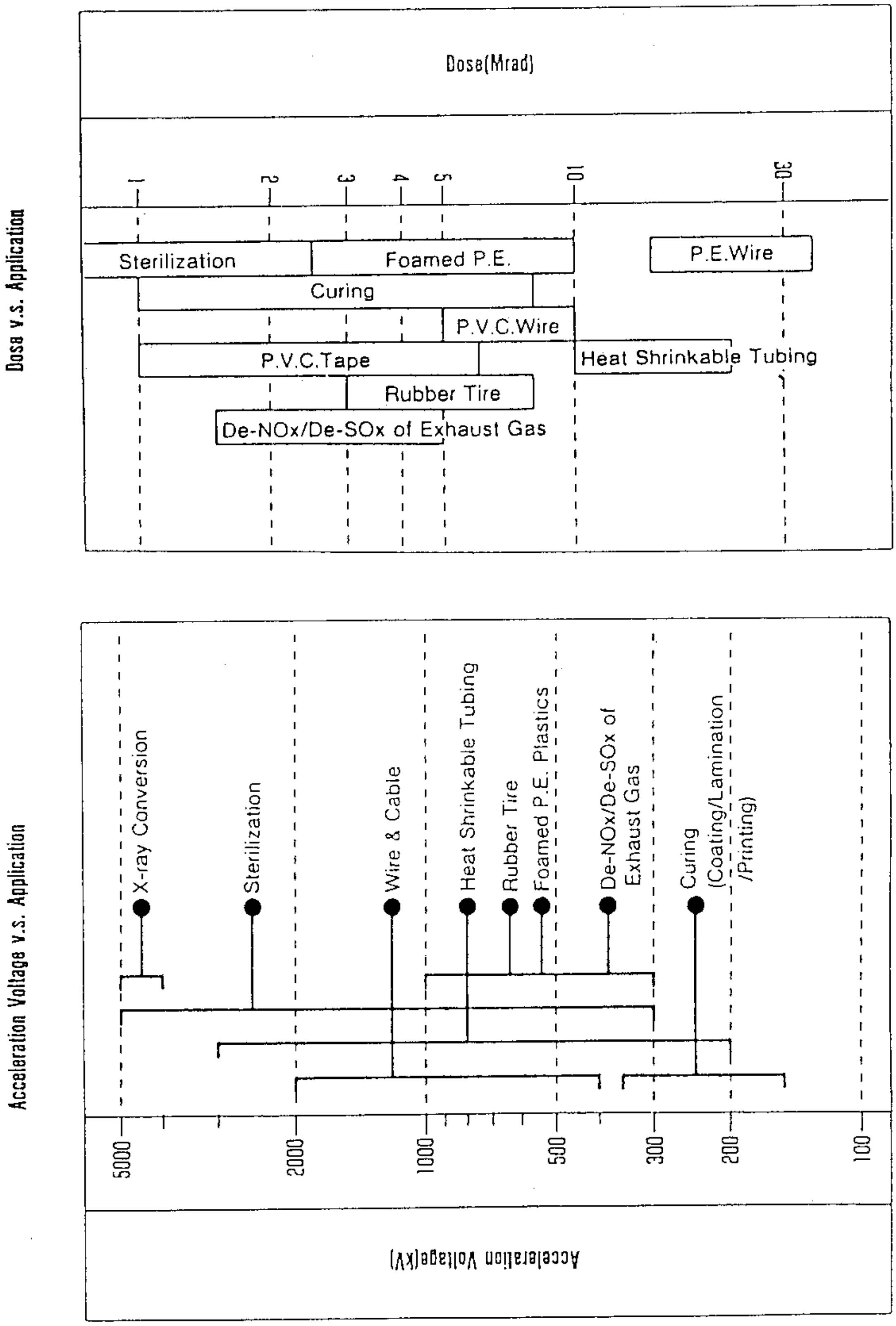

Dose v.s. Application
Dose(Mrad)
1
2
3
4
5
10
30
Sterilization
Foamed P.E.
P.E.Wire
Curing
P.V.C.Wire
P.V.C.Tape
Heat Shrinkable Tubing
Rubber Tire
De-NOx/De-SOx of Exhaust Gas
Acceleration Voltage v.s. Application
X-ray Conversion
Sterilization
Wire & Cable
Heat Shrinkable Tubing
Rubber Tire
Foamed P.E. Plastics
De-NOx/De-SOx of Exhaust Gas
Curing (Coating/Lamination /Printing)
5000
2000
1000
500
300
200
100
Acceleration Voltage(kV)

Fig. 4

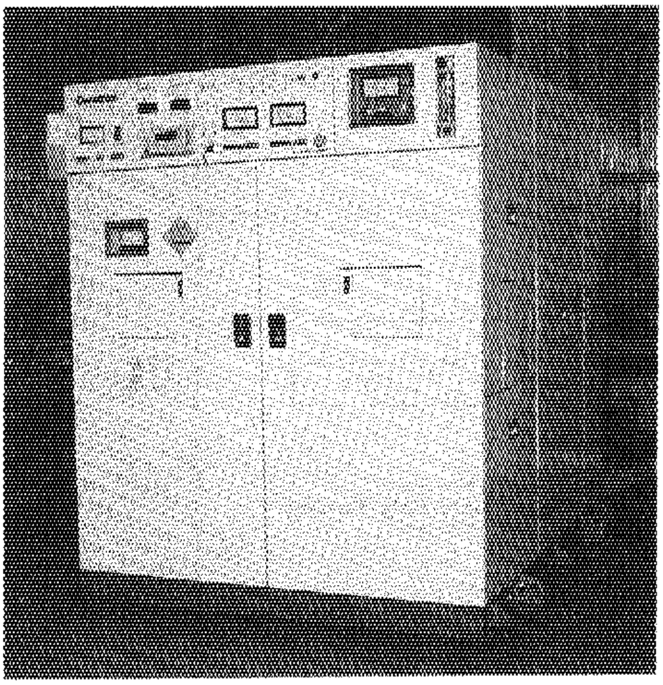


Fig. 5 Area beam type EB system
200kV 20mA 15cm

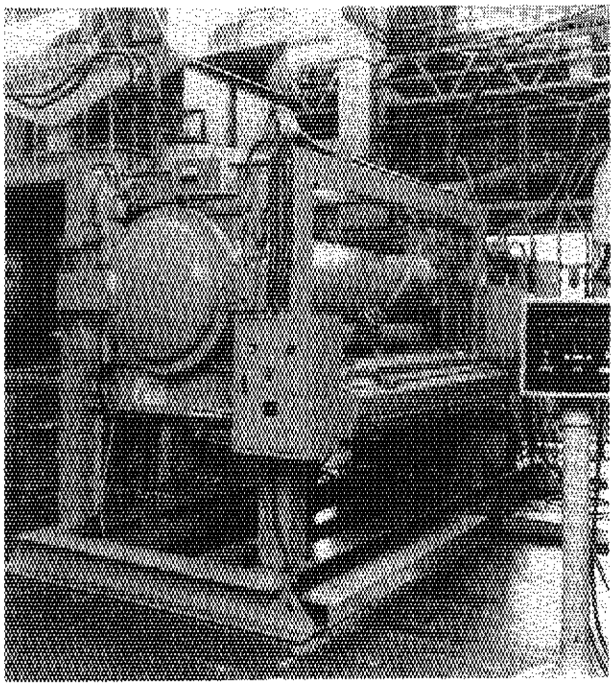


Fig. 6 Area beam type EB system
250kV 600mA 160cm

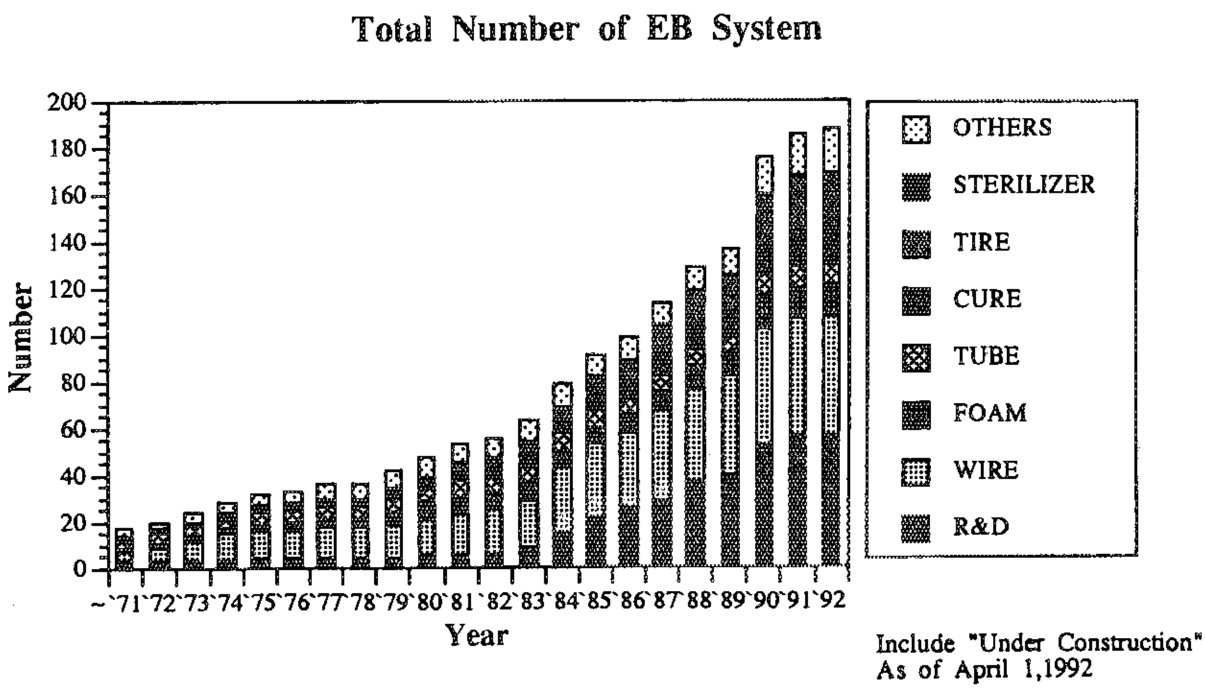


Fig. 7 Aggregate number of EB system

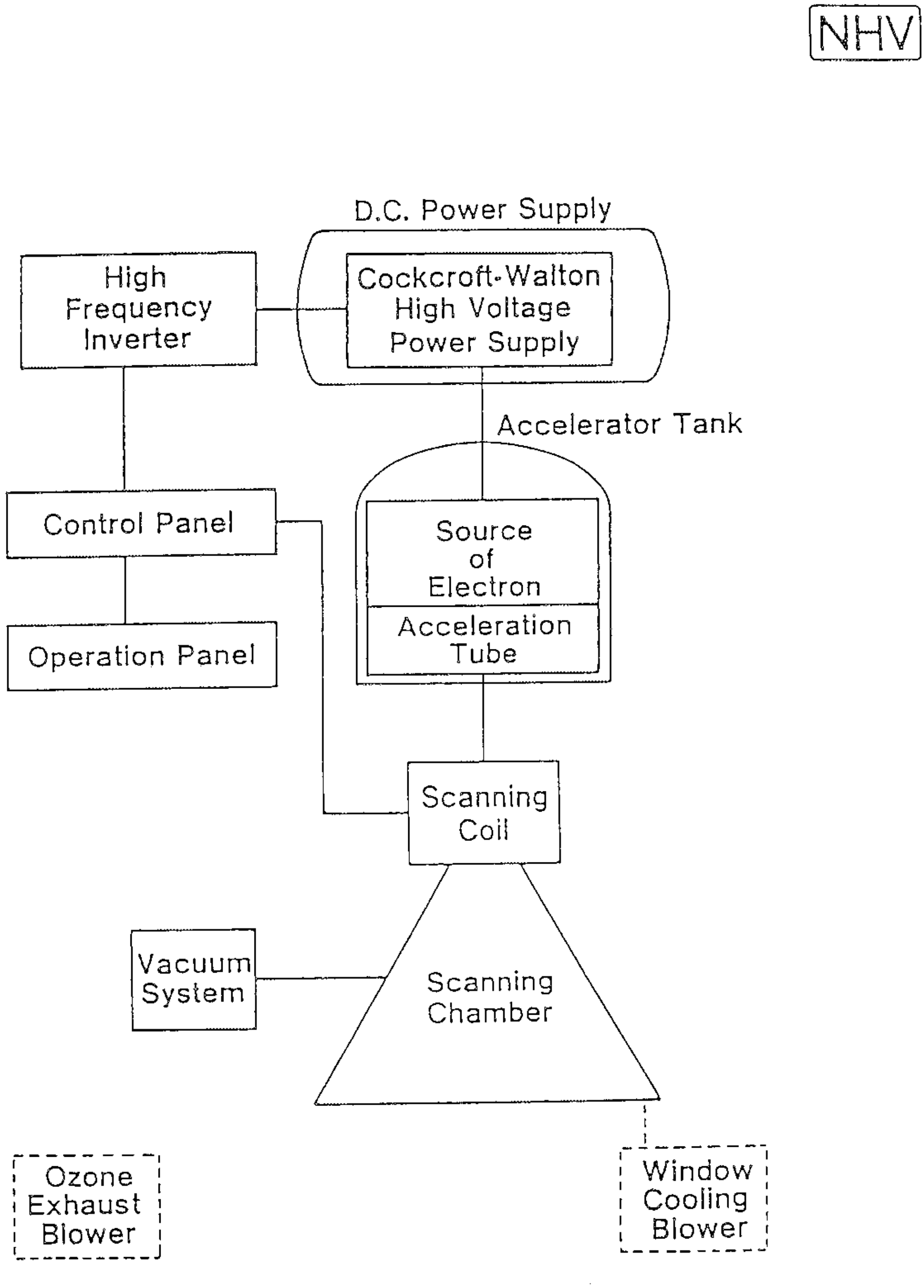


Fig. 8 Block diagram of EPS

Principle of EPS

Electrons originating from a cathode, and accelerated in high vacuum acceleration tube, emerge into air after passing through a titanium foil to irradiate material.

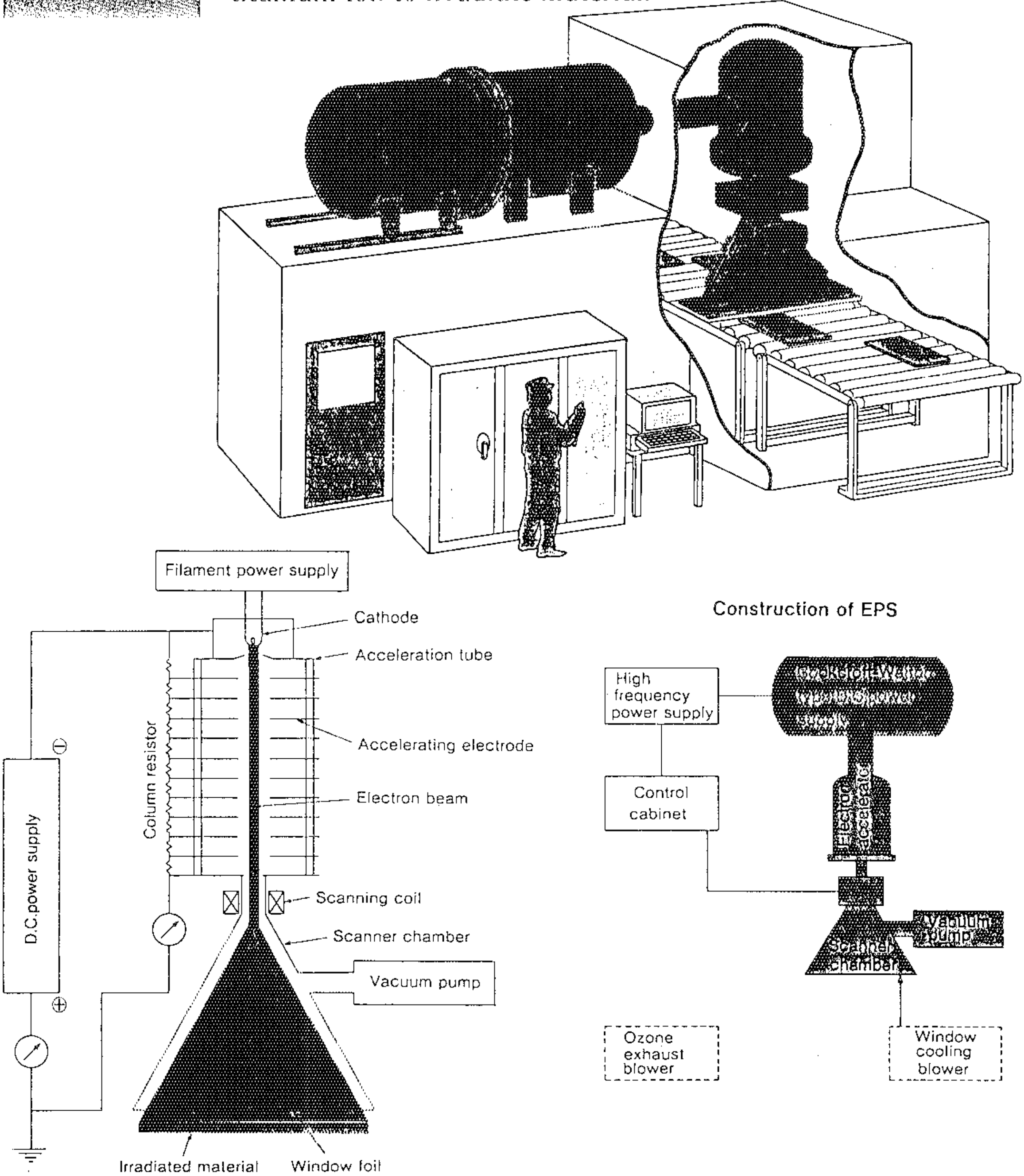


Fig. 9

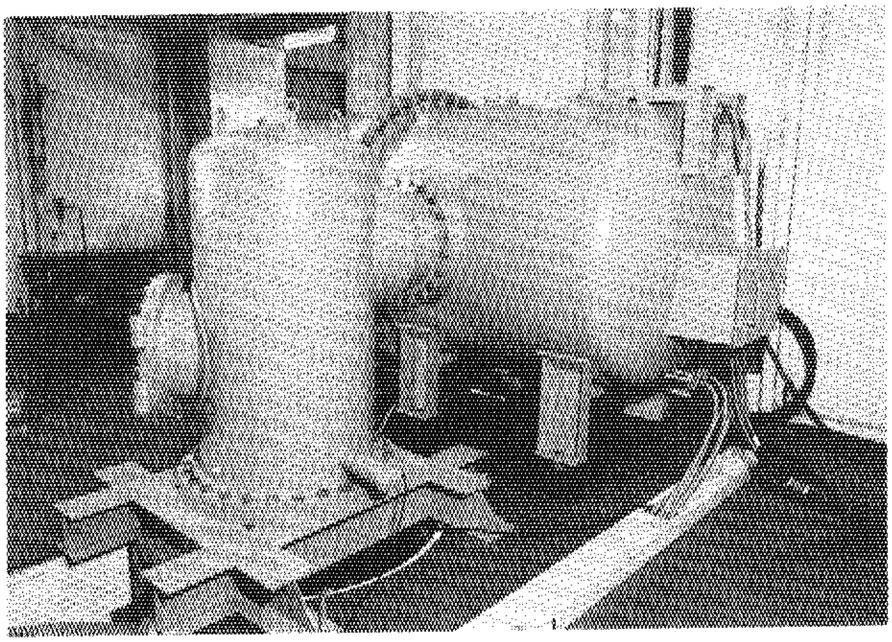


Fig. 10 DC power supply and accelerator tank

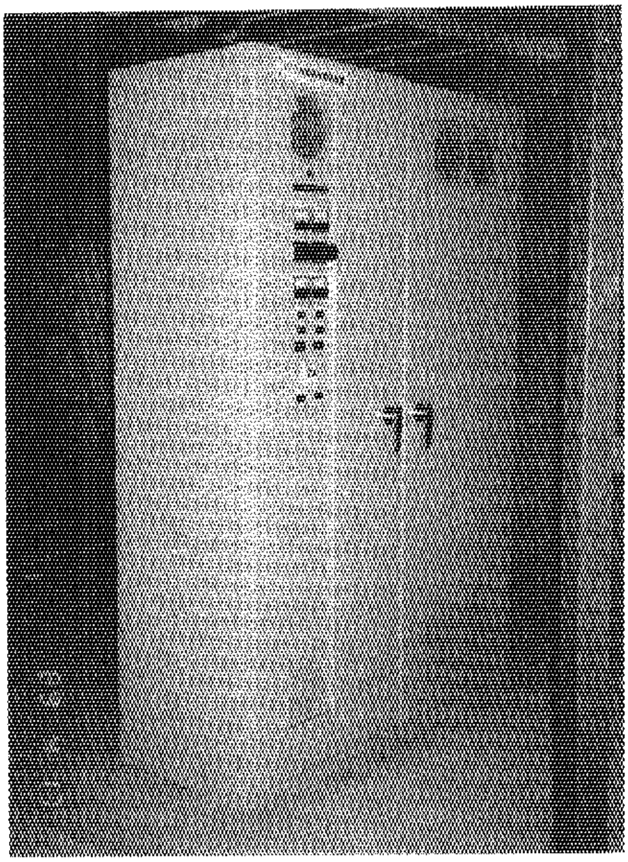


Fig. 11 High frequency inverter

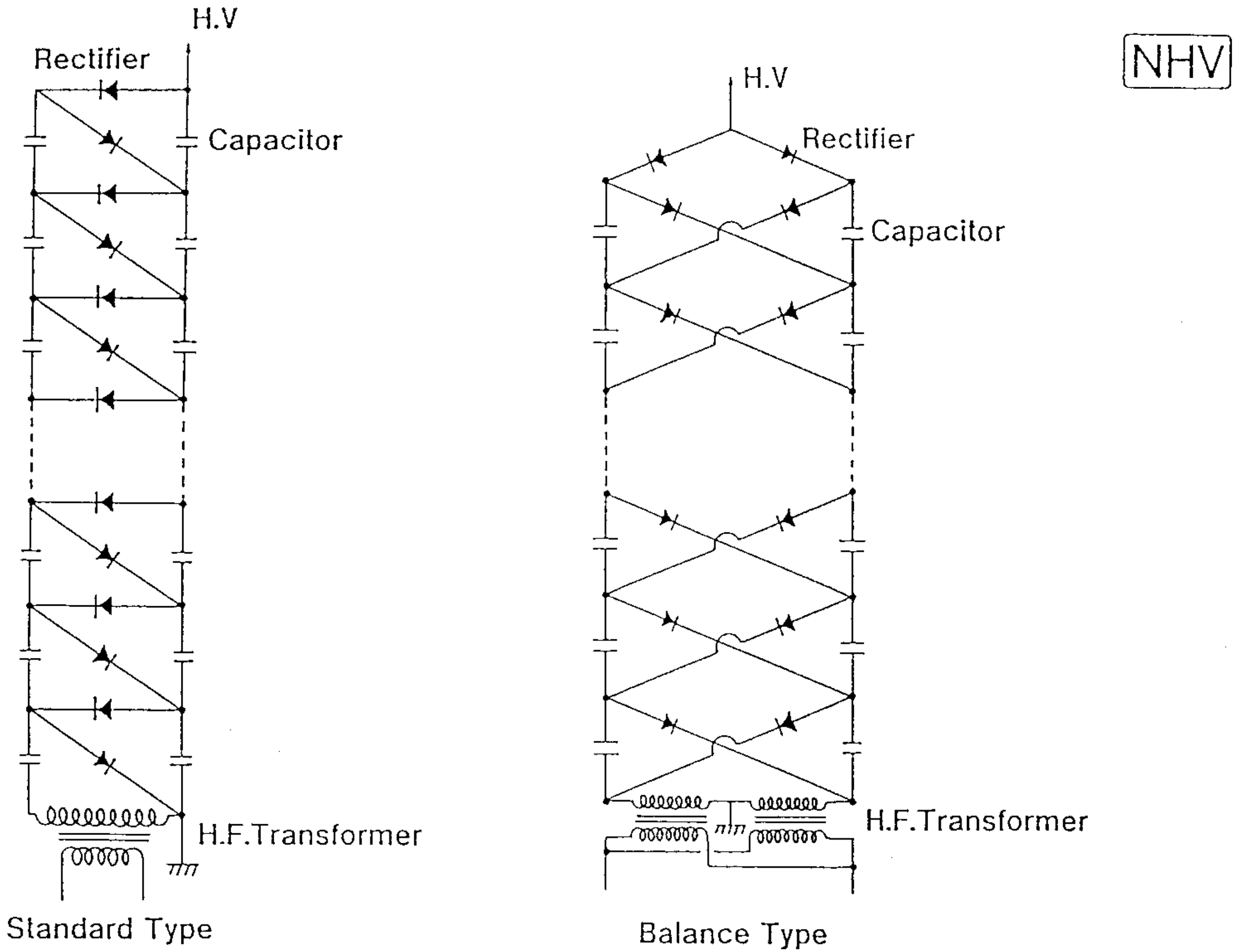


Fig. 12 Cockcroft-Walton circuit

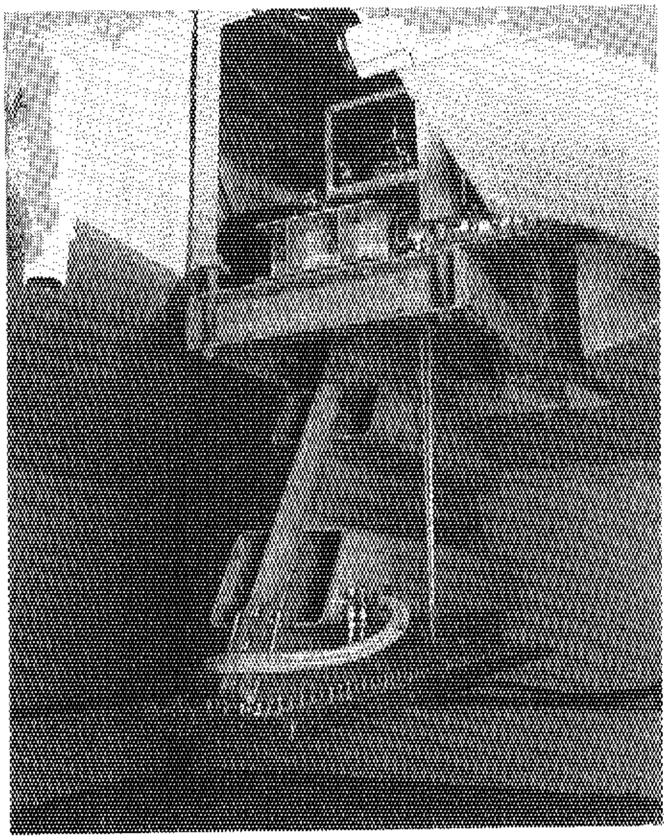


Fig. 13 Scanning chamber

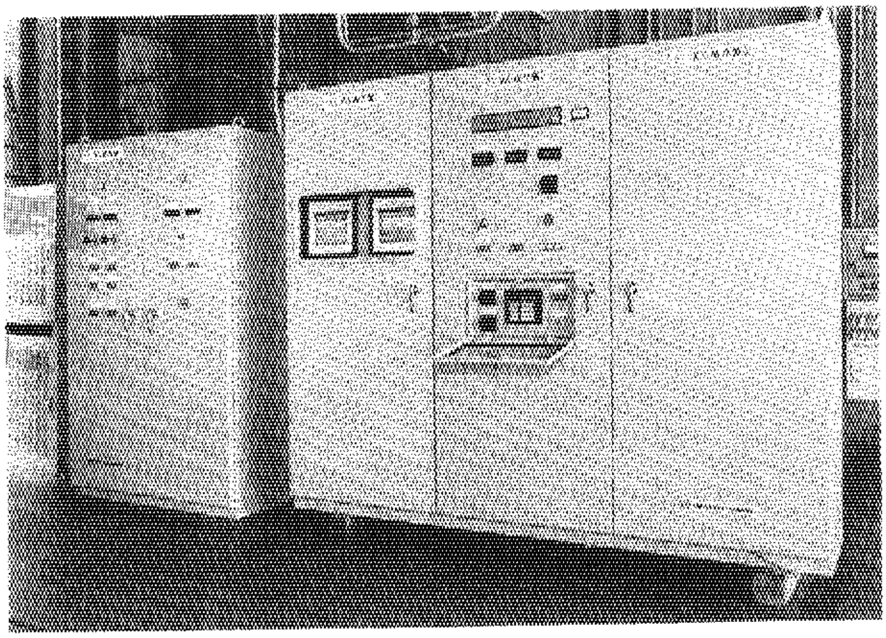
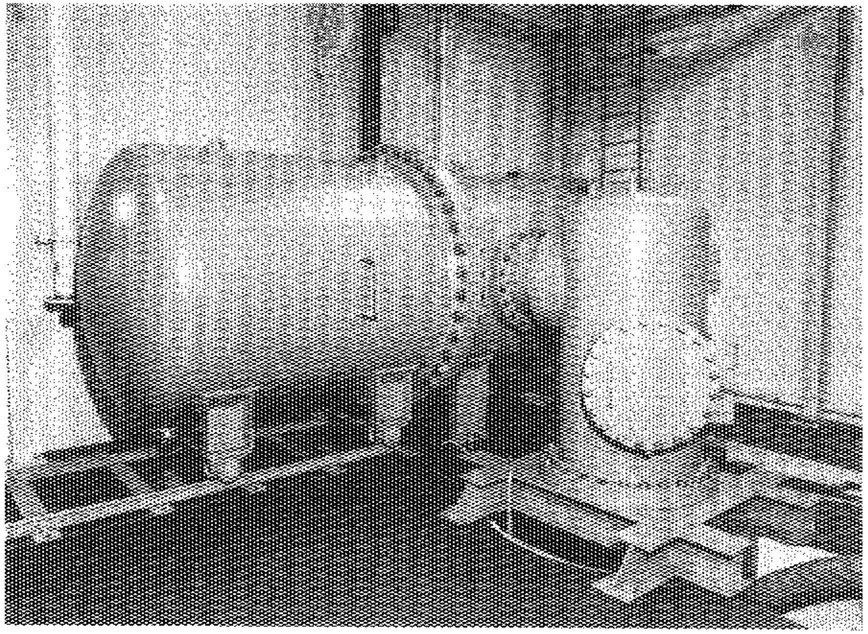
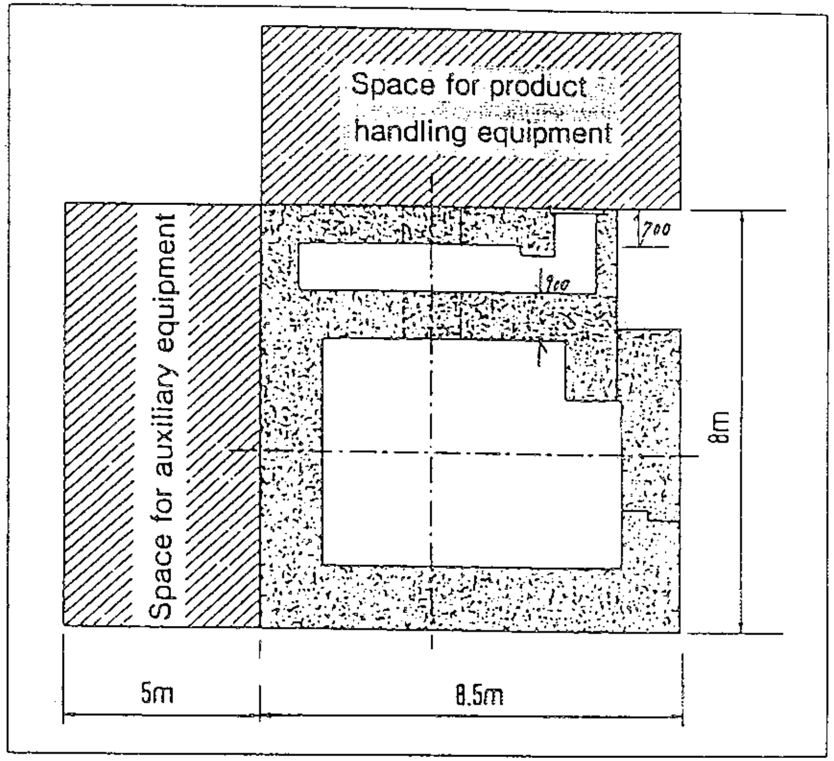


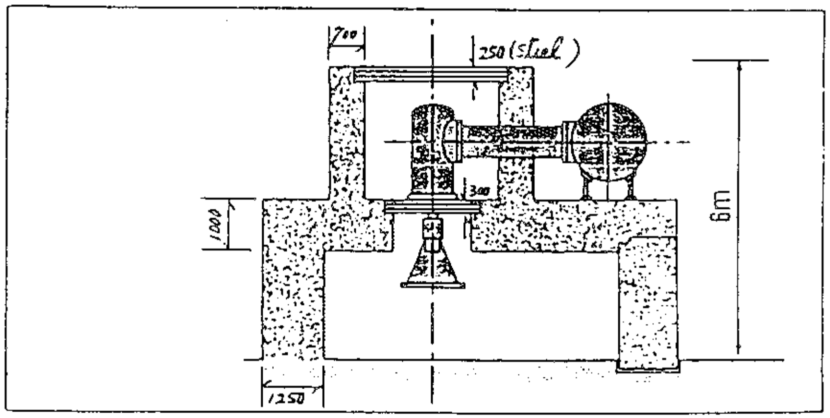
Fig. 14 Control panel



Typical X-ray shielding for wire/film (800kV)



X-ray shielding plane view



X-ray shielding sectional view

Fig. 15 Concrete-shielded type

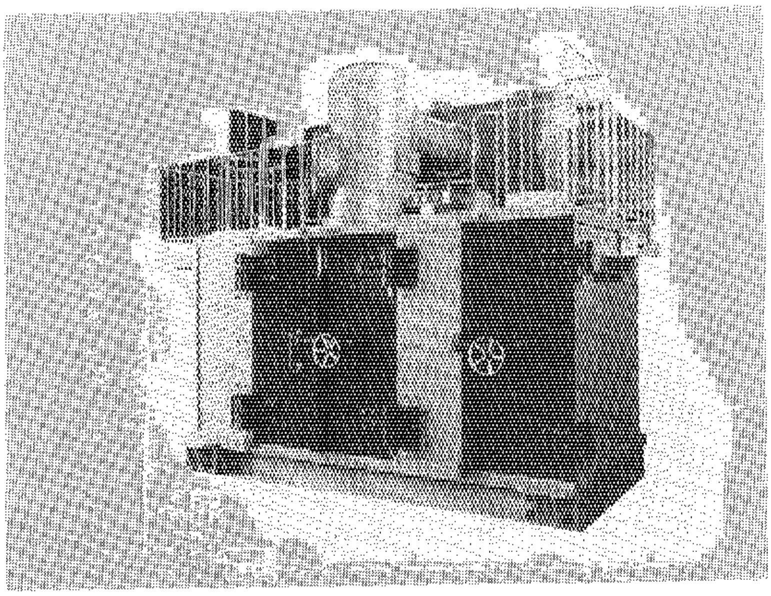


Fig. 16 Self-shielding type EB system
800kV 35mA 60cm

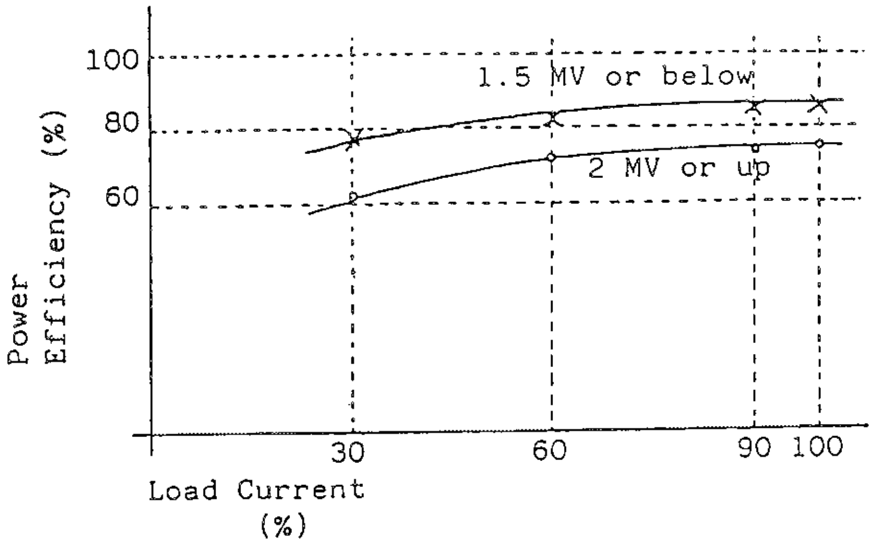


Fig. 17 The electric power conversion efficiency from the wall to the beam power

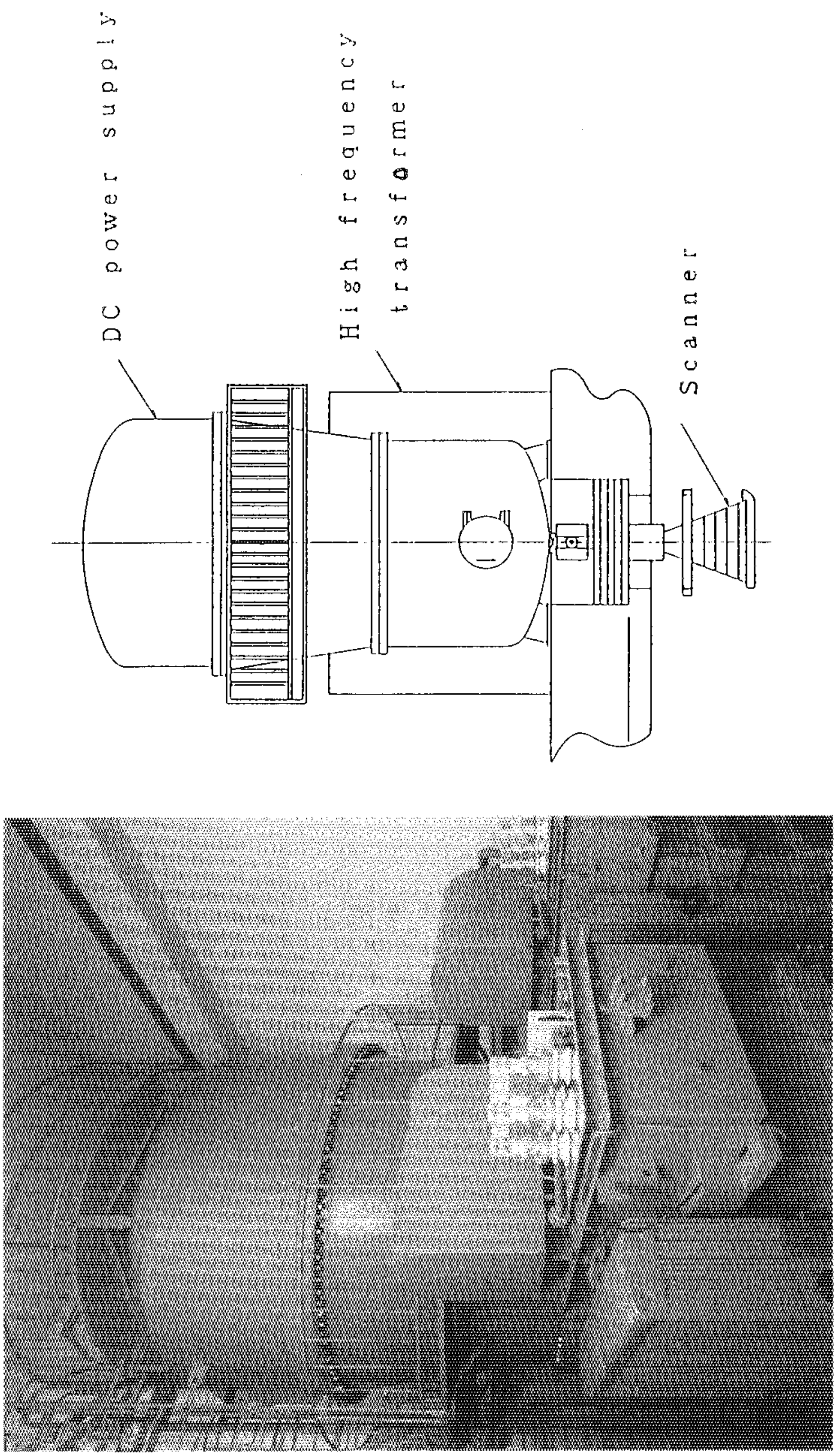


Fig. 18 5MV 30mA EPS

2.3. Economical Aspects of Industrial Electron Accelerators

T. Doi

NKK Corporation

1. Introduction

Utilization of industrial electron accelerators has been spread remarkably in many fields of industry in recent years. This popularization was brought by the advantages of electron irradiation ;

(1) Technological capability
(2) Economy
(3) Compact facility
(4) Easy operation, maintenance
(5) Safety
(6) Environmental protection

At present, electron irradiation is applied to the industrial fields as shown in Fig. 1.1. The output power of electron accelerator is up to 100kW, but in the newly developed fields which are considered to spread in near future, the more output-power will be required. For example, some hundreds of kW accelerator are necessary in flue-gas treatment technology.

As processing scale becoms larger, electron irradiation seems to be more advantageous, but that advantages should be evaluated individually.

In this paper, in order to prove the advantages of electron irradiation, economical evaluation in comparison with several conventional methods of some industrial fields are introduced.

2. Feature of electron irradiation

Electron irradiation is energy transfer which causes radio chemical reactions. Energy and current of electron beam depend on reaction and mass-flow of target materials. Necessary dose in various industrial fields distributes as shown in Fig. 2.1, from few kGy to several hundreds kGy. This is related to electricity consumption of electron accelerator and it's economy.

Secondary X-rays are emitted as target materials are irradiated with electron beam. Electron accelerator and irradiation apparatus are equipped inside of radiation shield for biological protection as shown in Fig. 2.2. For economical evaluation, electron accelerator and radiation shield should be taken into consideration.

Radiation dose rate at the outside of radiation shield is limited to a certain level by Government regulation. It is less than the level of one breast photo by X-ray as shown in Fig. 2.3. In actual plant, radiation dose rate at the outside of radiation shield is less than the regulated value, as same level as natural background.

3. Economical Evaluation

One of the most important parameter for the evaluation of industrial processes is economy. The spread of electron irradiation method is mainly due to economy.

In this chapter, economical advantages of electron irradiation method are introduced from several papers.

Electron irradiation method is compared to conventional method or other radiation processes in view of capital cost, operation cost including amortization and product cost in the field of

(1) Rubber crosslinking
(2) Cable crosslinking
(3) Paint curing
(4) Sterilization of medical products

3.1 Rubber crosslinking

(1) Automobile-tire production

About 70% of new rubber is used for automobile-tire production in Japan. More than 80% of radial tire are irradiated with electron beam.

Structure of radial tire is shown in Table 3.1.1. Electron irradiation contributes to reduction of rubber amount, manufacturing stabilization and quality stabilization.

Rubber sheets are irradiated with electron beam in the irradiation facility shown in Fig. 3.1.1.

(2) Economical evaluation

Energy cost (Utility cost / productivity) and product cost of rubber sheet crosslinking by electron irradiation are compared with that of other conventional methods, rotecure, micro-wave, thermal and molten-salt method for contineous process.

Comparison of electron irradiation and rotecure is shown in Table 3.1.2.

Electron accelerator of 1.5MeV×50mA is used to attain 100kGy of absorbed dose.

Product cost of electron irradiation method is 1/6 and energy cost is 1/6 of rotecure method.

Energy cost comparison is shown in Table 3.1.3. In this table, relative energy costs are shown. Energy cost of electron irradiation method is 1/2 ~ 1/9 of other conventional methods.

From the above, electron irradiation method is much more advantageous than other methods not only in productivity but also economy.

3.2 Cable crosslinking

(1) High-voltage cable production

Electron irradiation crosslinking in cable production is popular technology in Japan. There are already 20 ~ 30 accelerators of total power more than 1000kW. But these are only for thin cables not big high-voltage cables.

Cables are stretched under the accelerator and irradiated with electron beam as shown in Fig. 3.2.1.

Electron irradiation method of high-voltage cable is considered to be more economical rather than that of thin cable.

In this chapter, energy cost of electron irradiation crosslinking method of high-voltage cable is compared to that of other methods.

(2) Economical evaluation

There are several methods for crosslinking of high voltage power cable. Energy costs of four methods are compared in case of high voltage power cable of 6.6kV, 22mm^2 CV core as shown in Table 3.2.1.

In electron irradiation method, accelerator of 1.5MeV×25mA is used to attain 250kGy.

Energy cost of electron irradiation method is very cheap compared to that of other methods.

For saving energy, electron irradiation method is obviously much more advantageous.

3.3 Paint curing

(1) Feature of curing

In the field of paint curing, electron irradiation is applied, but it is only for high-polymer paint of radical grafting, not for all kinds of paints.

Feature of curing is shown in Table 3.3.1. Electron irradiation method has high productivity but limited to planner painting and special paints. Schematic view of electron irradiation curing apparatus is shown in Fig. 3.3.1. In paint curing, paint must be irradiated with electron in special gas atmosphere.

(2) Economical evaluation

Curing cost of electron irradiation method is compared to that of thermal curing method in case of veneer plate production, 90cm × 180cm in size and 4000plates per day.

Two cases of different dose 17kGy and 35kGy are investigated in this chapter.

Results are shown in Table 3.3.2. Product cost in case of 17kGy, is less than 1/2 of thermal curing cost, and cost in case of 35kGy, is about 20% less of thermal curing cost.

Electron irradiation method is more economical than thermal curing method if dose is less than about 35kGy.

Another cost comparison of electron irradiation of 20kGy with thermal curing by difference of operation time is shown in Table 3.3.3. Electron irradiation is economically superior to thermal curing at any operation time. And as productivity increases, electron irradiation becomes more advantageous.

3.4 Sterilization of medical products

(1) Medical sterilization

Because of development of medical technology, large amount of medical products should be sterilized. Ethylene-oxide was used for chemical sterilization, but recently it is considered to be harmful. So, sterilization by radiation was remarkably developed.

In this chapter, sterilization by electron irradiation and gamma-ray irradiation are compared.

Fig. 3.4.1 shows an example of electron irradiation facility for sterilization. Medical products are transported by conveyer through the irradiation facility, and irradiated with electron beam at the accelerator contineously.

(2) Economical evaluation

Electron irradiation by electron accelerator and gamma-ray irradiation by Co－60 source are compared in case of same radiation dose 30kGy.

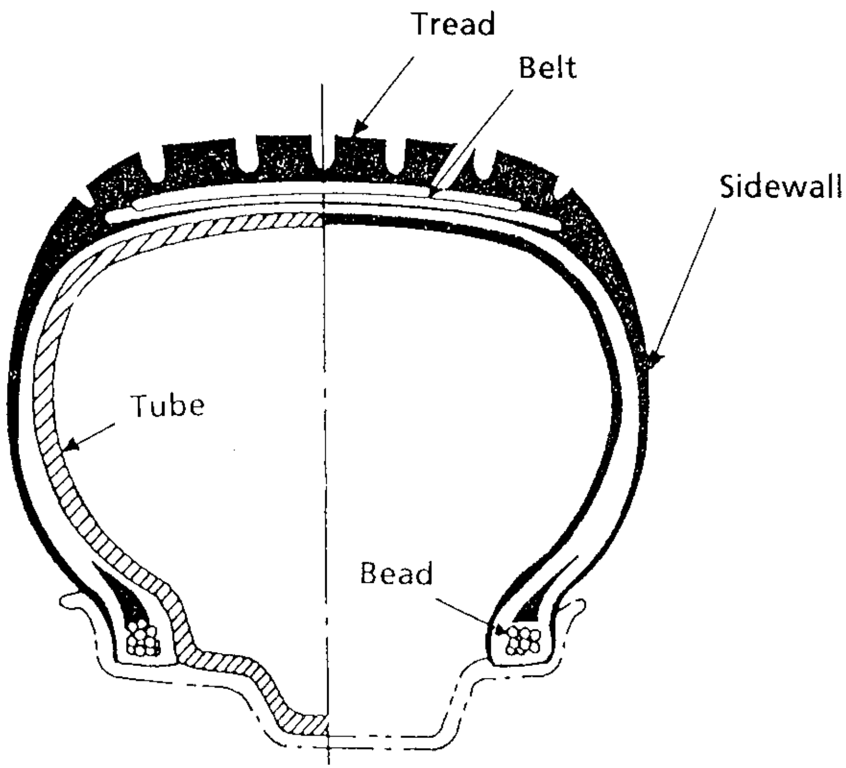
Results are shown in Table 3.4.1.

Gamma irradiation cost is about 4 times more than electron irradiation cost because of high cost of facility, Co－60 source and low productivity.

4. Conclusion

Economical advantages of electron irradiation were evaluated in the field of rubber crosslinking, cable crosslinking, paint curing and sterilization of medical products.

Some of data referred in this paper are some what old one, but relative comparison with conventional methods is possible today. Therefore, economical advantage of electron irradiation process is obviously valid. And as productivity increases, electron irradiation becomes more advantageous.



Cross section of radial tire

Utilization of irradiation to tire parts

Parts	Decrease of volume	Stabilization of manufacturing	Stabilization of quality
Inner-liner	○	○	○
Carcass	○	○	○
Sidewall	○	○	○
Belt	○		
Tread			○
Bead			○
Rubber tube	○	○	○

Table 3.1.1 Effects of electron irradition to rubber

Table 3.1.2 Comparison of electron irradiation method and rotecure method

Items		Electron irradiation (1.5MeV x 50mA)	Double band rotocure
Capital cost		$ 620,000	$ 585,000
Operation cost	Amortization (l0years)	$ 62,000	$ 58,500
	Direct labor	$ 36,000	$ 36,000
	Overhead	$ 36,000	$ 36,000
	Utilities	$ 43,200 (240kVA)	$ 42,000 (220kVA)
	Maintenance	$ 18,000	$ 6,000
	Total	$ 195,200	$ 178,500
Cost ($/hr)		$ 32.5	$ 29.8
Productivity (lbs/hr)		3,000	500
Product cost (¢/lb)		1¢	6¢
Energy cost (Utility/Productivity)		$ 14.4	$ 84

Parameters

- Operation hour/year 6,000
- Amortization period 10years
- Labor cost $ 6/hr
- Electricity cost 3¢/kW·hr

Quated from "Proceeding of the 15th Japan Conference on Radioisotopes" Japan Atomic Industrial Forum (1981)

Table 3.1.3 Comparison of energy cost in rubber crosslinking

Crosslinking methods	Energy cost	Product cost
Electron irradiation	1	1
Rotocure	5.8 ~ 8.5	6
Micro-wave	5	—
Thermal	2	—
Molten-salt	1.1 ~ 2.3	—

Relative energy costs are shown in this table.

Quated from "Proceeding of the 15th Japan Conference on Radioisotopes" Japan Atomic Industrial Forum (1981)

Table 3.2.1 Energy cost of crosslinking methods of HV power cable

Methods		Facility	Energy cost (¥/kg)	Relative cost
Electron irradiation		1.5MeV × 25mA Accelerator	2.8	1
Chemical Crosslinking	Vapour	CCV facility	43	15
	SF_6 Gas	CCV facility	57	20
Silane crosslinking			26	9

Parameters ◦ Electricity cost ¥20/kw·h

◦ Vapour

650kg/Hr, ¥6800/t for chemical vapour method

Quated from "Proceeding of the 15th Japan Conference on Radioisotopes" Japan Atomic Industrial Forum (1981)

Table 3.3.1 Comparison of feature

Items	Thermal curing	Electron irradiation
Curing time	5 ~ 60min	0.1 ~ 5sec
Facility	Long heating furnace	Compact size
Start-up and shut-down	Several hours	Instantaneous
Energy efficiency	0.2%	2.5%
Others	① Catalysis, Promoting materials are necessary ② Solvent recovery	① Planner painting only ② Restriction in paint selection

Table 3.3.2 Comparison of curing cost

(Unit : 1000Yen)

Item		Thermal curing	Electron irradiation 17kGy	Electron irradiation 35kGy
Investment	Building	6,000		
	Dry furnace	25,000		
	Accelerator		28,500	51,000
	Shield		2,850	5,100
	Total	31,000	31,350	56,100
Operation cost	Catalysis	7,500	—	—
	Steam	420	—	—
	Electricity	—	120	210
	Labor	2,400	1,200	1,200
	Maintenance	620	1,260	2,520
	Taxes (0.77% of invest)	240	240	430
	Amortization (10years)	3,100	3,140	5,610
	Total	6,360	5,840	9,760
Interest (5%)		1,550	1,570	2,810
Total		15,830	7,530	12,780
Product cost (¥/plate)		13.2	6.3	10.6

Parameters

- Decreased area for electron irradiation process 330m^2 (6M¥)
- Dry furnace 25M¥
- Steam 0.4t/h, ¥500/kg
- Electricity 20kVA, 35kVA, cost ¥3/kW·h
- Labor 1.2M¥/year, 2men

Table 3.3.3 Cost comparison for paint curing by difference of operation time

methods / operation time (H/year)	Electron irradiation		Thermal
	25mA	50mA	
1000	6.88	5.94	—
2000	4.14	3.50	7.3
4000	2.77	2.28	6.1
7000	2.18	1.75	5.6

Unit : yen/m^2

Remarks. Absorbed dose of electron irradiation of 25mA and 50mA are both 20kGy.

Table 3.4.1 Cost comparison in sterilization of medical products

(Unit : M¥)

Items		Electron irradiation	Gamma irradiation
Source Output power Penetration Efficiency Productivity (30kGy)		Accelerator 5MeV × 3mA 0.35g/cm^2/MeV 85% (both side) 1.53t/hr	Co－60 3.7×10^{16}Bq (1MCi) 12g/cm^2 30% 0.54t/hr
Capital cost		800	1600
Operation cost	Amortization (10years)	80	160
	Maintenance	15	3
	Co－60	—	150
	Electricity (100kW × 4300Hr)	9	—
	Water	2	—
	Labor	20	15
	Total	126	328
Irradiation cost		1150¥/m^3	5050¥/m^3

Quated from "Radiation and Industry" No.33

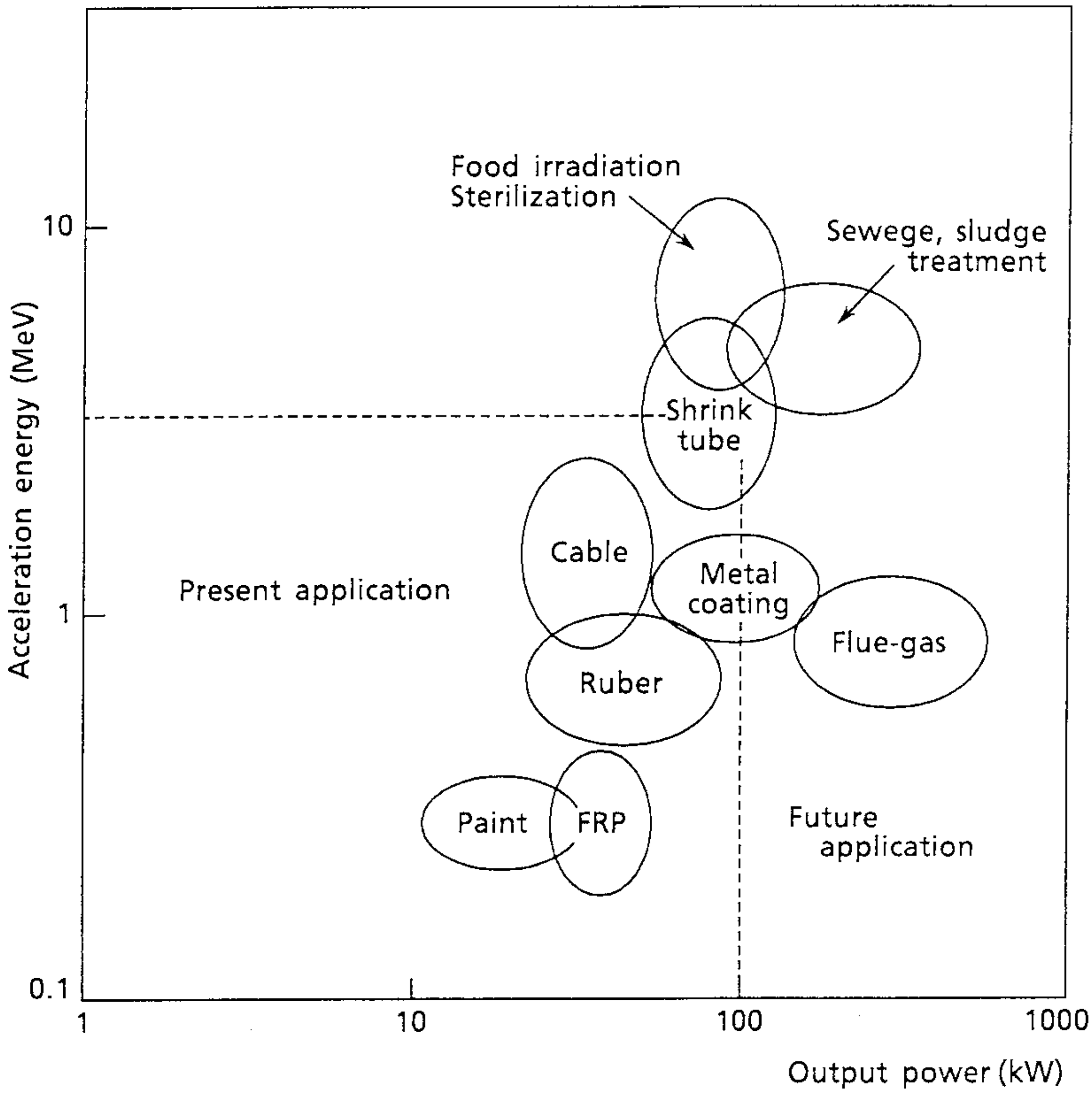


Fig. 1.1 Industrial fields of electron accelerator

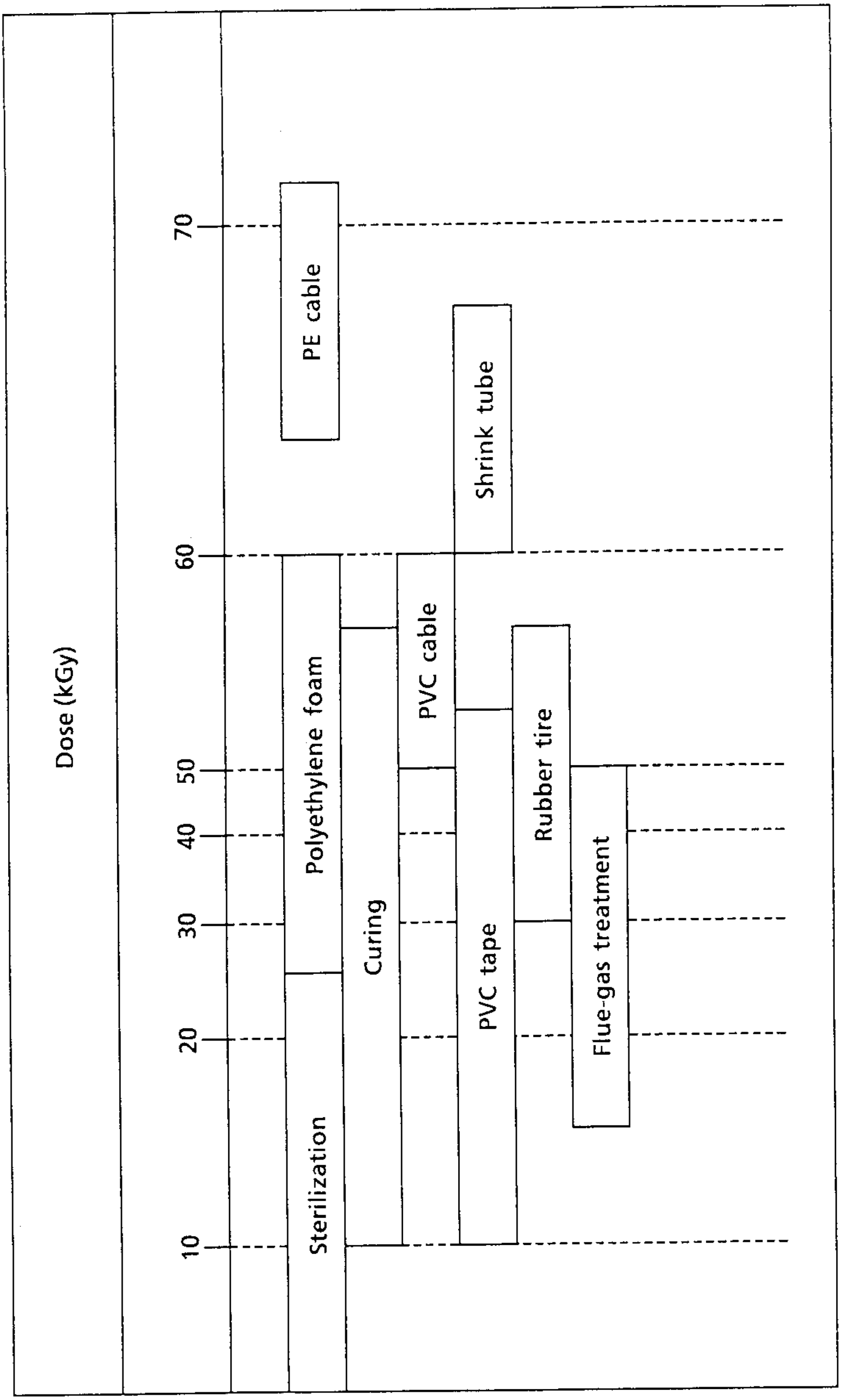


Fig. 2.1 Necessary dose in various industrial fields

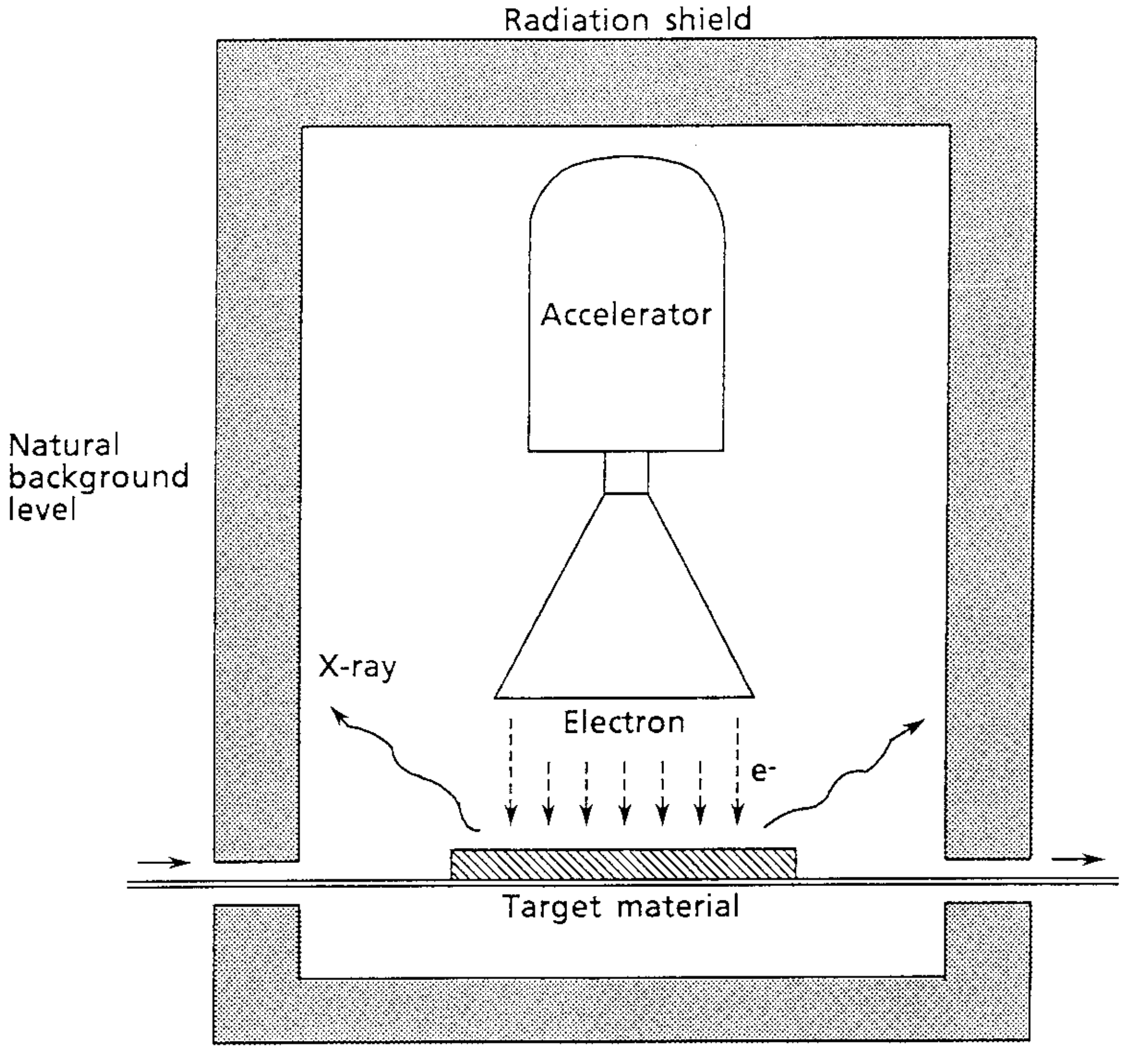


Fig. 2.2 Radiation shield of electron accelerator

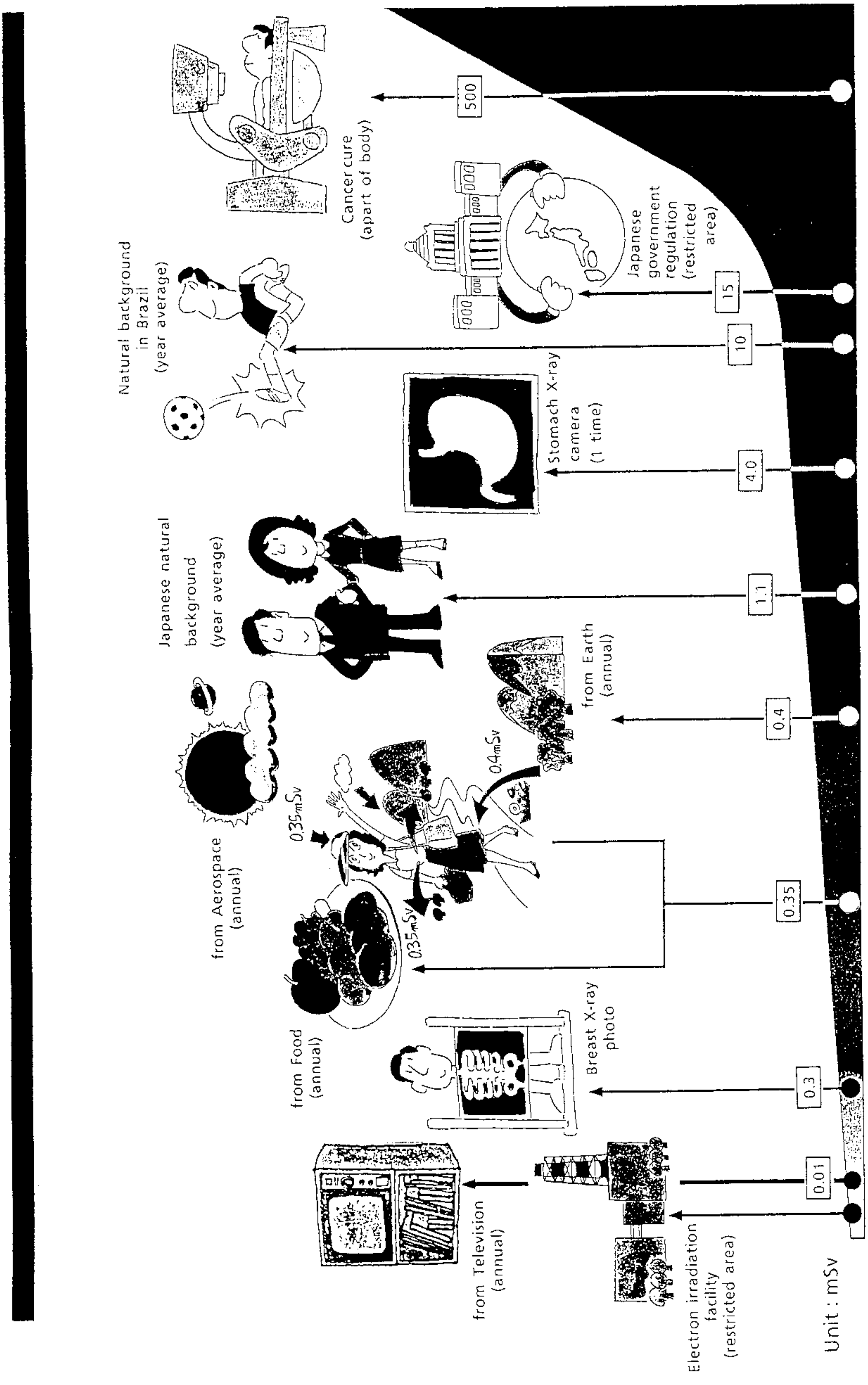


Fig. 2.3 Radiation dose of everyday-life

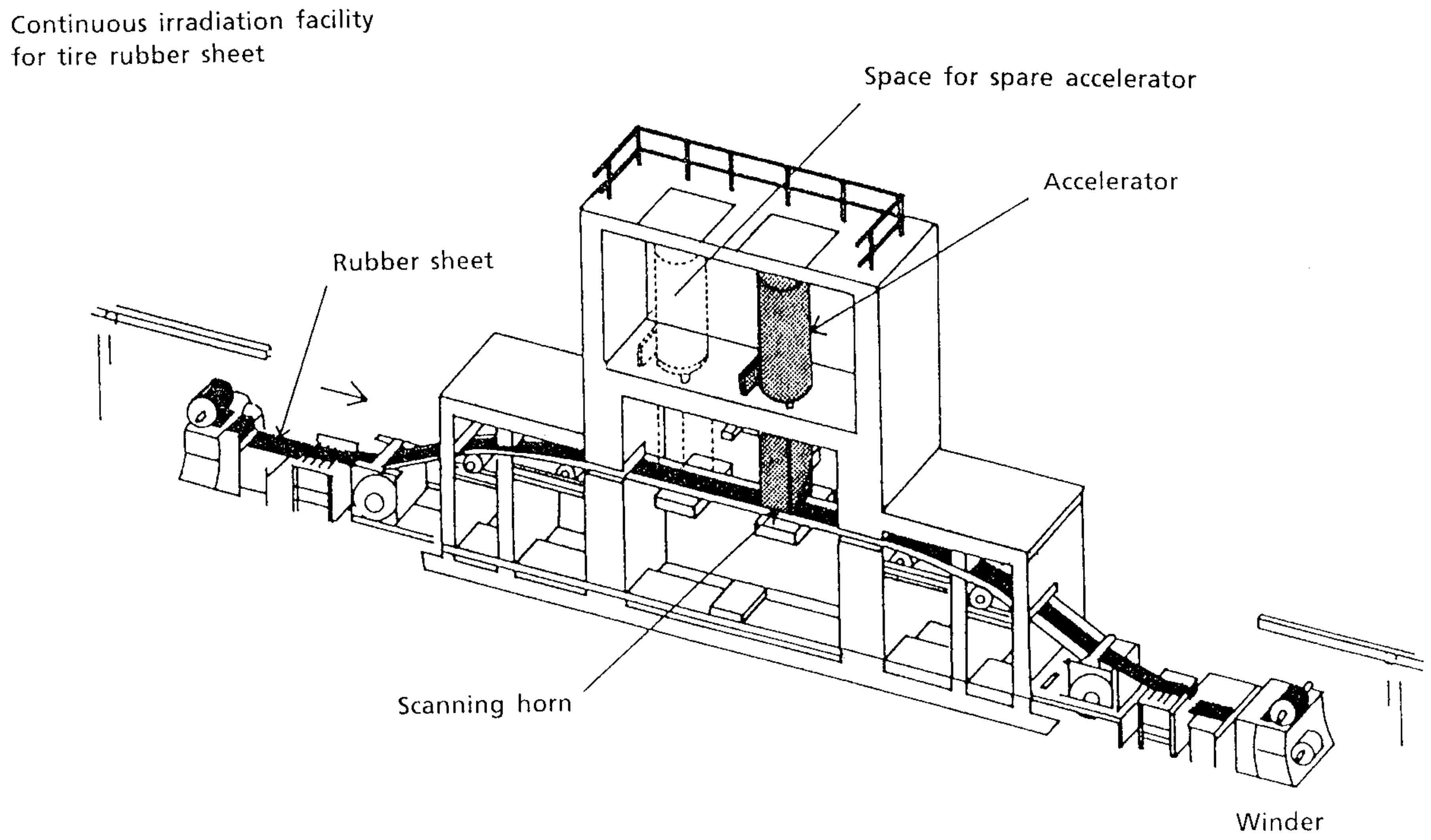


Fig. 3.1.1 Electron irradiation facility of rubber sheet

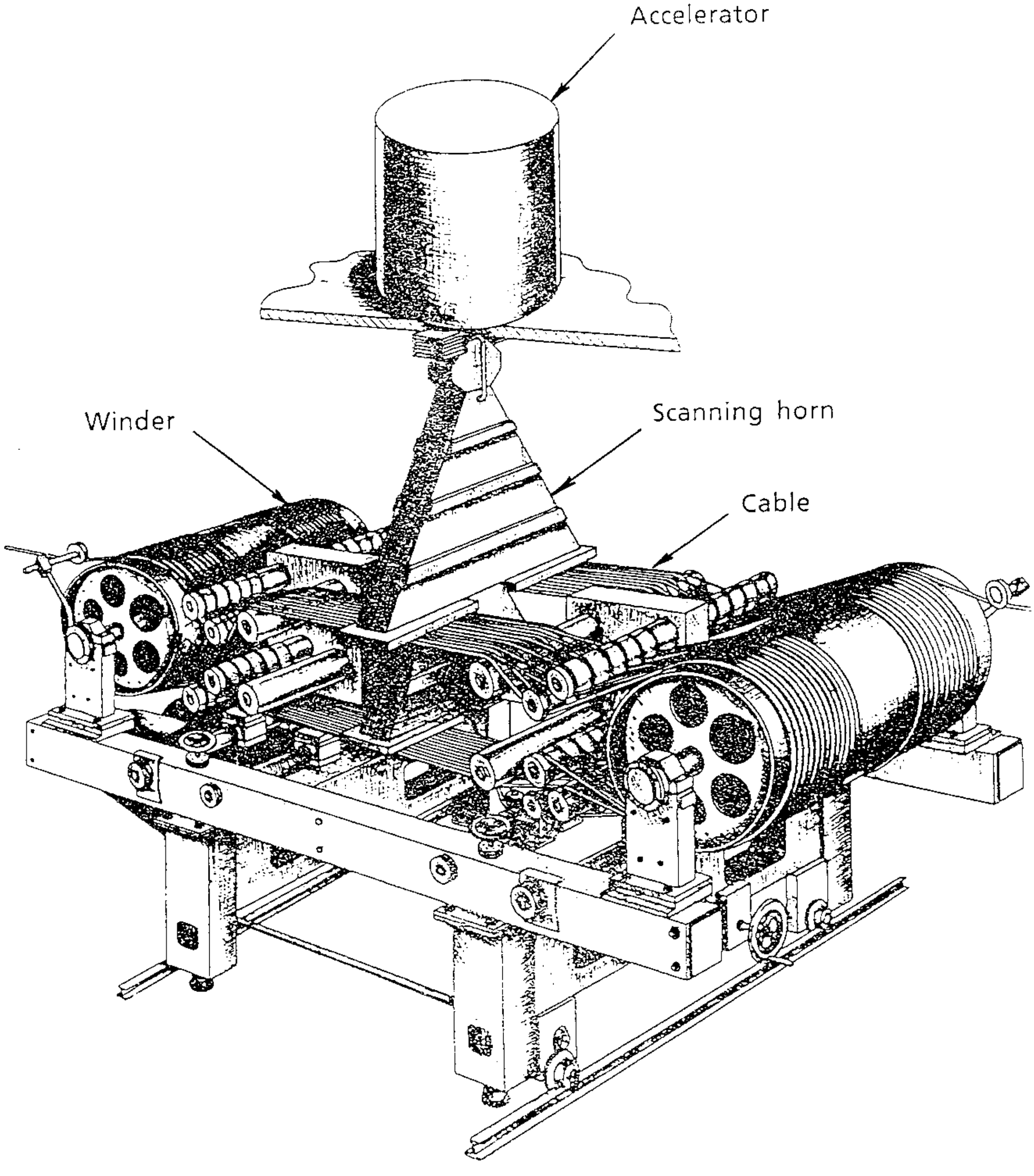


Fig. 3.2.1 Apparatus of cable irradiation with electron beam

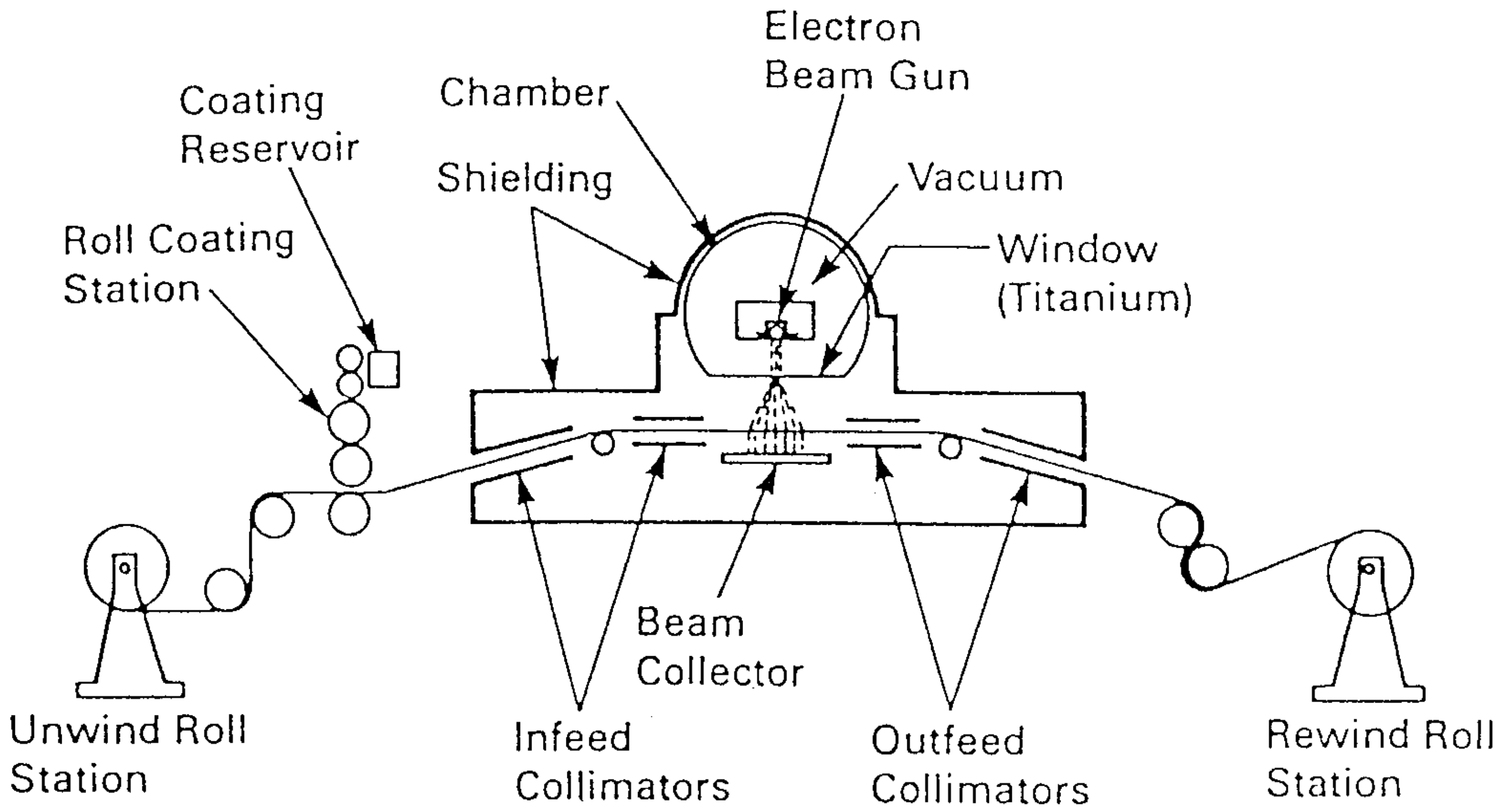


Fig. 3.3.1 Schematic view of electron irradiation curing

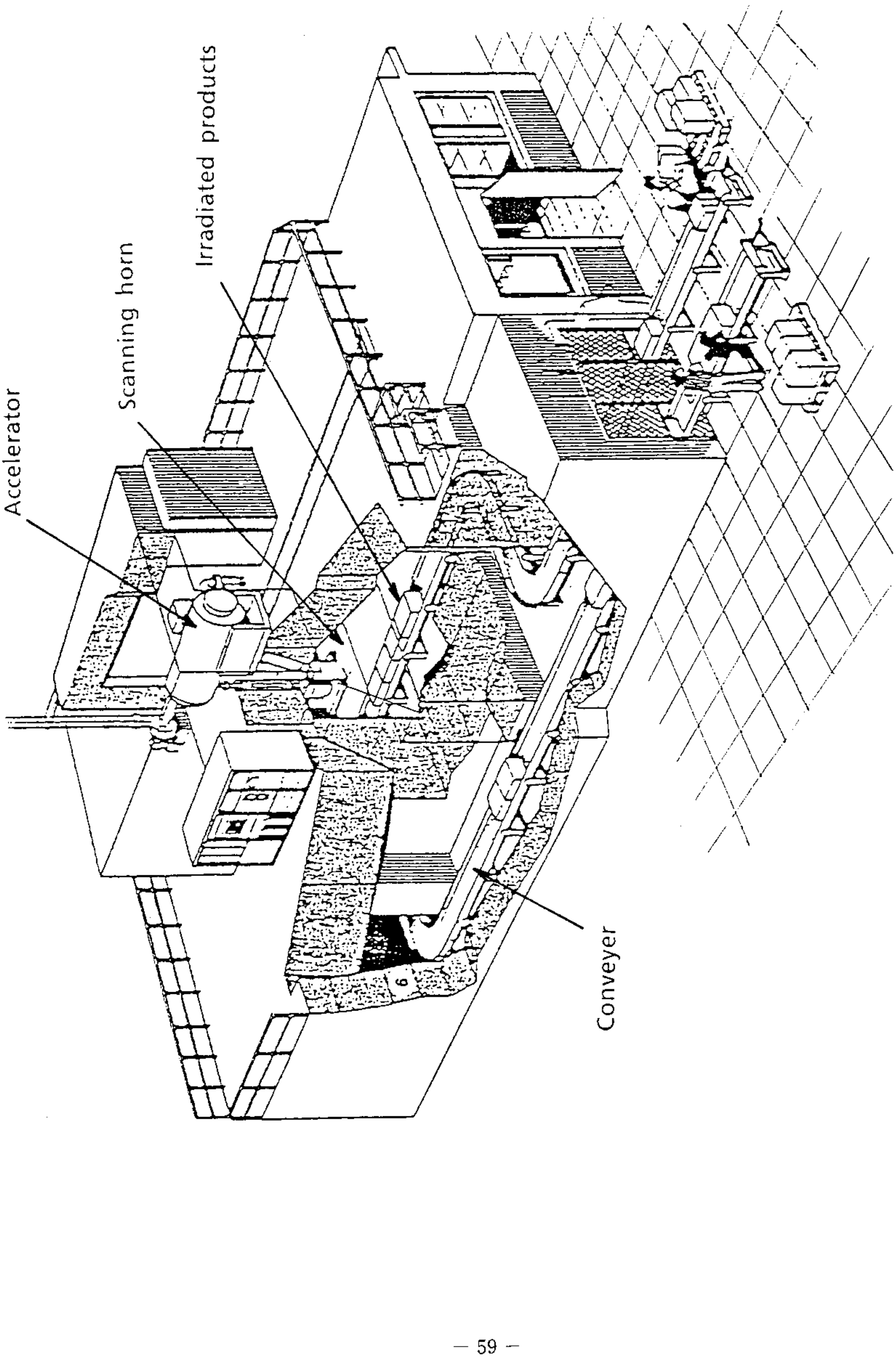


Fig. 3.4.1 Electron irradiation facility

2.4. Polymer Processing with Electron Accelerators

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More than one hundred electron accelerators are put to use to modify polymeric materials in industries in the world. One of the principal effects of radiation on polymers is the formation of radicals through ionization and excitation. Recombination of alkyl radicals formed in main chain of polymer is termed crosslinking. Main chain scission causes degradation of polymers. In general, crosslinking and degradation occur simultaneously in polymers. Graft polymerization is initiated by addition of monomers to the alkyl radical in the presence of monomers. Crosslinking is the most accepted electron beam (EB) processing followed by degradation of polymers and radiation grafting.

The predominant reaction that occurs in polyethylene, polyolerfins and elastomers by EB irradiation is crosslinking. Polyfunctional monomers such as diacrylates and triacrylates are being widely used to enhance crosslinking of polypropylene and poly(vinyl-chloride). The effects of crosslinking on the physical properties of polymers are increases in tensile strength, heat resistance and chemical resistance and decreases in elongation. The industrial applications of crosslinking are as follows:

Wire and cable
Heat -shrinkable tubing and film
Plastic foams
Tires

EB crosslinking are applied to the auto-temperature controlling heater systems that consist of polymers and carbon. Crosslinked polyurethane has been developed to improve hot water resistance of the outside jacket of the sensor cable for anti-lock brake systems. EB crosslinking technique is spread to the engineering plastics such as polyesters and Nylons are also crosslinked with EB to increase the heat stability.

Poly(tetrafluoroethylene), and butyl rubbers are typical polymer that degrade by irradiation. The degraded poly(tetrafluoroethylene) is utilized as solid lubricants. Butyl rubbers are reused as raw elastomers.

Numbers of applications of graft polymerization are increasing steadily for the manufacture of functional materials. The battery separators are prepared by grafting acrylic acid onto polyethylene films. Adsorbents that can adsorb ammonia and amines are developed by grafting sodium p-styrenesulfonate and acrylic acid onto non-woven fabric.

2.5. Potential Application of Electron Accelerators in Thailand

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Department of Nuclear Technology, Faculty of Engineering,
Chulalongkorn University

1. Introduction

High-energy electron can penetrate and give most of their energies to a material through interaction with the material. The energy given to the material results in excitation and ionization of molecules which lead to chemical reactions. Various chemical reactions induced by high-energy electons can produce new functional materials. Electron beam processing (EBP) is now considered to be industrial processes with high efficiency, room temperature capability, free of catalyst and good controllability.

EBP has a broad range of applications in industry which lead to manufacture of many products of high quality such as crosslinked wire and cable insulation, crosslinked PE foam, heat shrinkable tube and sheet, ion exchange membrane, battery separator, adhesive tape, computer floppy disc etc. A very useful alternative to conventional curing of coating is also done by EBP. Now EBP has been extended to apply successfully for environmental preservation such as flue gas treatment, waste water treatment, treatment of sewage sludge etc. The applications of EBP in radiation processing, grouping according to levels of development are shown in Table 1. The EB energies for pertinent applications are shown in Table 2.

Although EBP has been developed in USA, Europe and Japan for more than 30 years and has been developed in our neighboring countries like Indonesia and Malaysia for some years, it has not yet been developed in Thailand. R&D in radiation processing, however has been actively conducted in the field of food preservation, environmental preservation (radiation treatment of sludge and waste water), prevulcanize of rubber latex and grafting of cellulose using gamma-ray irradiator at OAEP. In 1984, Gammatron Co. (now Kendal Gammatron) has commercialized radiation sterilized medical products, also by using gamma irradiator. In 1991, Chulalongkorn University received a UV curing system from IAEA to commence R&D on UV curing of printing ink. The machine is under setting up for testing now.

2. The necessity to conduct R&D on EBP in Thailand

As the EB unit with its protective shielding have very high capital costs and EBP including its benefits are still very new to the local industries, prior the investment for such machine to the industry, the Government Agency (OAEP) should have a role to support the R&D on EBP. Extensive R&D on EBP connot be done unless an EB machine has been installed. The provision of EB machines (low and medium energies) can be done through technical co-operation or by government's budget. The objective of implementation should be aimed at

1) carrying out R&D on EBP
2) promotion of EBP as means to manufacture products of high quality with low cost
3) selection of the suitable EBP for local products on value-added purpose for export
4) development of manpower to support private sector on EBP
5) provision of technical assistance eg. through training course, work shop.

The R&D on EBP should be emphasized on technology transfer rather than developing our own technology to shorten the time to move forwards to pilot scale production and transfer to the industrial sectors. This can be done through regional training course and technical assistance in the form of expertise.

3. Potential Industrial Applications of EBP in Thailand

3.1 Curing of surface coating

Considering the established EBP technologies shown in Table 1 and the development of semi-fimish and finish products for export today, reveals that although the conservation of wood and forests has been promulgated, there is still a large momentum of wood products and manufacturing industry. Table 3 shows the export of particle board, fiber board and plywood in 1989. The relative small volume of the export might come from the consumption of furniture manufacturing industry and domestic uses. Table 4 shows the export of wooden furniture and furniture of cane. Although the total export of furniture of about 40,000 ton in 1989, this volume is just sufficient for a commercial EB cured wood coating line with the break-even figure of 40,000 m^3 per year. Another potential application of EBP for curing on substrate is ceramic tiles, the volume exported in 1989 exceeded 86,000 ton. Cement board, gypsum board are also products which can be put to EBP for curing of surface coating.

3.2 Radiation Crosslinking

There is a trend that in the future the crosslinked and halogen-free insulated wire and cable will dominate the world market. Many countries in Europe has already standard requirement that the insulation material must be crosslinked to enhance the properties in case of fire. The sheath must also be crosslinked to pass the requirement of hot set test. The crosslinked and halogen-free insulator is also necessary for health and environmental safety standard.

Crosslinking of wire and cable insulation by EBP has advantage over conventional peroxide and silane crosslinking in many aspects such as process is less complicated, high throughput, room temperature capability etc. It is important, therefore to note that EBP for crosslinking of wire and cable insulator is a potential technique. The plant capacity for such manufacturing is very large as dictated by the EB power of medium energy. The EB machine of 3.0 MV, 30 mA which normally used for this purpose, radiation dose of 25 Mrad is needed eg. for P.E. insulator, through put is roughly 300 t (PE)/ month. In the future, however if the demand for the cable of this kind is higher and locally produced commodity plastic resin : PE,PP, PS are available, crosslinked cable insulator manufacturing might be of interest for the industry.

Radiation crosslinking also finds wide applications in production of polyolefin foam. The production cost, however can be competitive with conventional chemical technique only if the production amount is more than about 100 t/month.

Another potential application of radiation crosslinking is the manufacturing of heat shrinkable tube and sheet. These products are widespread used for packaging, insulation of electrical parts, connector for telecommunication cables, corrosion protection of welding line of steel pipe, etc.

3.3 Pre-curing of tire rubber

Tire manufacturing process can be improved through the use of precured rubber sheet by EBP. In the process, bead insulation, innerliner, tread, sidewall and compounding applied to ply are to be irradiated by electron beam to improve their green strength or toughness so that they can withstand the rough handling of the tire building drum. It is one of the potential applications for domestic industry in the future as the export is increasing expecially tires for buses, lorries and motocycles. The total number of exports were about 1.2 million in 1989.

3.4 Other applications

R&D on radiation vulcanization of natural rubber latex is now in good progress using gamma irradiator. Its potential products are medical products of non-cytotoxic and corcinogen-free. EBP can be very useful for large scale production of prevulcanized latex, either for domestic industries or for export to secure higher value added. It has been investigated that for the production rate of greater than 12,000 ton per years the unit cost of production is cheaper than that of using gamma irradiator (Table 5).

4. EBP for environmental preservation

As mentioned earlier, EBP has been successfully extended to use for environmental preservation, a good example is the treatment of industrial flue gases to remove NO_x and SO_2 from stack gases. Conventional method of treatment is by wet scrubber and selective catalytic reduction for SO_2 and NO_x respectively. EBP for flue gas treatment is a dry scrubber which can eleminate SO_2 to nearly 100% and NO_x to 85-90%. In 1997, all lignite or coal-fired power stations in the country have to be attached with SO_2 scrubber to prevent acid rain. It is of interest to consider EBP for such purpose.

5. Conclusion

EBP should be of great potential to be used in industries in Thailand in the future. To begin with it, however the Government Agency should have a role to support R&D on EBP and its utilization. The first thing to do is to provide EB machines of low and medium energy to be installed at a Government Agency such as OAEP. This can be done through the government budget or through a research contract with foreign assistance. The most promising industrial application of EBP in Thailand in the near future, considering from potential export items, may be in the field of curing of surface coating. This is to secure value added and higher quality of semi-finish products like partitioned boards, ceramic tiles, gypsum tiles, fiber board or finish products such as funiture for export.

Table 1 Status of EBP for industrial application

Status	Application Field
Established Technologies	- Radiation sterilization - Curing of surface coating - Wire & cable insulation - Pre-curing of tire rubber - Heat shrinkable tube & sheet - Polyolefin foam
Emerging Technologies	- Food irradiation - Treatment of industrial flue gases - Decontamination of animal food - Decontamination of municipal waste (sewage sludge)
New Development	- biomass conversion - Prevulcanize of natural rubber latex - Radiation immobilization of bioactive materials

Table 2 Acceleration voltage and radiation dose required for certain applications

Application field	Voltage (KV)	Radiation Dose (Mrad)
Sterilization	300 - 5000	up to 2.5
Heat shrinkable tubing	200 - 3000	10 - 25
Wire & cable insulation		
PE	400 - 2000	20 - 30
PVC	400 - 2000	5 - 10
Tire rubber,		3 - 8
PE foam	300 - 1000	2.5 - 10
Treatment of flue gases		1.5 - 5
Curing of surface coating	175 - 350	1 - 8

Table 3(a) Export of particle board, fiber board and laminated wood

	export (1989) (MT)	value (million of TB)
Particle board	9,570	61.65
Fiber board	3,231	26.40
Laminated wood & plywood	3,502	119.71

Table 3(b) Export of glazed and unglazed ceramic tiles

	export (1989) (MT)	value (million of TB)
Glazed & Unglazed Ceramic tiles	86,463	1,179.72

Table 4 Export of furniture in 1989

	export (1989) (MT)	value (million of TB)
Wooden furniture	35,197.3	1,988.477
Furniture of cane	4,755.262	373.899

Table 5 Cost of RVNRL produced by gamma rays and EB

	Co-60	EB
Source	2 MCi	5 MV, 30 mA
Power (KW)	30	150
Efficiency (%)	40	95
Annual operation (h)	6,000	6,000
Sensitizer	n-BA	none
Vulcanization dose (Mrad)	1	25
Annual production (MT)	20,000	12,000
Annual operating cost	¥ 450 M	¥ 250 M
Cost/ton	22,500	20,850

2.6. Food Irradiation with Electron Accelerators

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Abstract

Both gamma rays and energetic electrons are widely used for the sterilization of disposable devices and for food irradiation. Radioactive isotopes (Co−60, and Cs−137) emiting gamma rays have been the predominant energy source of these processes but particle accelerators producing high power beams of energetic electrons are now taking share of this business. The food irradiation processing requires an electron beams of 10 MeV of energy and more than 10 KW of power. The electron beam which suitable for industrial food irradiation processing can be obtained by an electron linear accelerator having a high accelerating field gradient (10−5 MV/m). High−intensity X−ray convertor are also being considered for applications requiring more penetration than electron beams can provide.

1. Introduction

Food irradiation is a physical means of food treatment comparable to processing food by heating or freezing. The process involves exposing food, either package or in bulk, to gamma rays, X−rays, or electrons in a special room and for a specified duration to achieve the technical purpose. The most common and approved sources of gamma rays for food and industrial processing are cobalt−60 and caesium−137. These are so called radioisotope sources. There are also 'machine' sources which can produce electrons and/or X−rays for food processing as shown in Fig.1.

2..Benefits of food irradiation.

Benefits of food irradiation are to extend the shelflife, decon-tamination of both pathogenic and spoilage microorganisms, disinfection of parasites, disinfestation of insects and inhibition of sprout of agri-cultural produce and products. This technology will not only reducing spoilage losses of food but also increasing trade in a number of food items in many regions.

The cost of irradiation for food preservation should be less than comparable physical methods in view of its lower energy requirement and competative with chemical treatment in significant volume of products is treated in a plant within a given a unit of time. Techno-economic feasibility studies proved that food irradiation is economic efficient and convenient method for processing of food in many countries (Banditsing 1985, Banditsing 1988, Martin 1988, Lustre 1985, Maha 1988, Khan 1988, and Moy 1984.).

3.Sources of radiation

The choice of energy source for a specific application depends on the process requirements such as product configuration and handling pro-ceedure through put rate, minimum dose and max/min dose rate, as well as the user's criteria for capital and operating costs, process versatility, equipment availability and reliability, social acceptability and risks.

4.Penetration

Industrial electron accelerators provide concentrated, high-intensity radiation with limited penetration in solid materials. In contrast, gamma-ray source provide diffuse, low intensity radiation with greater penetration. However, X-ray convertor having high penetration is now available.

The percentage depth dose distribution in water or unit density materials for single－sided irradiation is shown in Fig.2. In addition the max/min dose ratio versus unit－density product thickness two－sided irradiation of gamma ray and X－ray is shown in Fig.3.

5.Advantages and disadvantages of gamma ray, electron beam,and X－ray.

Comparisons of the advantages and disanvantages of gamma ray, electron beam, and X－ray for radiation processing of medical devices and food have been reported by Cleland 1987 as it is shown in Table 1. Each type of energy sources has a number of advantages and disadvantages which make the choice for new facilities a rather complex issue. Gamma－ray processing in terms of numbers of installations and aggregate experience is still the dominant technology in this fields. However, utilization of linacs for industrial processing in various fields is also existed in many countries as shown in Table 2.

6.Economics.

Comparisons of X－ray and gamma－ray sources for industrial irradiation process have been reported by Cleland et. al. (1987) and economical evaluation in comparison of sterilization of medical products by electron and gamma irradiation was also conducted by Doi (1992). It was founded that the operating costs (unit cost/ft^3) of gammas : X－rays was $ 0.64 : $ 0.52 whereas the irradiation cost electron : gamma was 1150 Y : 5050 Y m^3.

7.Conclusion.

Food Irradition has been proven to be a safe and wholesome physical means of food treatment by exposing food to gamma rays, X－rays, or electrons to achieve the technical purpose of reducing spoilage loss. Each type of radiations has a number of advantages and disadvantages. Gamma rays processing in terms of numbers of installations and aggregate experience is still the dominant technology in these fields. However, high－power beams of energetic electrons are now taking share of this business.

Considering of the electron beam processing of food, interesting suggustion which should be taken in account has been given to accumulate of data in commercial plants and pilot plants in USA and France. Meanwhile, linac technology must be prepared for propable development of the demands on larger power rating for processing of the larger volume of food stuffs, higher efficiency of power conversion from wall to beam, and the development of X-ray convertor to accomodate thick samples.

As far as the promoting electron accelerators utilization of food irradiation in development countries is concerned, government organization which responsible for nuclear science and technology R & D should have this facility through the national budget and/or through international agency technical assistance. this machine not only giving opportunity for scientists to gain operation and maintainance of irradiation facility experience but also to bridge the food irradiation technology to the private investor through technology transfer process.

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Table 1 Advantages and disadvantages of gamma-ray, electron beam and X-ray

	Radiation		
	Gamma-ray	Electron beam	X-ray
1.Advantages	(1)The penetrating quality of radiation permits the treatment of variety of medical and agricultural products packed in shipping cartons. (2)Steady emission of energy assures the availability of power when need and gives producible results from the treatment process. (3)Modular source capsules permit matching the power output to the production requirements. (4)The irradiation process can be monitored by physical means (dosimetry) and controlled by a single parameter (exposure time). (5)The efficacy and reliability of gamma-ray processing has been demonstrated in numorous facilities over many years. (6)This technology is suitable for the underdeveloped countries because the operation and maintainance of irradiation facility does not require highly skilled personel.	(1)The radiation intensity within the beam is very high so the exposure time is very shot and product degradation is minimized. (2)The product conveyor is simpler and less expensive than in a gamma-ray facility since a single pass or at most two passes through the beam is sufficient. (3)The power utilization is higher than with gamma rays due to the forward concentration of the beam and its controlled penetration. (4)Operating exposures can be minimized by running the accelerator only when it is needed. (5)Process validation proceedures need not be repeated after the accelerator is serviced, provided that the operating parameters have not changed. (6)The accelerator can be installed above ground within an ordinary building. (7)Accelerators facilities are licensed by state agencies in the same manner as medical X-ray equipment and the procedure are less than the licensing of large gamma-ray facilities. (8)The future availability and price of accelerators will be determined by the market place rather than by governmental policies. (9)The total cost of electron beam processing is less than gamma ray sterilization in facilities with throughput capacities of 1 million cubic feet per year or greater.	(1)Most of the advantages of electron beam processing also apply to X-ray processing, w/o the disadvantage of low electron penetration. (2)The greater penetration of 5 MeV X-rays versus Co-60 gamma rays will reduce the max/min dose ratio in pallet loads of heavy products, especially agricultural commodities. (3)The forward concentration of the X-rays versus isotopic gamma-rays will reduce the irradiation time, there by reducing product degradation. (4)The smaller radiation zone will simplify the product conveyor, there by improving its reliabilty and reducing its cost. (5)The smaller volume of material in the irradiation chamber will increase operating efficiency by reducing the time lost between production lots with different dose requirements. (6)An X-ray generator can provide the comfort and convenience of a controllable eletrical device with the product penetration and dose uniformity now obtainable only from radioactive materials.

Table 1 (continued)

	Radiation		
	Gamma−ray	Electron beam	X−ray
2.Disadvantages	(1)The relatively low intensity of the radiation requires long exposures during which the quality of the product may be degraded by oxidative reactions . (2)The power utilization efficiency is low due to the isotopic distribution and excessive penetration of the radiation. (3)The radiation facility must be operated continuously to avoid wasting the energy of the radioactive sources. (4)The process validation procedures must be repeated whenever the source loading is changed. (5)Once built, a large gamma irradiator with an in−ground storage pool and thick concrete walls is a permanent installation that cannot easily be moved or converted to one other industrial use. (6)The approvals of various federal and state agencies are required for the design, construction and operation of gamma facilities as well as for the procurement, transportation and installation of the source capsules. (7)The growing antipathy of the public and the news media regarding nuclear installations may impede the construction and operation of new facilities in some localities. (8)The persistent emission of energy from the radioactive sources can be a continuing liability in the event of unforeseen equipment mal−functions or deliberate acts of sabotage.	(1)The penetrating quality of electrons is less than that of gamma−rays and some thick objects cannot be processed with this kind of radiation. (2)Detailed dose of mapping must be done within the shipping cartons and inside the various products during the process qualification procedures to assure adequate treatment of all materials. (3)The operating parameters of the accelerator may have to be varied to obtain the optimum dose uniformity and process efficiency. (4)Several machine parameters in addition to the conveyor speed must be monitored to control the quality of the treatment process. (5)While highly reliable, an electron accelerator cannot match the dependability of a radioactive source. (6)The capital cost of an industrial accelerator does not scale down linearly with its beam power rating for low−capacity facilities. (7)The few electron machines now being used for sterilization have accumulated less operating time than the many gamma−rays facilities. (8)The accelerator specifications for new processing facilities may exceed the ratings of existing equipment, thereby requiring the development of new models with no operating experience.	(1)The cost of X−ray will be higher than electron beam processing because of the low efficiency for converting electrons to X−rays. (2)Further development on the efficacy and reliability of X−ray processing in a commercial operation should be conducted.

Table 2 Linacs for industrial processing

FACTORY OF INST.	ENERGY (MeV) TWorSW	POWER (kw)	Mfg	YEAR COM.	APPL ICA.
IRT,San Diego	6−18 TW	2 X 7	ARCO		S
RISO,Denmark	6−14 TW	10	HAIMSON	1975	S&R
Raychem,Denmark	6−14 TW	10	Varian	1976	O
CARIC, France	7TW	7	CGR−MeV	1967	S
Waesaw, Poland	13 TW	9	Efremov		R,S
Harwell, UK	8−12 TW	25	Tech.Sys.L.	1985	R,S
SPI, France	8 VHF	5	CGR−MeV	1986	F
CARIC	10 TW	20	CGR−MeV	1987	S
SCAN−CARIC, Sweden	10 TW	25	CGR−MeV	1988	S
Florida−USA	10(E3)TW	10	CGR−MeV	1990	F
Florida−USA	5(X−ray)	20			
Iowa−USA	10 TW	20	CGR−MeV	1990	F
ChampArdenne	10 TW	20	CGR−MeV	1990	S
SPI, France	10 TW	20	CGR−MeV	1990	F
Molnlycke,Sweden	10 TW	25 X 2	CGR−MeV	1991	S
Karlsruhe, West Germany	10 TW	20	CGR−MeV	1991	F,S
Aerospatial,France	10 TW	20	CGR−MeV	1991	O

S:Sterilization, F:Food, R:Research, O:Cross−linking application

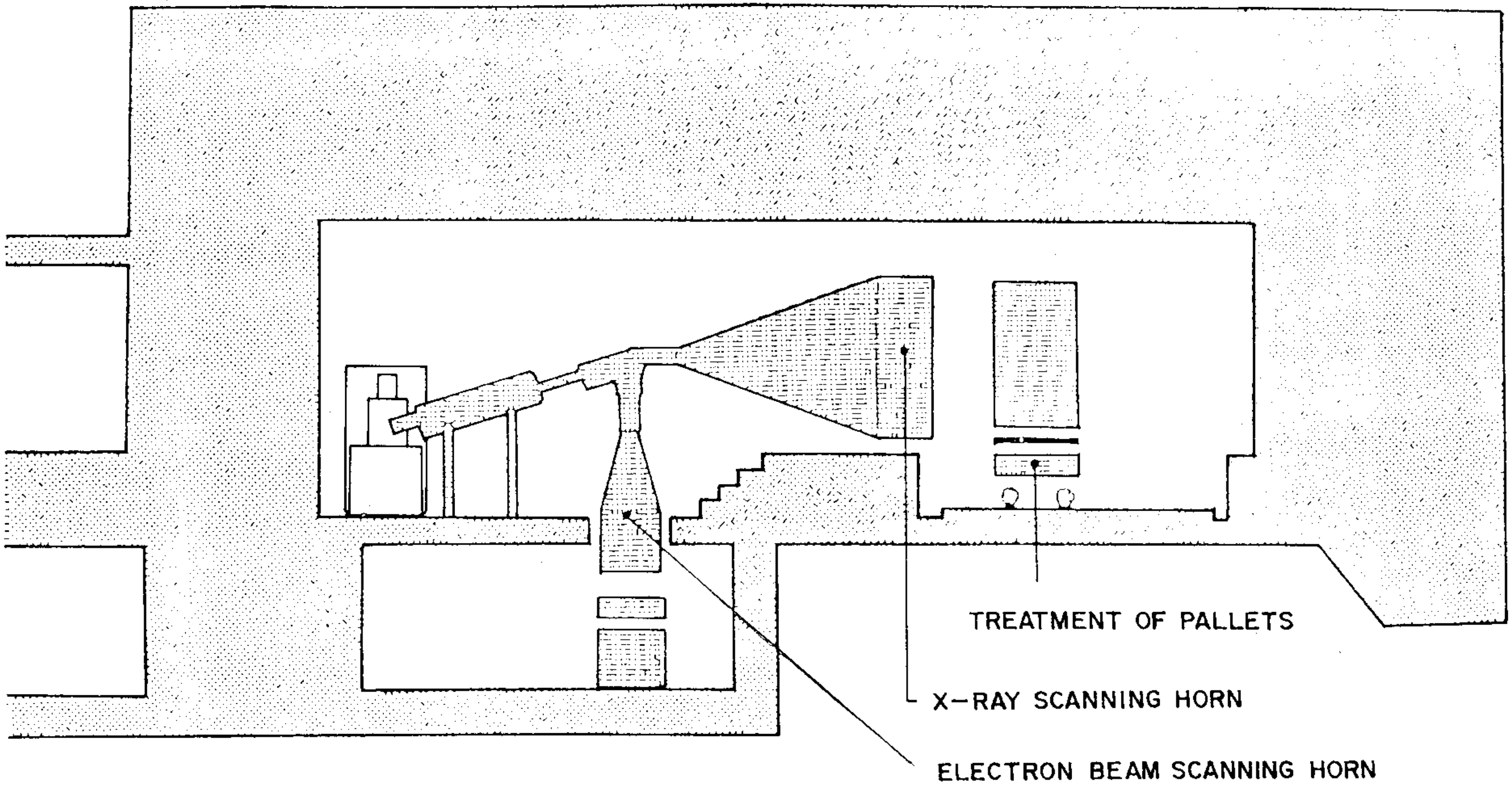

Fig. 1 A linac facility for research of food processing by electrons. It has two beam lines and scanners. One for direct electron irradiation at 10 MeV and another for generation of and processing by 5 MeV X-rays. Energy of electrons incident on samples is limited within a narrow range by a bending magnet.

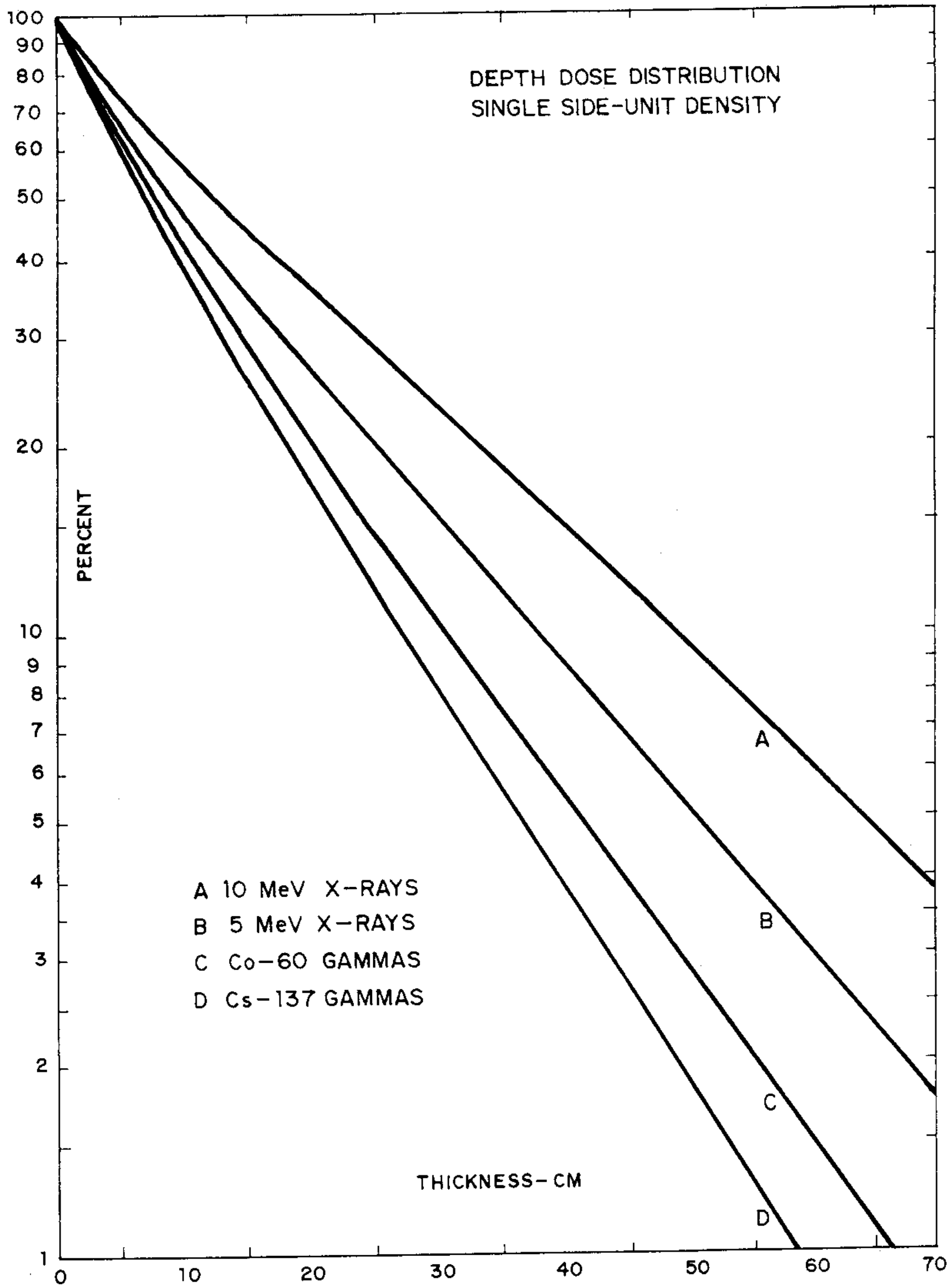

Fig. 2 Percentage depth dose distribution in water or unit density materials for single-sided irradiation: (A) 10 MeV X-rays: (B) 5 MeV X-rays: (C) ^{60}Co gamma-rays: (D) ^{137}Cs gamma-rays.

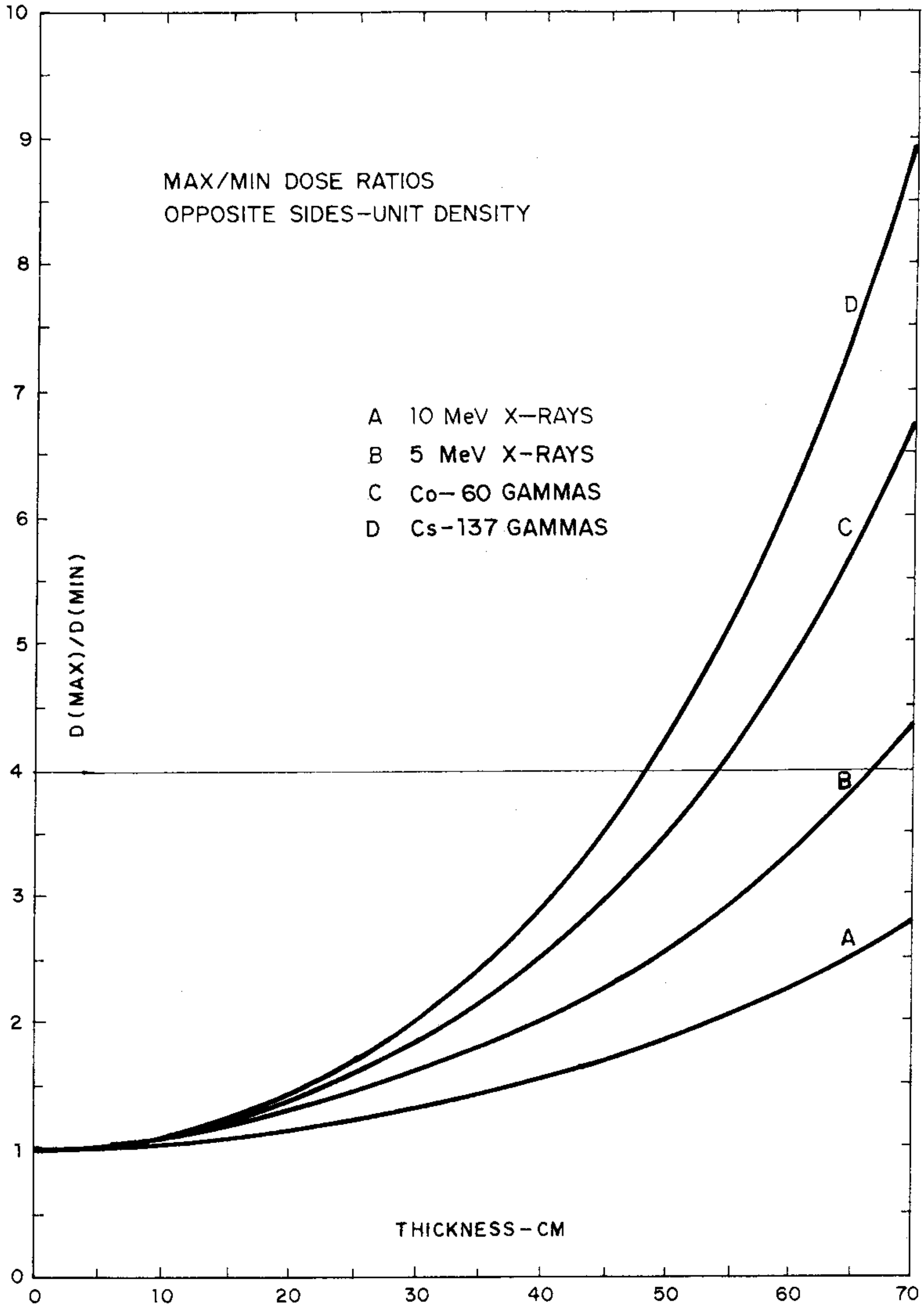

Fig. 3 Max/min dose ratio vs unit-density product thickness for two-sided irradiation: (A) 10 MeV X-rays: (B) 5 MeV X-rays: (C) ^{60}Co gamma-rays: (D) ^{137}Cs gamma-rays.

2.7. EB Treatment of Wastewater and Sewage Sludge

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ABSTRACT

Ionizing radiation is useful for decomposition of pollutants in wastewater and disinfection of solid waste as sewage sludge. For application of electron beam, quite different technologies from those of gamma-ray are required because of short penetration range and high dose rate of electron beam. In this report, differences of irradiation effect between gamma-ray and electron beam and irradiation technologies are introduced from a viewpoint of application of electron beam to environmental conservation.

1. Introduction

Applications of ionizing radiation to environmental conservation are well known. There are several effects of radiation on pollutants as follows;

1) Removal of pollutants by oxidative degradation.
2) Elimination of toxicity, color and smell of pollutants and addition of biodegradability by changing chemical structure.
3) Inactivation of dangerous microorganisms and parasites.
4) Improvement of precipitation and filtration properties of fine particles of pollutant.

Recently, an electron accelerator has been evaluated as a practical and economical radiation source because of large output power. But, penetration range of electron beam is usually very short and dose rate is very high compared with gamma-ray from cobalt-60. These properties require quite different technologies from those of gamma-ray for the application of electron beam.

In this report, effects of penetration range and dose rate of electron beam on decomposition of organic pollutants and disinfection of bacteria are discussed. Irradiation technologies for liquid and solid are also introduced from a viewpoint of applications of electron beam to environmental conservation.

2. Treatment of wastewater

Experimental results on decomposition of pollutants by ionizing radiations are summarized in Table 1. Various kinds of organic pollutants are possible to decompose by radiation.[1] It is well known that oxygen often shows important roll on the decomposition of organic pollutants. Effect of oxygen on radiation decomposition of phenol in aqueous solution is shown as an example.[2] The initial concentration of the phenol was adjusted to be 10^{-3} mol/l. Irradiation dose to decrease the concentration to 1/10 is about 8 kGy in the solution with oxygen, but, more than 30 kGy is necessary without oxygen. Oxygen is also effective for decoloration of dye in wastewater.[3]

3. Disinfection of sewage sludge

Ionizing radiation is also useful for disinfection of solid wastes as sewage sludge. Fig. 2 shows reduction of total coliforms in sludge after irradiation by electron beam. In this case, dose rate was adjusted to be the same order of gamma-ray by special irradiation method. Initial value of total coliforms in sludge is about 10^7 cells/g. The irradiation dose for two log cycle reduction of surviving fraction is about 0.15 kGy in aerobic condition, but, more than 0.75 kGy in anaerobic condition. Oxygen shows very important roll for effective disinfection as same as radiation decomposition of organic pollutants.

4. Important factors for EB irradiation

1) Depth dose

One of the big differences between gamma-ray and electron beam is dose distribution along the pass in the sample to be irradiated. A depth dose curve for gamma-ray from cobalt-60 in the water is shown in Fig. 3. Relative dose decrease exponentially with thickness of water. Half-value layer in water is about 11 cm. Fig. 4 shows depth dose curves for electron beam. Dose in water increases at first with increase of thickness and then decreases. Maximum penetration range (mass thickness, g/cm^2) is different depend on beam energy and the value is 1.1 cm for 2 MeV. The thickness to give the same dose as that at the surface is called

"Effective penetration range".

Fig. 5 shows surviving fraction of total bacteria in sludge after irradiation. To kill bacteria effectively, sludge thickness must be less than 6 mm for beam energy of 2 MeV and 3 mm for 1 MeV. These values correspond to the effective penetration ranges for those energies.[4)]

2) Dose rate

Usually, dose rate of electron beam is very high compared with gamma-ray because output power of electron accelerator is very large and penetration range of electron beam is very short. The dose rate of electron beam is, sometimes, higher more than 100 times compared with that of gamma-ray irradiation.

This deference of dose rate often give a large deference of reaction rate for polymerization. But the effect of dose rate is not so large for decomposition of organic pollutants like phenol as shown in Fig. 6.[2),5)] Fig. 7 shows effect of dose rate and energy of electron beam on disinfection of microorganisms in sludge. Results for gamma ray irradiation are also shown in this figure. No effects of energy and dose rate can be seen in the survival curves of total bacteria and coliforms.[6)]

5. Irradiation technology for electron beam

1) Wastewater

By an electron accelerator, short time is enough to give a certain dose because dose rate is very high as mentioned before. So, it is necessary to remove the wastewater quickly from the penetration range (reaction zone) of electron beam. In addition to this, effective oxygen supply is required during irradiation for aerobic decomposition of organic pollutants and disinfection of microorganisms.

A thin layer reactor as shown in Fig. 8 is possible to get a uniform irradiation and suitable for removing the wasterwater quickly from the reaction zone. Oxygen in the reactor decreases during the irradiation according to the G-value of oxygen consumption by chemical reactions caused by the irradiation. The concentrations of oxygen were calculated[1)] and shown in Fig. 9. It can be seen that the oxygen concentrations decrease rapidly with irradiation dose. This means, oxygen supply during irradiation can not be expected. But, this reactor is effective when oxygen supply is not necessary. A flat nozzle is also possible to use for making thin layer of wastewater.

A spray tower reactor as shown in Fig. 10 is more effective to supply oxygen because the surface area, which contacts with the gas, is larger than that of thin layer reactor. But, oxygen supply is not enough even in this reactor.

Fig. 11 shows a mixing-type reactor. Irradiated liquid is removed from the reaction zone by mixing. Oxygenated liquid is continuously supplied from the area under reaction zone.

A dual-tube bubbling column reactor is improved from the mixing-type reactor. As shown in Fig. 12, this reactor has a outer tube and a inner tube. Wastewater circulates in the reactor by airlift. Oxygen is effectively supplied to the liquid in the oxygen absorption zone under the reaction zone and go to the reaction zone by circulation. After irradiation, the liquid quickly flow down from the reaction zone. Oxygen concentrations in the liquid were calculated and shown in Fig. 13. Compared with those for the thin layer reactor, values for the dual-tube bubbling column reactor are higher. This shows that oxygen supply in the bubbling column is effective.

A multi-stage bubbling column reactor as shown in Fig. 14 was used in our study to treat a larger amount of wastewater.[3),5)] Five dual-tube bubbling columns were connected together. In this case, we can make the irradiation dose for each culumn small. This means that oxygen supply become easier and it is also possible to prevent back mixing which make the treatment ineffective.

2) Sewage sludge cake

In dewatered sewage sludge irradiation with moisture content of 75 to 80 %, it is very difficult to supply oxygen during irradiation because effective mixing is impossible and diffusion factor of oxygen in sludge cake is very small. In addition to this, sludge contains large number of microorganisms and the consumption of oxygen by respiration of microorganisms is very large even without irradiation. As conclusion, effect of oxygen can not be expected in practical treatment of sewage sludge cake and most important technology is how to make a thin layer of sludge cake for enough penetration of electron beam.

Fig. 15 shows the machine we used for making thin layer of sludge cake. This machine was set under the scan horn of electron accelerator in the irradiation room. The raw sludge was transported from a reservoir to flat nozzle by a sludge pump. The width of the nozzle was 20 cm and sludge thickness was adjusted to be 6 mm. The maximum feed rate of sludge is 300 kg/hr. It was proved that continuous disinfection of sludge cake is possible by the combination of an electron accelerator and this machine.[7)]

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Table 1 Decomposition of various pollutants by ionizing irradiation

Pollutant	Initial conc.	Dose	Degree of reduction
Cyanide	30 ppm	4×10^5 rad	100 %
Sodium sulfate	25	1.5×10^5	100
COD	110	4×10^5	36
Dieldrin	20	8×10^6	65
Dimethylphthalate	192	4.2×10^5	50
ABS	14	5×10^4	99
ABS	20	5×10^5	92
Phenol	100	5×10^5	80
Hydroquinone	100	5×10^5	75
Pyrocatechol	100	5×10^5	75
PVA	340	6×10^6	91
Dyes			
Acid red 265	120	3×10^5	90
Acid Blue 40	25	3×10^5	95
PCB	100 ppb	10^7	90
Organochloride compounds			
o-chlorophenol	20 ppm	10^6	82
2,4dichlorophenol	20	10^6	96
2,4,6trichloro-phenol	20	10^6	98
Pentachlorophenol	20	10^6	99
Parathion	10	5×10^5	99
β-naphthylamine	1	10^4	99
Benzidine	1	10^4	68

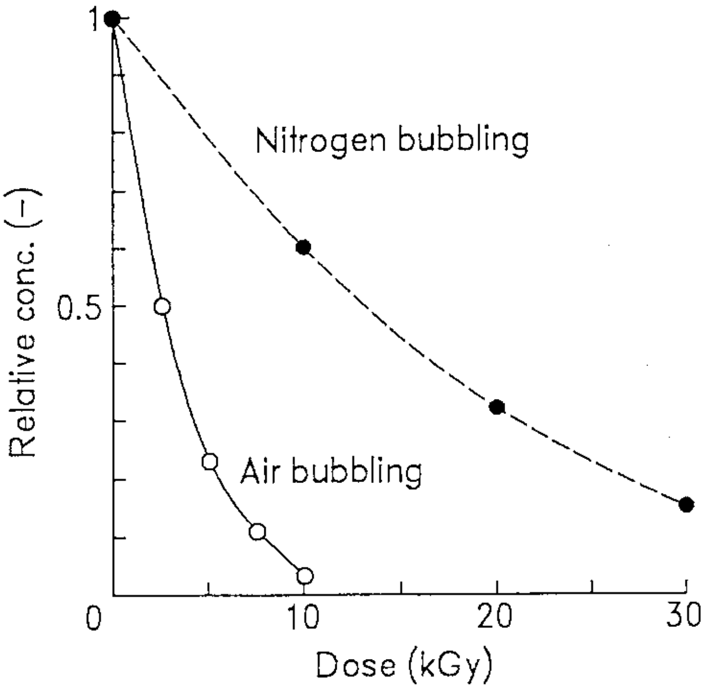
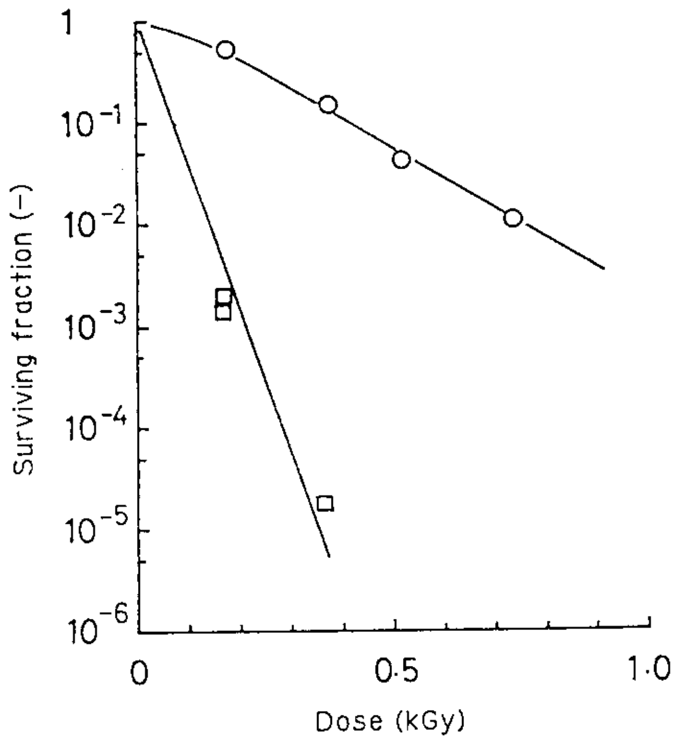


Fig. 1 Effect of oxygen on decomposition of phenol



Beam energy and dose rate were 2 MeV and 20 kGy/h. ○ shows the result without oxygen and □ with oxygen.

Fig. 2 Effect of oxygen on reduction of coliforms in sewage sludge

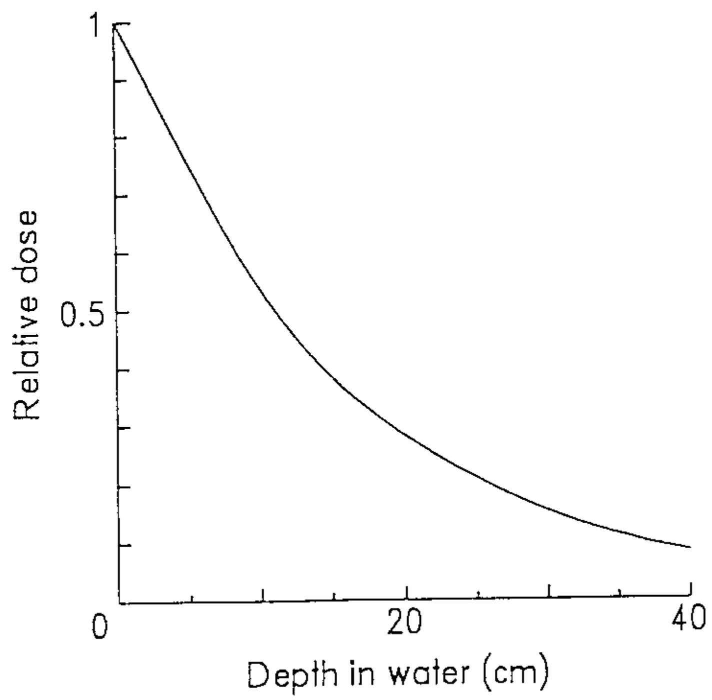


Fig. 3 Dose distribution of gamma ray in water

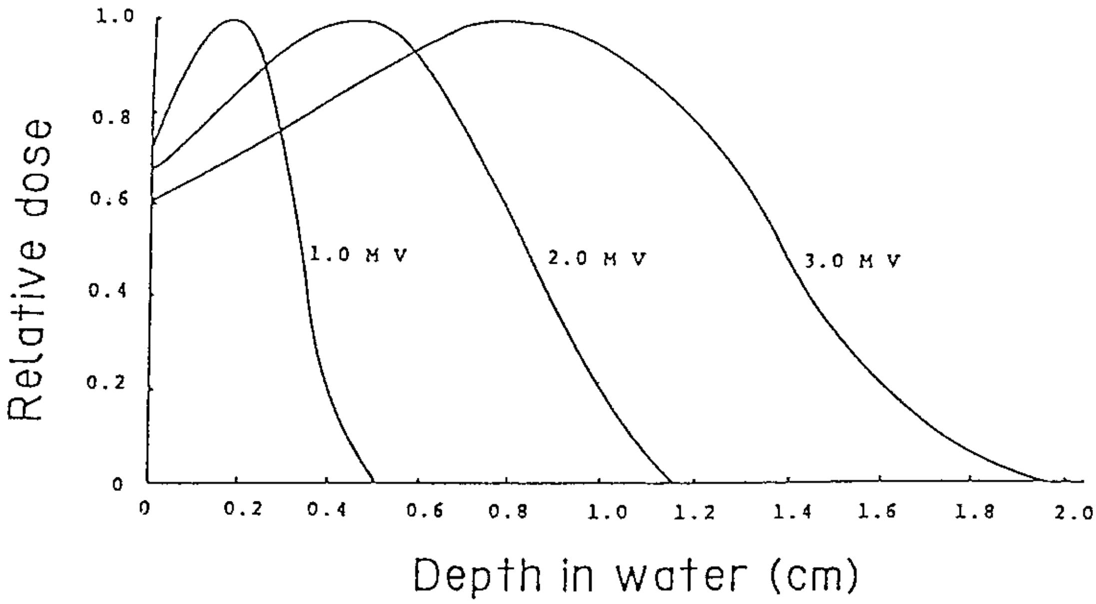


Fig. 4 Dose distribution of electron beams in water

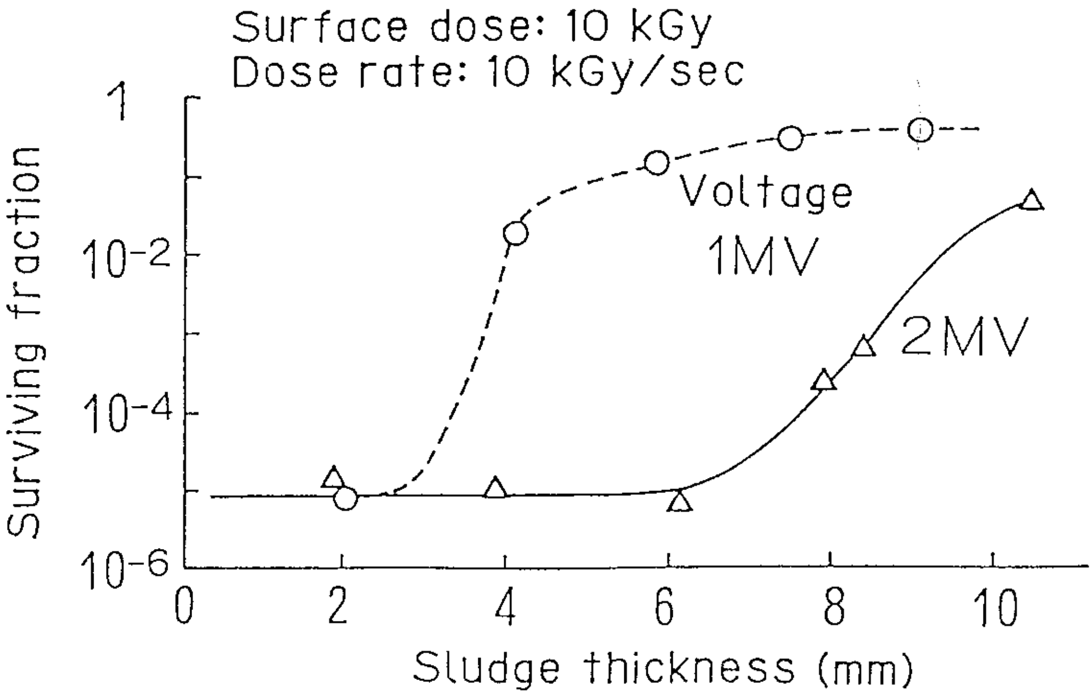


Fig. 5 Surviving fraction of bacteria in sludge irradiated with various thickness

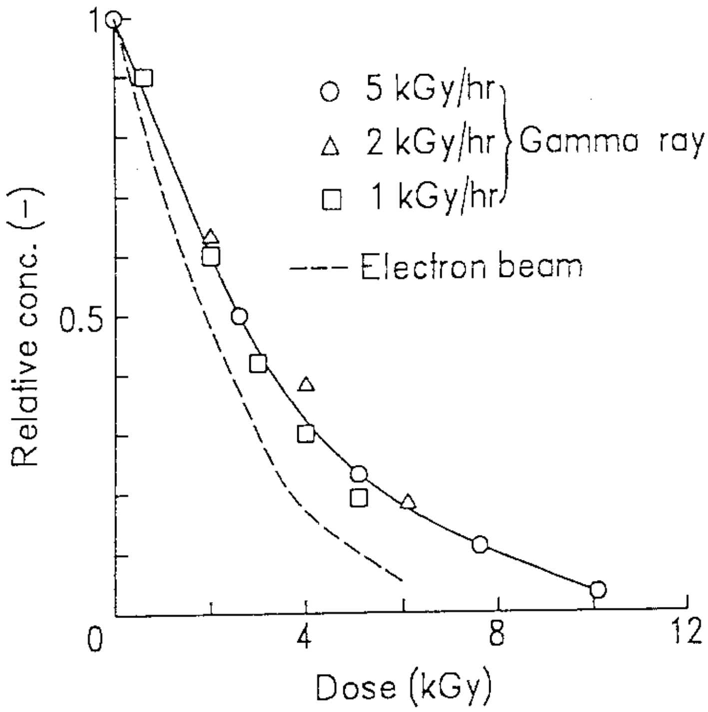


Fig. 6 Effect of dose rate on decomposition of phenol

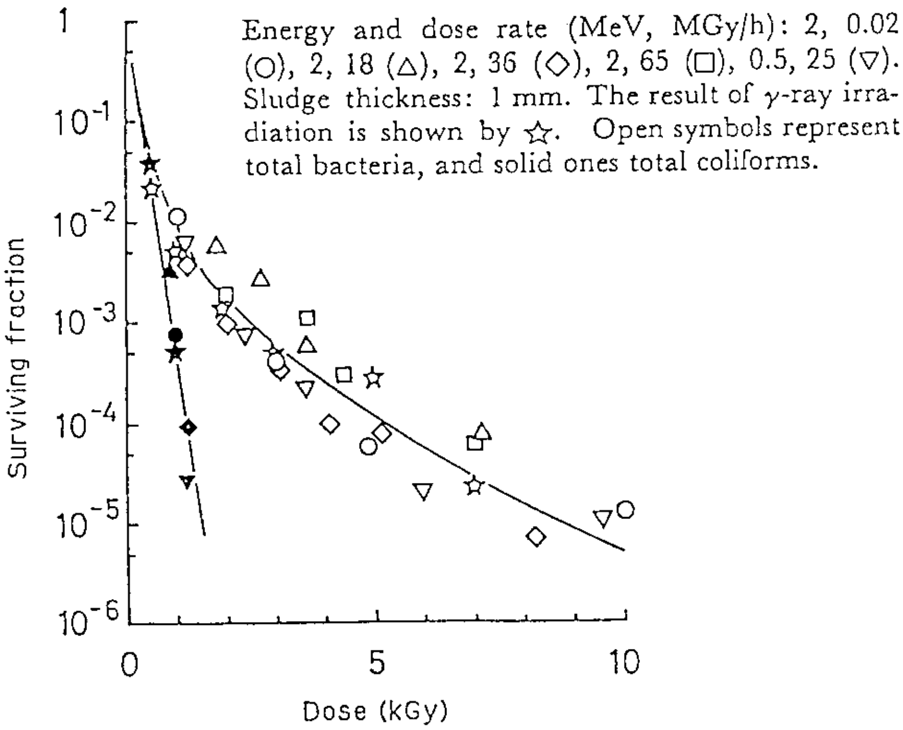


Fig. 7 Effect of dose rate and energy on disinfection of bacteria in sludge

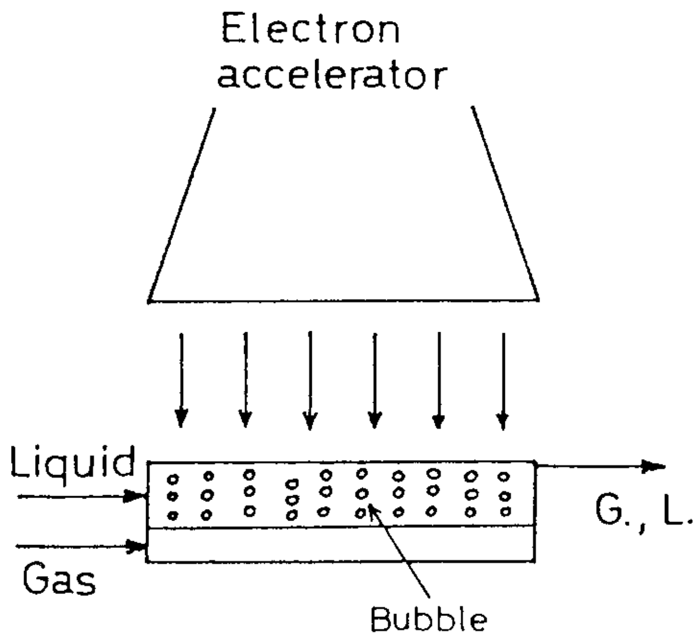


Fig. 8 Thin layer reactor

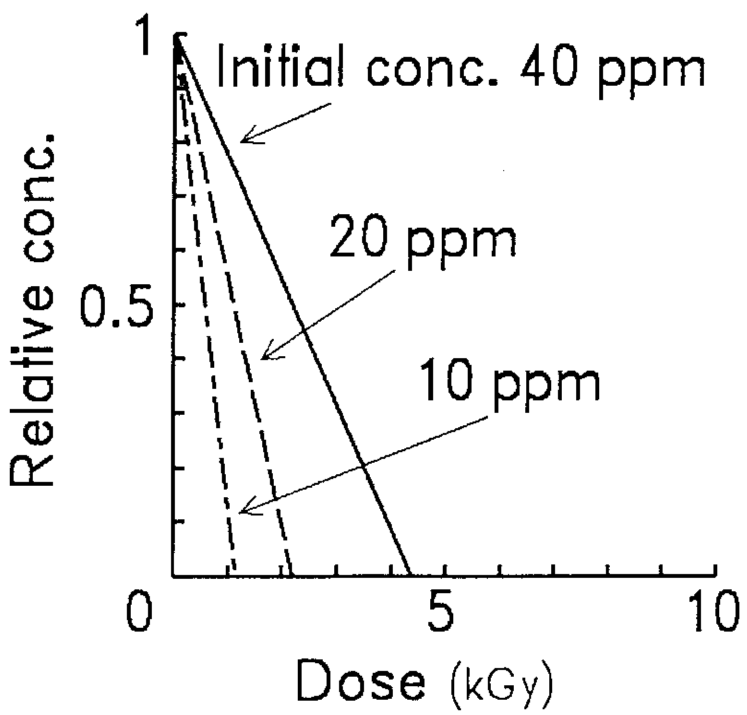


Fig. 9 Oxygen concentration in thin layer reactor

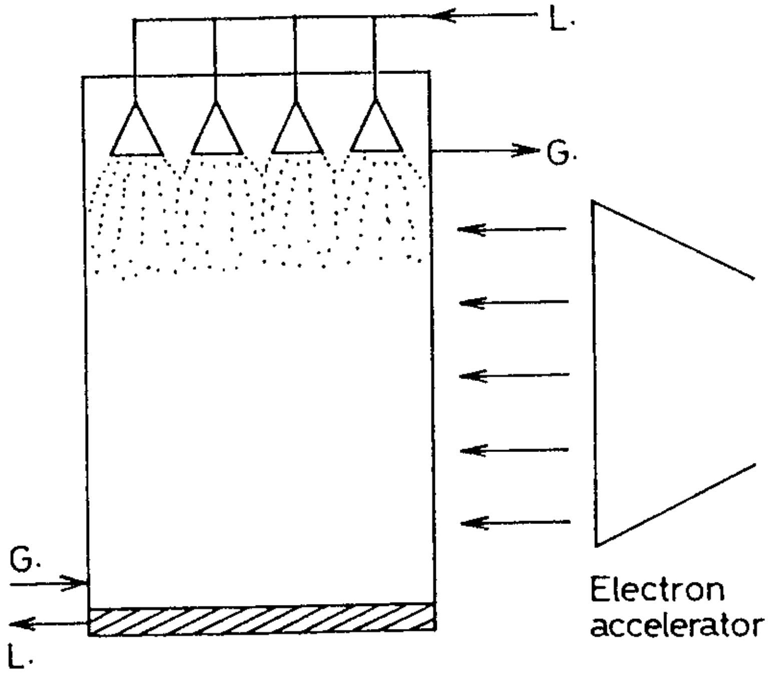


Fig. 10 Spray tower reactor

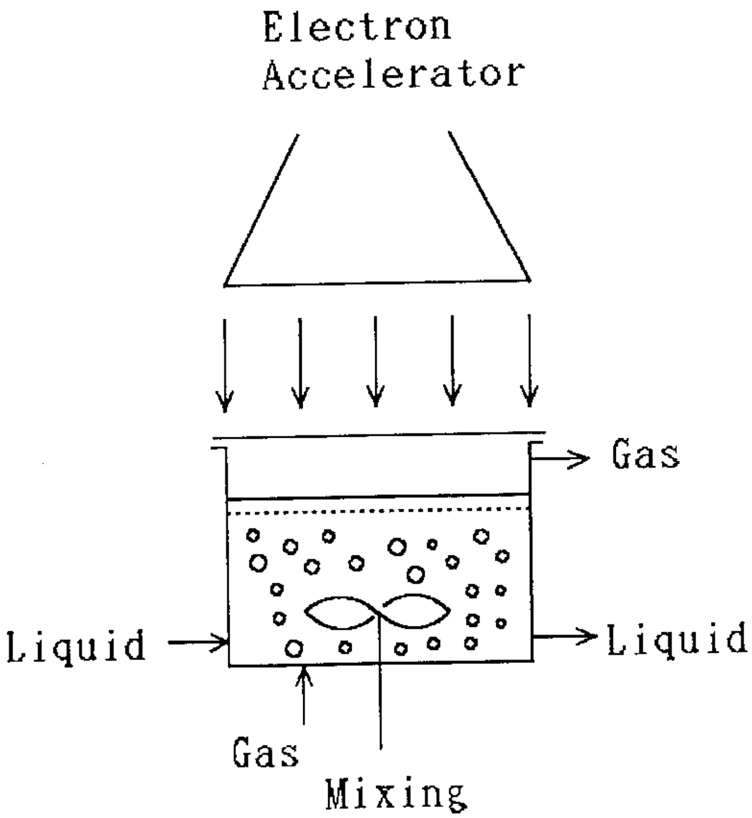


Fig. 11 Mixing-type reactor

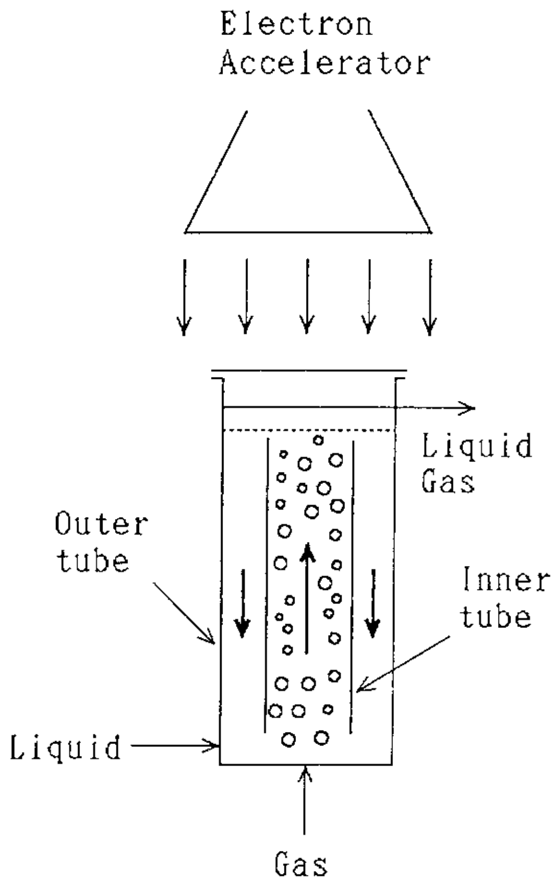


Fig. 12 Dual-tube bubbling column reactor

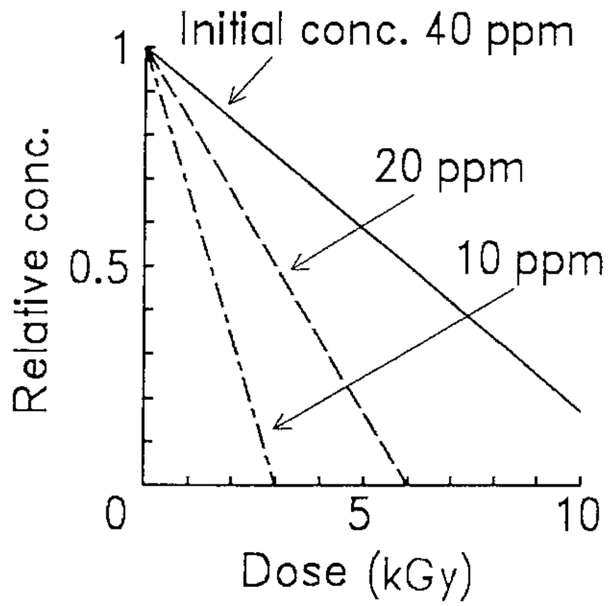


Fig. 13 Oxygen concentration in dual-tube bubbling column reactor

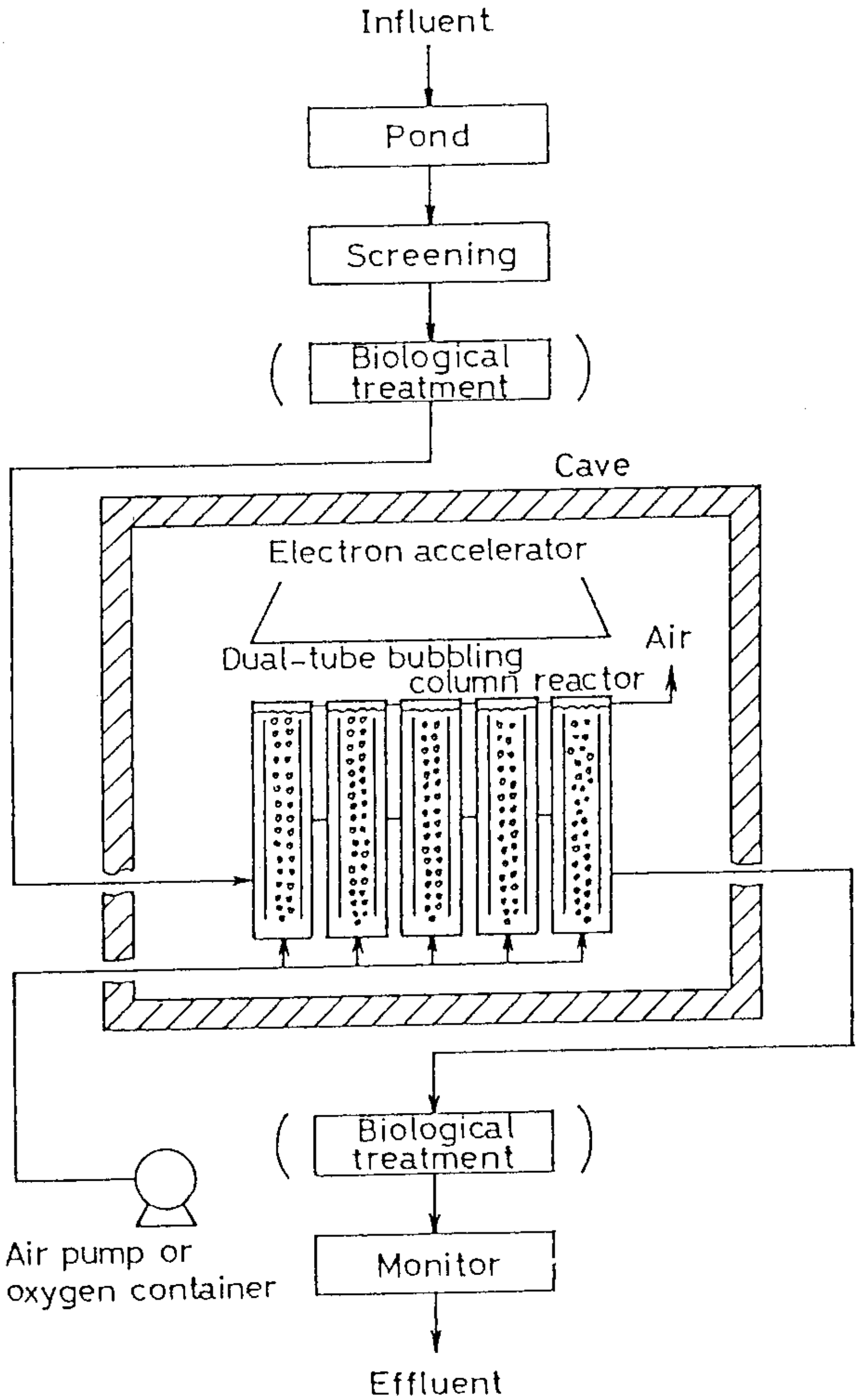


Fig. 14 Multi-stage dual-tube bubbling column reactor

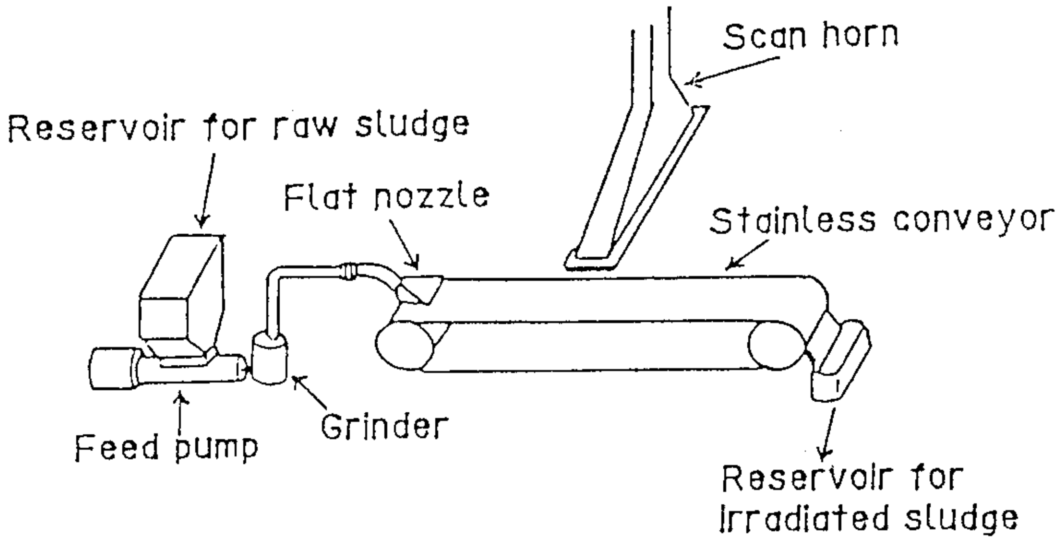


Fig. 15 Irradiation of dewatered sludge by electron beam

2.8. Flue Gas Purification with Electron Accelerators

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Takasaki Radiation Chemistry Research Establishment
Japan Atomic Energy Research Institute

1. INTRODUCTION

Higher industrialization and living standard have been realized on much consumption of fossil fuel as a major source of energy. Consumption of fossil fuel accompany with emissions of SO_2 and NOx which cause acid rain of recent serious global environmental problem.

Diversification of energy sources, on the other hand, has been important in Japan from a viewpoint of energy security. Use of coal, in addition to natural gases as fuel in electric power stations have been revaluated to avoid being partial to petroleum. So a new process has been required for SO_2 and NOx removal from coal−fired flue gas.

Most of municipal waste, further, have been treated by incineration, in Japan. Recently, municipal governments are asked often to make slow down operation of incinerators in sunny days of summer to reduce emission of NOx which cause photo−chemical smog.

EB treatment technology of flue gases for simultaneous removal of SO_2 and NOx has a long history in its developmental research as shown in Table 1. We started two pilot tests for applying this technology to treat−ment of coal−fired flue gas and exhaust gas from municipal waste incinera−tor 1991.

This paper reviews JAERI's R & D of this technology for applying to flue gases from heavy−oil burning boiler, iron−ore sintering furnace, coal−fired power station and municipal waste incinerator.

2. TREATMENT OF HEAVY OIL BURNING FLUE GAS

The systematic research of the EB process of flue gas treatment was started under the cooperation of JAERI and Ebara Co., in 1972(1). In this research, a small scale flow–type apparatus(60 Nm^3/h) shown in Fig.1 was used. Flue gas from a heavy oil burner was led to the irradiation chamber after removing dust by an electrostatic precipitator. The gas contained 600–900ppm SO_2 and 80ppm NOx. The gas was circulated using a blower at a higher flow rate than the supplying rate between the chamber and an electrostatic precipitator for mixing gas to get uniform irradiation.

Fig. 2 shows effect of EB irradiation on SO_2 and NOx removal for various conditions. It was firstly found that the EB treatment of exhaust gas could remove SO_2 and NOx in it, simultaneously.

3. FLUE GAS FROM AN IRON-ORE SINTERING FURNACE

The EB technology was applied to removal of NOx in exhaust gas from iron–ore sintering furnace. The exhaust gas from the furnace contains high concentration of dust which make the life time of the catalyst for removal of NOx shorter, so a new process was required for NOx removal. JAERI carried out a basic research (gas flow rate: 1 Nm^3/h) using synthetic gas to develop this technology(2). It was shown that SO2 and NOx could be effectively removed by EB irradiation in the presence of added Ammonia.

Based on these results, a pilot plant test was carried out at the scale of 10,000 Nm^3/h by Research Association for Abatement and Removal of NOx in the Steal Industry and Ebara Co. at Wakamatsu Works of Nippon steel Corporation(3). In this plant two electron accelerators of 750keV, 60mA each were installed. Fig.3 shows the result of pilot plant test. As seen in this figure, the SO_2 and NOx removal efficiencies were maintained over 95% and 85% at 15kGy and 80°C, respectively.

4. FLUE GAS FROM COAL-BURNING POWER STATION

For EB treatment of coal-burning flue gas, systematic experiments were carried out using simulated gases and a small scale flow-type apparatus shown in Fig.4(4). Standard gases were led a mixing vessel to get the simulated gas. The simulated gas was led to a irradiation chamber, before irradiation NH_3 gas was added. Products in the irradiated gas were collected in an electrostatic precipitator and filter. In these experiments, multi-stage irradiation was examined to get higher removal efficiency for the same dose irradiation. The irradiation chamber are divided to three section as shown in the figure. Unirradiated time was 0.5 second, which is the gas passing time through the irradiation zone. So gas is irradiated intermittently.

Fig.5 shows effect of multi-stage irradiation on removal of NOx. It was found that higher NOx removal efficiency could be achieved by this method. Fig.6 shows effect of irradiation temperature on SO_2 removal. At 65 °C, higher removal efficiency is obtained than 70 °C.

Fig.7 shows the mechanism of NOx and SO2 removal reactions which are composed of both radical and thermal reactions(5). Solid lines indicate radical reaction, while dotted lines indicate thermal reactions. Formation of HNO_2 is very important for removal of NOx. Under irradiation, HNO_2 react with OH to produce NO via NO_2, that is a reverse reaction. Without OH, HNO_2 decomposes thermally to HNO_3. This mechanism is reason why the multi-stage irradiation give higher removal efficiency of NOx. In SO_2 removal, there are thermal reactions between SO_2 and NH_3 as shown in this figure.

On these basic results, a pilot−scale test for EB treatment of flue gas from coal−burning boiler has been started under the joint research of JAERI, Chubu Electric Power Company and Ebara Corporation. The plant was constructed in the site of Shin−Nagoya thermal power plant of Chubu Electric Power Company in Nagoya in October, 1992. The operation will be carried out for one year until December, 1993. The main purposes are to evaluate the three−stage irradiation method and the reliability of this process in long term operation.

Fig.8 shows a flow diagram of the pilot plant(5). 12,000Nm^3/h coal fired flue gas is led to the pilot plant. The temperature is supposed to be 110 °C, and concentration of SO_2 is 800ppm, NOx is 225ppm. Firstly, gas is cooled at the cooling tower to 65 °C. After adding NH_3, the gas is led to irradiation vessel and irradiated by electron beams using 3 electron acceler− ating tubes. Voltage is ranging from 400 to 800kV, current is 135 mA maximum. Irradiated gas is led to the electrostatic precipitator and bag filter to remove by−products; ammonium sulfate and ammonium nitrate. Treated gas is vented from a stuck. Target of the test are; SO_2 concentra− tion is reduced to lower than 50ppm from inlet concentration of 800ppm, NOx is reduced to lower than 45ppm from 225ppm.

In Table 2, engineering problems in application of the EB process for treatment of flue gas from coal−fired power generation plants are summa− rized. The first one is saving of electricity consumption. It is required that energy consumption should be less than 2−3% of electricity generation of the plant. When the required dose is 10kGy, the consumed electricity for EB is about 0.6%. The total required electric energy will be less than 2% including utility. The second is non−uniform distribution of dose rate and flow rate in reactors, which will be large scale for stem power stations. In this pilot plant, flow regulator are installed to adjust flow rate to dose rate distribution in the reactor. The third is use of by−products. Production of by−products is estimated as follow: When the treatment capacity is 3 MNm^3/h which correspond to flue gas flow rate from 1 MkW power generation plant, and the inlet concentration is 1,000 ppm, and removal efficiency is 80%, the production rate of $(NH_3)_2SO_4$ is estimated to be 124 kton/y(26 N−equivalent kton/y), and correspond to about one tenth of pro−duction(340 N−kton/y) in Japan, 1990 as shown in Table 3. So use of N−fertilizer should be discussed of compatibility with conventional industries.

5. FLUE GAS FROM MUNICIPAL WASTE INCINERATOR

More than 70% of municipal waste have been treated by burning, in Japan, as shown in Table 4. Other is treated by landfill. Recently, munici−pal government are asked often to make slow down operation of incinera−tors in sunny days in summer to reduce emission of NOx.

To apply the EB process for treatment of flue gas from incinerators, simultaneous removal of NOx, SO_2 and HCl was studied by EB irradiation in the presence of $Ca(OH)_2$ using a small scale apparatus(5 Nm^3/h). Fig. 9 shows example of experimental results of NOx removal. Inlet gas compo−sition are shown in the figure. Lower irradiation temperature give higher removal efficiency. In this case, we used $Ca(OH)_2$ powder instead of NH3. SO_2 and HCl were shown to be removed almost 100%.

On these basic data, a pilot−scale test was also planned, and has been started under the joint research of JAERI, Matsudo−city and NKK. Fig. 10 is a flow diagram of the pilot plant at Matsudo−city(6). 1,000 Nm^3/h flue gas is led to the pilot plant from the incinerator which generates 30,000 Nm^3/h. The gas is irradiated under spray of $Ca(OH)_2$ slurry. Electron accelerator is from Russia and is .9 MV in voltage and the current is 45 mA maximum. Irradiated gas is led to the bag house to remove calcium sulfate, chloride, and nitrate. Treated gas is vented from a stuck.

Target of the test are; NOx is reduced to lower than 50ppm from inlet concentration of 100ppm, HCl is reduced to lower than 10ppm from 1,000ppm, and SO_2 is reduced to lower than 10ppm from 100ppm. The main purposes are to evaluate simultaneous removal of NOx, HCl and SO_2. The plant was already completed in Matsudo city and was started to operate from June, 1992.

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2. O.Tokunaga et al., Radiat. Phys. Chem.,24,145(1982).
3. K.Kawamura et al., Environ. Sci. Technol., 14,288(1980).
4. O.Tokunaga et al, "ELECTRON BEAM IRRADIATION TECHNOLOGY FOR ENVIRONMENTAL CONSERVATION", Proceeding of the International Conference on Evolution in Beam Applications, Takasaki, 1991.
5. H.Namba et al, "BASIC STUDY ON ELECTRON BEAM FLUE GAS TREATMENT FOR COAL-FIRED THERMAL PLANT", ibid.
6. T. Doi et al, "PILOT-PLANT FOR NOx, SO2, HCl REMOVAL FROM FLUE-GAS OF MUNICIPAL WASTE INCINERATOR BY ELECTRON BEAM IRRADIATION", ibid.
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Table 1 History of development of EB process for flue gas treatment

Flue Gas from		
Oil Burning Boiler		
60 Nm^3/h	JAERI/ Ebara	1972–1973
1,000 Nm^3/h	Ebara	1974–1977
Iron Ore Sintering Furnace		
10,000 Nm^3/h	Ebara/RAAR	1975–1978
Coal Burning Power Station		
1 Nm^3/h	JAERI/Ebara	1981–
1 & 12,000 Nm^3/h	JAERI/Chubu/Ebara	1990–
Municipal Waste Incinerator		
1 Nm^3/h	JAERI/NKK/Ebara	1988–1990
1,000 Nm^3/h	JAERI/Matsudo/NKK	1991–

RAAR:Research Association for Abatement and Removal of NOx in the Steel Industry

Table 2 Engineering problems in EB process

Saving of Electricity Consumption

Non–uniform Distribution of Dose Rate
and Flow rate in Reactor

Use of By–Products($(NH_4)_2SO_4$, NH_4NO_3)

Protection of Window

Table 3 Production of by-products

Treatment Capacity	: 3 Mm^3/h (for 1 MkWe)
Inlet Conc. of SO_2	: 1,000ppm
Removal Efficiency	: 80%
$(NH_4)_2SO_4$	: 124 kton/y(26 N-kton/y)

Production of N-Fertilizer in Japan
(N equivalent kton/y)

	Production	Import	Export
1986	988.2	187.1	191.3
1987	986.4	215.0	217.9
1988	976.7	187.0	200.6
1989	945.7	232.0	184.0
1990	956.8	212.6	232.1
(1990	339.4 by $(NH_4)_2SO_4$)		

Table 4 Treatment of municipal waste in Japan

	1990	1991
Amount of Waste(t/day)	126,956	132,582
Treatment of Waste(t/day)		
Incineration	89,116(72.6%)	93,552(72.8%)
Landfill	28,773(23.4%)	29,552(23.0%)
Composting, Animal Feed	144 (0.1%)	170 (0.1%)
Others	4,730 (3.9%)	5,285 (4.1%)

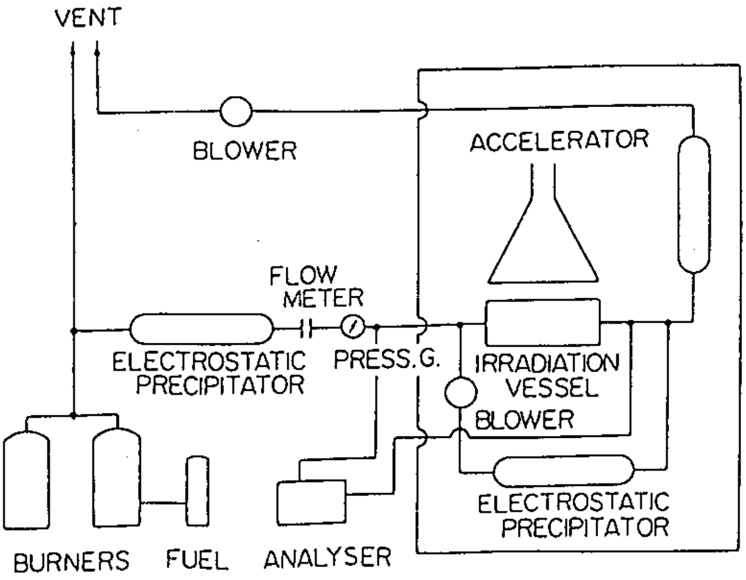

Fig. 1 Flow sheet of a small scale flow type apparatus

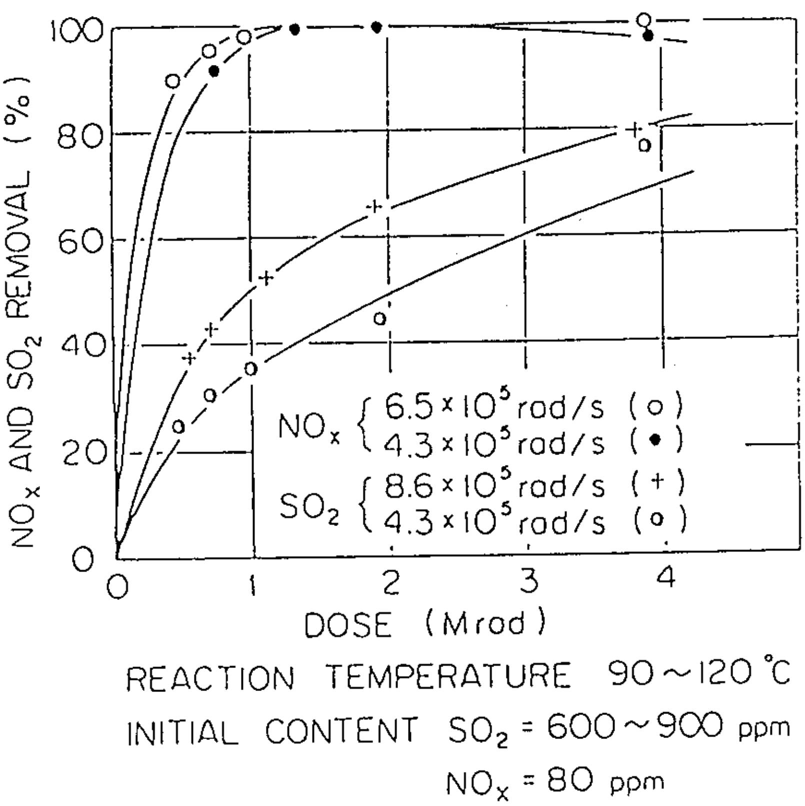

Fig. 2 Removal of SO_2 and NO_x at various dose rates

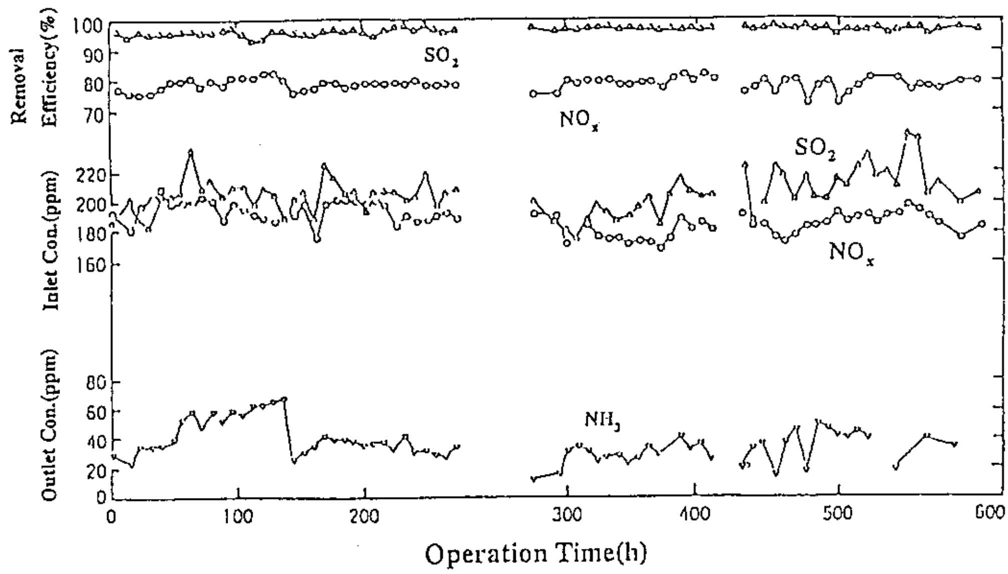

Fig. 3 Pilot plant test of iron ore sintering furnace exhaust gas
Gas flow rate: 3,000Nm^3/h, Dose: 1.5Mrad, Temp.: 80°C

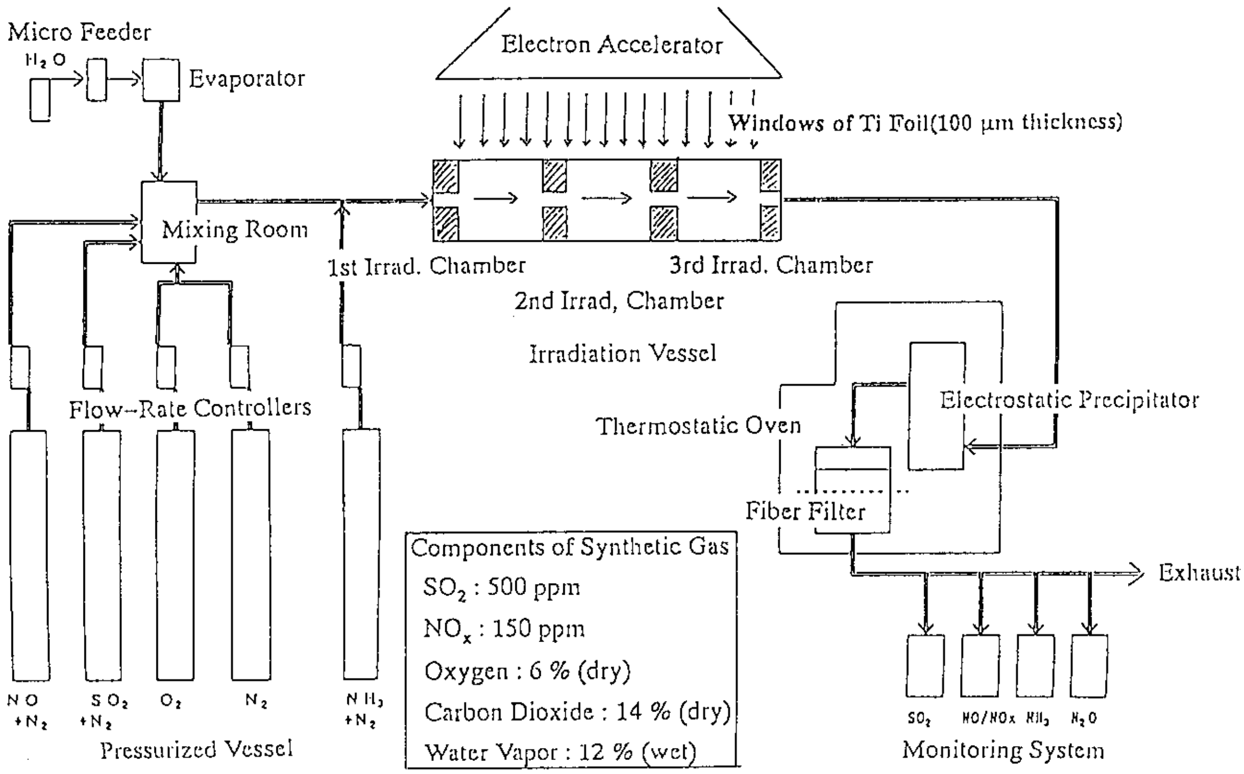

Fig. 4 Experimental apparatus for basic test of EB treatment of flue gas from low-sulfur coal burning boilers

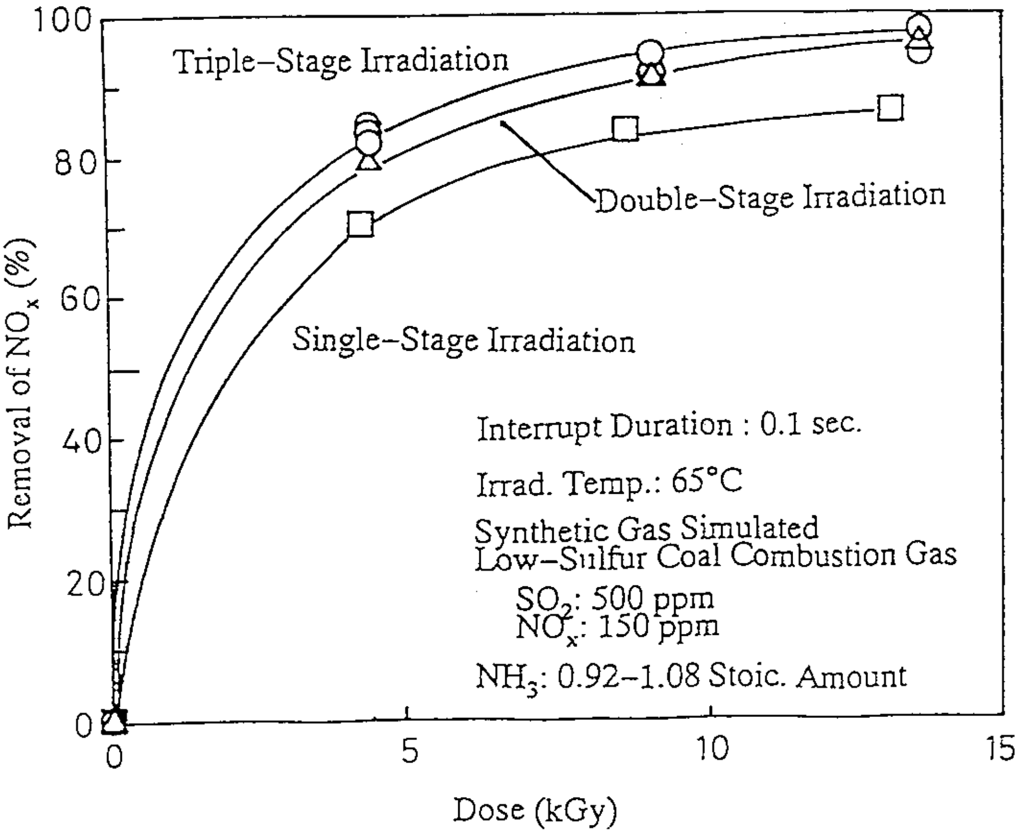

Fig. 5 Effect of multi-stage irradiation on NO_x removal

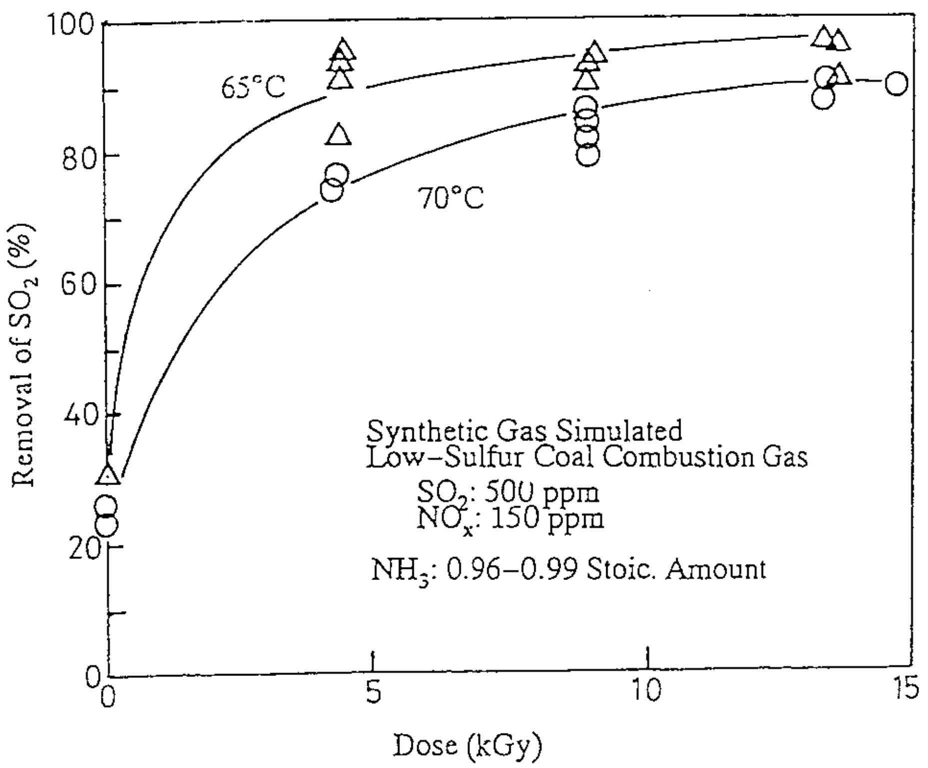

Fig. 6 Effect of irradiation temperature on SO_2 removal

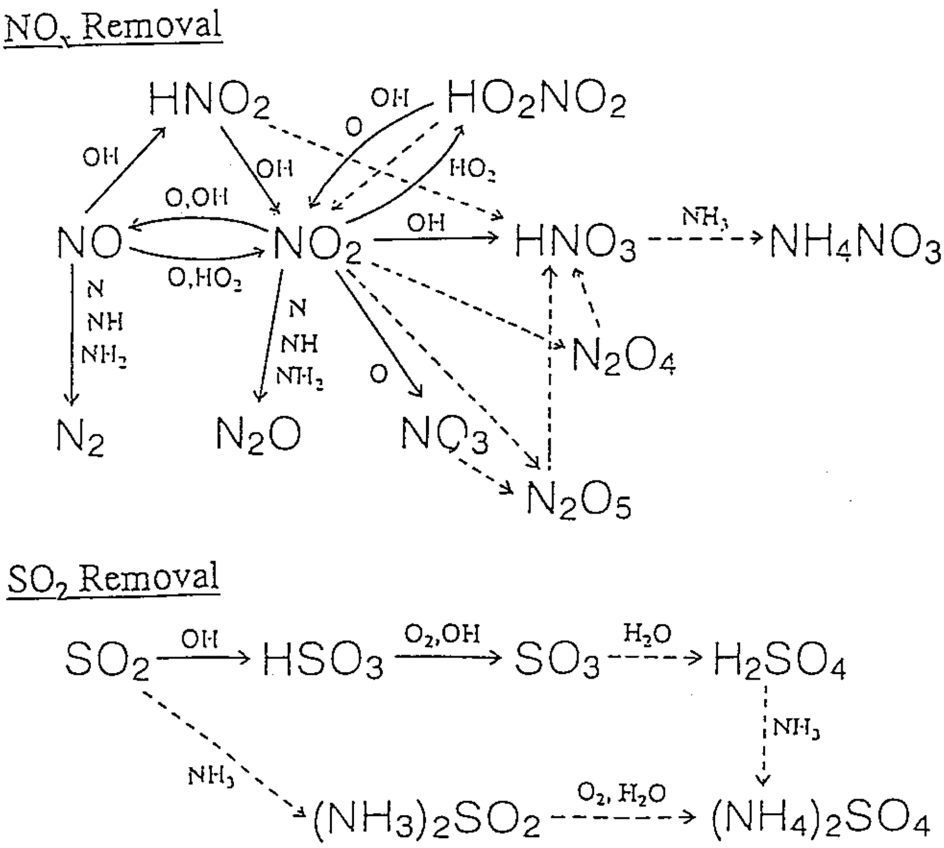

Fig. 7 Main reaction path to remove NO_x and SO_2
solid arrows indicate radical reactions
dotted arrows indicate other "thermal reactions"

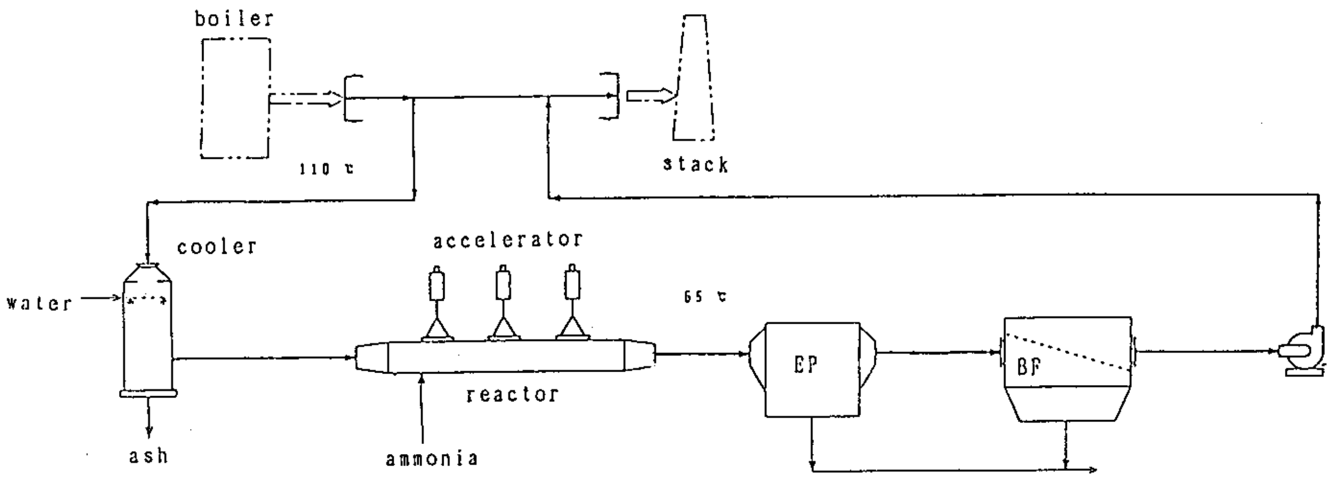

Fig. 8 Flow diagram of the pilot plant for EB treatment of coal-fired flue gas at Nagoya

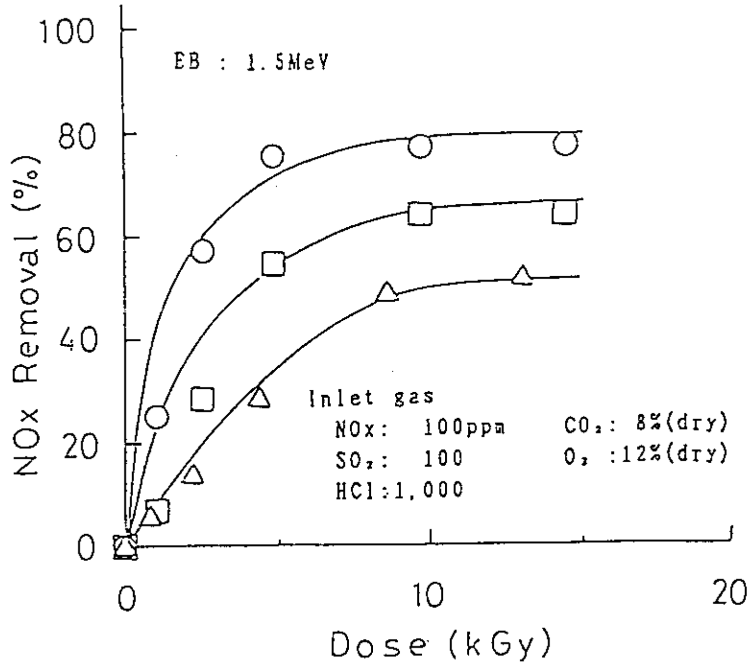

Fig. 9 Effect of temperature on NO_x removal
150°C, 200°C, 250°C
$Ca(OH)_2$: twice mol of HCl
water : 22.0 ~ 24.8%

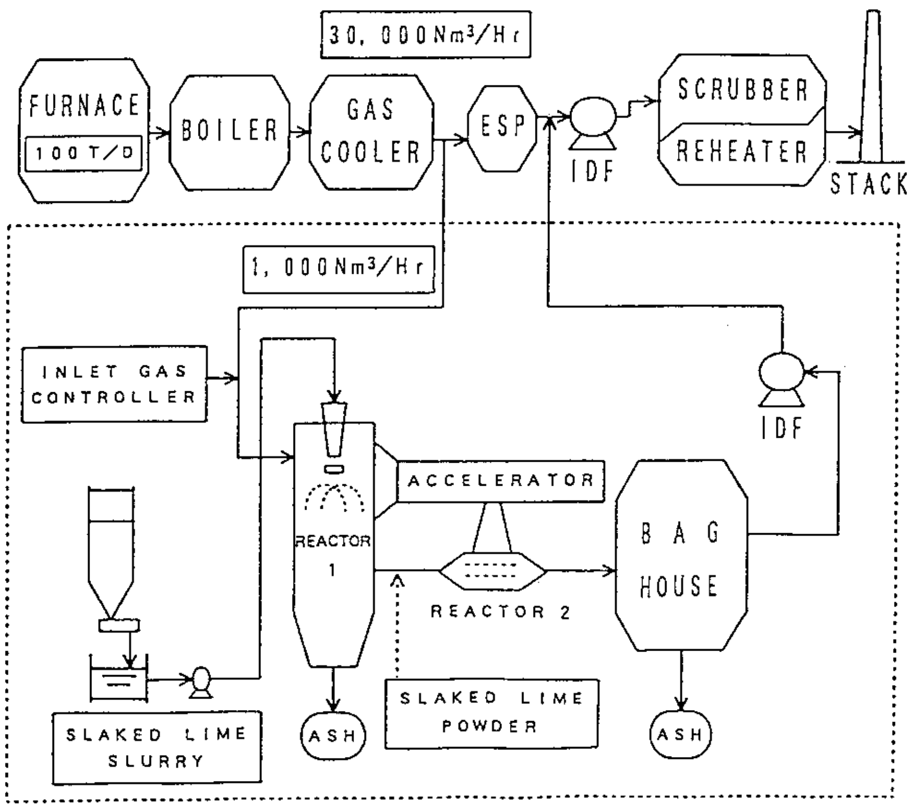

Fig. 10 Flow chart of the pilot plant for treatment of flue gas from an incinerator at Matsudo-City

2.9. Potential Industrial Application of Electron Accelerators in Indonesia

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INTRODUCTION

Today's technology concerns with high quality and high performance products, save in energy and preserve environment.

Since the last decade, radiation technology has made a great progress in the production method, particularly in the production of high quality sterilized medical products, wire and cable and shrink tubing,heat shrinkable film, the partial curing of tire components, and foam manufacture (1-4).

The near future, the electron beam (EB) accelerators will aplicable in crosslinking packaging films and in curing coatings and inks (5). New materials like pressure sensitive adhesives, silicone release coatings and other specialty coatings will expand the market potential of EB accelerator (6).

Very recently, the surface sterilization of medical devices and food packages and the treatment of stack gases to remove sulfur and nitrogen oxides are also being explored (7,8).

Indeed advanced countries such as Japan, Germany, France and USA have used the radiation technology to improve their industrial performance and capability. In Asia region, Taiwan and South Korea are recognized as the new industrial countries who are also applying EB accelerator in their production line.

Indonesia however, has a great potential in the application of EB accelerator. This is because of a remarkable growth of industrial sector ,the abundant of natural resources, and the increasing demand of the product quality to support high-tech and high risk industries.

The present paper discusses the potential industrial application of EB accelerator in Indonesia. It is expected that the paper could be able to presence informations and to invite a useful discussion.

STATUS OF RADIATION PROCESSING IN INDONESIA

National Atomic Energy Agency, Centre for Application of Isotops and Radiation (CAIR-BATAN) is the only institute to take initiative to conducting research and development of radiation technology in Indonesia.

Two gamma ray irradiators with a total power of 225 kCi Cobalt-60 source and Electron Beam (EB) accelerator of 300 KeV are available at the CAIR-BATAN.

During the last 10 years, CAIR-BATAN has gained a great progress in the depelopment of irradiation techniques, particularly to produce pre-vulcanized Natural Rubber(NR) latex, diffe- rent kind of preserved spices, to sterilization of medical and pharmaceutical products and to curing of wood surface coating (9,10). The present

EB accelerator available in CAIR-BATAN is a low voltage (300 keV) and low penetration of electron beam. It is only applicable for curing of surface coating and other surface treatments.

In order to perform R&D in polymer crosslinking such as crosslinking of wire and cable insulators, heat shrinkable tube and film, polyethylene foam and other possible industrial application of radiation technology,then a higher voltage (energy) EB accelerator is necessary.

CAIR-BATAN plans to build a new EB accelerator with a medium energy of 2 MeV. The building and shielding will be constructed this year and the EB accelerator will be installed later in 1993.

The most important progress in the transfer technology program is the establisment of a commercial plant of gamma rays iradiator in near Jakarta. The irradiator with an initial loading of 400 kCi Cobalt-60 source is belong to private company, INDO-GAMA, and it is commissioned last month (May 1992)

The irradiation facility will be mainly used as an irradiation sevice centre for the sterilization of medical and pharmaceutical products.

A bilateral research cooperation between JAERI and BATAN has successfully developed the adhesive and thermoplastic elastomer made from irradiated natural rubber (NR) latex (11).The bench scale results, however needs further efforts to bring it to be industrial scale. Another results as an output of the bilateral research cooperation are the development of hydrogels for biomaterials which are now under progress. Some of the results have been jointly patented in Japan.

ELECTRON BEAM CROSSLINKING

In fact the biggest applications of EB accelerator is occupied by the process of crosslinking of wire insulation (12).

There are at least 123 electric industries available in Indonesia i.e. 7 companies are foreign invesment and the rest are domestic companies. Not less than 26802 ton of different types of wire and cable products are produced annually by 14 companies as shown in Table 1. Its clear that wire and cable industries could be a great potential of EB accelerator processing, particularly when a heat resistant wire and cable insulation is required to support the industrial development in Indonesia.

The crosslinking technologies that are available to the industry are mainly chemical method.

- Continuous Vulcanization = CV Technology(peroxide and salt bath crosslinking)
- Monosil crosslinking and
- Sioplas crosslinking (silane crosslinking).

Each type of crosslinking has its specific advantages and an disadvantages. The CV crossliking is the most widely used technology to date.

However, it is necessary to discuss the advantages of EB crosslinking over the conventional process.

As compared to the CV method, the important advantages factor to EB crosslinking are:

1. Eliminate start-up and end scrap. By using the CV method, the start-up or end scrap is generally about 100 m long with the EB method, on the other hand , there is absolutely no star-up scrap.

2. Lower energy consumption. The CV method requires up to five times more.

3. Less factory space needed. EB crosslinking requires only about 50 % of the space needed by the CV method.

4. Higher crosslinking speed.
CV method: low voltage, e.g.1kV, 60-200 m/min
EB method: low voltage, e.g.1kV,up to 500-600 m/min

5. A longer spectrum of possible coss section can be terated
6. Faster and more flexible processing
7. Process control. It is easier to reproduced the crosslinking.

The factor that are often under estimated by those who are not thoroughly familier with radiation process:
- the cost of instalation and handling
- the length of time during which radiation process is interupted due to reel changes, different cross-sections or materials.

It should also be noted that no radiactivity can be induced in materials with accelerator energy levels up to 8 MeV and therefore it is a safe technology.

Some success companies that using EB crosslinking in USA, Europe and Japan are: Brond-Peek
ESSEX
Nothern Telecom
Shan
Siemens
Supernant
Sumitomo Electric
Furukawa Electric
Hitachi Cable
Taisho Electrical
Oki electric
Showa Cable etc.

Indeed, the use of EB accelerator is very important to produce the common good of mankind, especially in high risk area such as in the chemical industry, nuclear power plant, public building etc.

RADIATION CURING

There are 110 plywood mill with total capacity 10,700,000 cubic meters per year. In addition there are 58 blockboard industry and 8 particle board factory with total annual capacity of 981,500 cubic meters and 435,000 cubic meters (13). These are a potential raw materials that can be proceeded further by using EB accelerator technology in order to obtain value-added items.

EB accelerator can be potentially used to produce PVC-laminated plywood , acrylic-coated plywood and to surface finishing work for several kinds of wood products, paper and metals. These are because the EB accelerator is capable to be used for curing of surface coating instead of conventional heating technique.

Technical and economical evaluation on the application of EB accelerator for curing of wood surface coating will be presented in another manuscript at this meeting.

RADIATION STERILIZATION

A wide variety of medical devices are sterilized by gamma rays irradiator and EB accelerator. Included are items such as syringes, catheters,cotton balls, miscellaneous vials, latex gloves, blood lancet, disposable scalpel, birth control rings,surgical suture, artificial joint, gauze and dialysis unit (14).

The major competing sterilization method for medical disposables is Ethylene Oxide (EtO) method. The share of EtO sterilization method is gradually decreases from 70 % in 1988 to 55 % in 1993, whereas Gamma rays sterilization method increases from 27 % to 40 % and the EB method is 3 % in share during the same period. The changing market share of EtO to Gamma rays is mainly because of some disadvantage factors of the use EtO. For example, product residues and patient health concerns, worker safety, environmental emissions of the gas, legislation regarding the use of a hazardous chemicals, increasing capital and operating costs (15).

For the sterilization of medical supplies, it needs a high voltage (energy) EB accelerator type. For example EB accelerator with voltage in the range of 3 to 10 MeV. Only few such high voltage EB accelerators are available in the world (16).

To estimate the voltage requirement for the sterilization of 2 ml disposable syringe, the following formula can be applied (16):

$$\text{Voltage} = 2.63 \ TD + 0.32 \quad (\text{single sided treatment})$$
$$\text{Voltage} = 1.19 \ TD + 0.32 \quad (\text{double sided treatment})$$

where Voltage is in MeV, T is thickness in cm, and D is density. Alternatively, the value of TD can be expressed as the ratio of weight (g) per unit area (cm). Unit area is the length and width normal to the electron beam. In case of 2 ml syringe the value of TD becomes 4972/1609 g/cm = 3.1 g/cm

Therefore the voltage of EB accelerator should be,

$$E = 1.19 \times 3.1 + 0.32 \quad (\text{double sided treatment})$$
$$= 4.0 \text{ MeV}$$

The potential application of EB sterilization technique in Indonesia can be estimated by the health care activities such as the existence of hospitals, physicians, pharmacists, nurses and medical doctors as well as Indonesian population as shown in Table 2.

The most important factors in determined a cost for the EB accelerator faciliity in general are :
- the accelerator voltage
- the building and shielding
- the product conveyor and
- the people involved

FOOD IRRADIATION

The most promissing application of radiation technology in food treatment seems to be the irradiation of spices. As well as gamma irradiator, EB accelerator has also a great potential to be applied as far as the public acceptance and the legislation of the technology are world wide approved. Table 3 shows export statistic of different spices which are considered profitable (17).

FLUE GAS TREATMENT

The growing of industrial sector in Indonesia needs an early awarness to environmental concervation. Recently, EB accelerator has been examined to be used at pilot scale for the treatment of exhaust gas from steel sintering plant and Coal electric power plant (2,8). Figure 1 shows a process flow diagram of EB flue gas treatment system. Briefly, the exhaust gas or flue gas is introduced into a cylinder vessels at 100 C to be irradiated with two accelerators. Small amount of ammonia is added before irradiation to enhance removal rate of NO and to decrease the formation of NO2. Under irradiation, SOx and NOx are converted to complex salt of ammonia sulfate and nitrate, which is collected in an electron precipitator. Details will be reported in this workshop.

Indeed all the combustion gas from heavy oil and coal factories should be treated before it is released to the environment. At present, at least 2 (two) coal electric power plants and several oil electric power plants as well as different chemical plants are available in Indonesia. The radiation treatment of combustion gases to remove sulfur dioxide and nitrogen oxide is one alternative to have a clean environmental industry.

CONCLUSION

The potential applications of EB accelerator in Indonesia, particularly in the production of heat resistance wire and cable insulators, surface coated of plywood by radiation curing techniqnue, electronic parts by radiation curing technique, spices and herbs treatment for export,heat shrinkable film and sheet for packaging materials, treatment of a part of tire component, sterilization of some selective medical divices and treatment of flue gas from different industries have been presented.

Research and development in the field of radiation technology and some progress of a bilateral research cooperation between TRCRE-JAERI and BATAN have been reported.

The application of EB accelerator in industrial line is much depended on the good will and attitude of Indonesian's enterprenuer as well as the ability to absorb the knowledge and know how of radiation technology. BATAN as the only research institute in Indonesia who is doing a lot of work in this field is ready to provide necessary informations and consultations.

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Table 1 Some wire and cable industries in Indonesia

No.	Name of Company	Typical Products	Annual Capacity
1	PT. Kabelindo Murni	Electrical Wire & Cable Telephone Cable	4100 ton
2	PT. Kabelmetal Indonesia	Electrical Wire & Cable Telephone Cable	3800 ton
3	PT. Suraco	Telephone Cable	1200 ton
4	PT. Terang Kita	Electrical Wire & Cable Telephone Cable	7357 ton
5	PT. Indotrijaya Industries	Telecomm Cable	100 ton
6	PT. IKI Indah Kabel Indonesia	PVC Power Cable Telecommunication Cable Medium Voltage Cable	770 ton
7	PT. Jembo Cable Company	Telephone Cable	1450 ton
8	PT.Nikkatsu Electric Works	Electrical Cable Telecommunication Cable Electronic Cable Automobile Cable	500 ton
9	PT. Sinar Merbabu	Telecommunication Cable	2400 ton
10	PT. Voksel Electric	Electrical Cable	600 ton
11	PT. Jayako Murni Abadi	NYA, NYM, NYY, NYFGBY, AAC, AAAC ACSR,XLPE	840 ton
12	PT. Nasiodelta Electric	PVF, PEW, UEW, EIW	1800 ton
13	PT. Phenolic Prima Indonesia	NYA, NYM, NYY	885 ton
14	PT. Pudji Tjahaja	Electrical Cable	1000 ton
	Total capacity		26802 ton

Table 2 Health statistics

Life Expectancy (male)	57 years
Life Expectancy (female)	61 years
	Number
Hospitals	1,408
Hospitals Beds	83,101
Physicians	20,768
Dentists	2,500
Pharmacists	3,587
Nurses	122,945

Table 3 Export of spices from Indonesia to different countries in 1988 (7)*

COUNTRY	SPICES IN TONNAGE		
	WHITE PEPER	BLACK PAPER	NUTMEG
USA	5,934	10,938	704
Netherlands	5,249	235	1,351
France	60	25	444
Belgium & Luxemburg	275	-	440
Canada	892	160	-
Hungary	855	744	-
China	50	70	-

* Source : Indonesian Central Bereau of Statistic

Table 4 Plywood industries and its capacity

Product	Total capacity	Production (m^3)
Plywood	110	9,000,000
Blackboard	58	700,000
Partickleboard	8	101,000

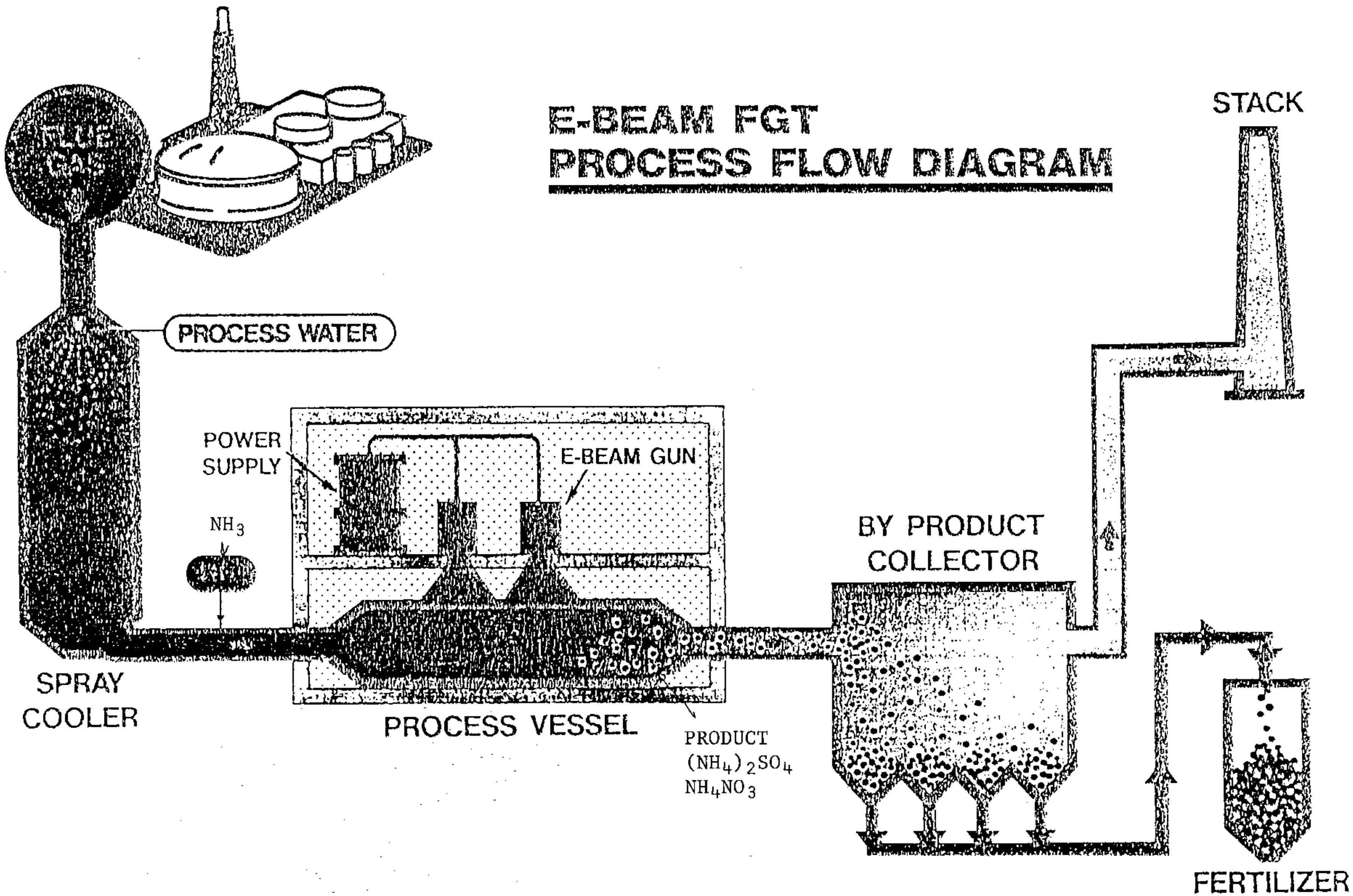

Fig. 1 Flue gas flow sheet

2.10. Progress in Electron Beam Curing in Indonesia

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INTRODUCTION

The use of radiation, both ultra-violet (UV) or electron beam (EB) is becoming important in the present time for curing and pigmented film. UV radiation is generally used for smaller scale, slower line speed operation and clear coating, where as EB is more suitable for large volume processing and relatively thick pigmented coating. Commercial application of EB curing of surface coating for wood products had appeared since early of 1970 decade. Today there are several companies using this technology successfully. This technology appears to be attractive to countries producing a large amount of wood panel such as Indonesia, Phillipine, Malaysia etc.

Under a cooperation between IAEA/UNDP and the government of Indonesia, a radiation curing of surface coating pilot plant had been installed in Jakarta (1984). The mission of the plant is for training, demonstration as well as for studying both technical and economic aspect of the technology in the region. Approximately one million US $ was spent for this project. Although the equipments of the plant are commercial size, but the plant was not designed for commercial production.

Several Regional Training Courses on radiation curing had been held in Jakarta from 1984 to 1990 using this plant. These courses were followed by a number of participants from RCA Member States : Bangladesh, India, Pakistan, Thailand, Indonesia, Sri Lanka, Malaysia,China,Rep. of Korea, Singapore,Phillipine and Vietnam.

PRINCIPLE OF RADIATION CURING TECHNOLOGY

Basic chemistry of the technology is a liquid compound which will undergo polymerization, crosslinking or grafting under EB or UV radiation, forming a hard solid compound. There is a great number of formulation of this compound but generally the compound is a mixture of oligomers with mono or poly functional monomers and additives such as pigmented materials. This is a liquid compound which can be coated readily on any surface ,such as wood panel, using conventional coating equipments: roll coater, curtain coater, sprayer etc. These compounds are commonly called radiation curable materials. The formulation of the radiation curable materials depend on the utilization and technical specification required for the products : for coating on wood panel, metal, ceramic, plastic etc.

Example formulation of radiation curable material for top coat is as following :

	Wt part
Epoxy acrylate (EA-81)	70
Polyethylene glycol diacrylate (PEGDA)	30
Silicon oil	1

Principle flowsheet of radiation curing of surface coating is shown in Fig.1. Wood panel is passed through a coating machine, such as roll coater, where the panel is coated with a radiation curable material. The coated panel then is passed through an EB machine under an inert atmosphere, by flowing N_2 gas, where the radiation curable coating is polymerized, crosslinked or grafted, forming a solid hard coating. This process takes about 0.5 minute for one piece of wood panel (1.2x2.4 m) using EBM with beam current about 20 mA. This is a basic flowsheet of the process. In practice to obtain an excellent coating, several times of coating and radiation are required using different formulation of radiation curable material.

Instead of EBM , UV source can be used for radiation, but this radiation is limited for a clear coating and further more a photoinitiator should be added in the radiation curable formulation. The advantage of using UV radiation is unnecessary of using inert atmosphere and low cost of UV source which consequently resulting low cost of operation.

THE PILOT PLANT

The pilot plant is housed in a building of 720 sqm, steel construction and located inside the area of Center for the Application of Isotopes and Radiation, Jakarta. Building construction and equipments installation were completed in the end of 1984, while a small modification was done in 1989.

Specification of essential equipments available are as following:

1. Electron beam machine (EBM)

This machine is made by Nissin High Voltage Co.,Japan, scanning type EBM with 120 cm beam width, 300 keV , 50 mA maximum beam current, and lead shielded. Inert gas requirement ($N2$ gas) is normally about 100 NM^3/hour, or about 150 liter of liquid nitrogen/hour. The speed of conveyor is between 2.5 m and 25 m/min. Conveyor speed and beam current determine the dose of irradiation (Figure 2).

2. Ultra Violet (UV) source

This source is equipped with an UV lamp of about 80 Watt/cm length. The length of the lamp is about 120 cm while the conveyor speed is between 3 and 6 m/min.

3. Roll coater

Two kinds of roll coater available in this plant: direct roll coater and reverse roll coater. Both with 120 cm coating width and speed between 10 and 40 m/min. The electrical power requirement is 1.2 kW and 6 kW respectively.

4. Film laminator

The speed of the machine is between 5 and 20 m/min. The size : 174 cm width, 135 cm length and 188 cm height. The electrical requirement is about 1 kW. Compressed air is required with pressure between 6 and 7 kg/cm^2

5. Sanding machine

This machine is equipped with an exhaust blower with capacity 160 nM^3/h.

Equipments layout of the plant is shown in Figure 3, but this lining is not reflecting a flowsheet of a typical process. For a typical application, a typical flowsheet of the process is required. Total investment of the plant is about one million US $ (Table 1).

Table 1 Description of the pilot plant investment

Items	Cost, US $	Budget
1. EBM	540,000	IAEA/UNDP(1984)
2. Wood hand.equip.	128,500	Batan/Ind.(1984)
3. Lab.equipt.	70,000	Batan/Ind.(1984)
4. Building	259,500	Batan/Ind.(1984)
5. UV source	15,000	IAEA (1986)
6. Reverse RC&Laminator	65,000	IAEA (1989)
Total	1,078,000	

APPLICATION OF THE PILOT PLANT

The equipment of the plant was reported to be running well from the begining of operation, but not for the plant as a whole. The plant has been reported unable in producing a product with property as formerly desired. There were some problems with :

- radiation curable materials
- inert gas consumption
- poor raw material available
- eqipment lining
- wood handling equipments

A ready for use of radiation curable materials with desired property and reasonable price was unavailable at the begining of operation.The expert accompanying the equipments did not give any satisfying recommendation. Finally our group decided to develope by themselve the formulation of radiation curable materials for a specific application using the available component. Although it takes a time but we have higher degree of freedom in using the materials. Radiation curing of surface coating technology actually was not a well established technology so far, and that is why a ready for use radiation curable material with reasonable price is not available locally.

Flowing an inert gas is very important in EB curing because the polymerization reaction is retarded with the existance of trace oxygen. In practical purposes, N_2 gas is used which is coming from evaporation of liquid nitrogen. It was reported that consumption of liquid nitrogen is between 150 and 200 liters/h. It is easily to understand that this technique cannot be used in region where unavailable liquid nitrogen plant. A very high purity of liquid nitrogen is required. The oxygen content should be less than 1000 ppm, otherwise there will resulting a sticky surface. Unfortunately the purity of commercial liquid nitrogen was unconsistant from one batch to the other, and this will causing a difficulty in adjusting the dose of irradiation required for curing.

After years of operating the wood handling equipments, it was concluded that the equipments were unable to produce a fine coating as formerly expected. One of the reason is the poor wood panel available : unevenness in thickness, defecting on the surface and poor dimensional stability due to humidity. This will causes a great difficulty in the pretreatment processing as a whole. The other reason is coming from the equipments itself.

PROCESS DEVELOPMENT

A number of processes had been developed in the facility either the radiation curable materials or its processing flowsheet: coating on particle board, multiplex and wood parquet flooring. A number of formulation of radiation curable materials, process flowsheet and cost analysis of thechnology had been reported. Example of the process is the process of coating on wood parquet flooring. It had been reported that the coating cost was largerly coming from radiation curable materials(74.3% , based on US $ 8.33/kg), followed by liquid nitrogen cost (16%) and the rest is plant operation (9.7%). Investment required for a plant producing 5 million sqm of wood parquet flooring /year is about two million US $ and the coating cost was about US $ 2.17/sqm.

Table 2 Coating on wood parquet flooring

	Cost, %
Radiation curable mat.	74.3
Liquid nitrogen	16.0
Plant operation (labour, depreciation, maintenance etc)	9.7
	100.0%

For clear coating of wood parquet flooring, instead of using EBM it can be used UV source, and this will be resulting of lower investment cost but the production cost may be not so far differ because the production cost is largerly coming from radiation curable materials. The cost of radiation curable materials for UV curing is higher than for EB curing because in UV curing, a photoinitiator is required , which is an expensive material.

Example formulation of radiation curable material for clear coating on wood panel is shown in Table 3.

Table 3 Radiation curable materials for EB curing of wood parquet flooring

I. Base coat	**Wt part**
Laromer EA-81(epoxy acrylate) or urethane arylate	60-50
PEGDA(polyethylene glycole diacrylate)	30-40
Talc powder	10
II. Top coat	
Laromer EA-81	60-70
PEGDA	40-30
Matting agent	5-10
Silicon oil	1

For UV curing, 1-5% of photoinitiator is required in the mentioned formulation.

Cost evaluation of pigmented coating on wood panel showing the same result : the cost was largerly coming from radiation curable materials followed by liquid nitrogen and plant operation (Table 4).

Table 4 Pigmented coating on wood panel

	Cost, %
Radiation curable materials	73.8
Liquid nitrogen	18.1
Plant operation	8.1
Total	100.0%

Total operation hours of EBM from 1984 to 1992 is more than 400 hours (Table 5), which is mainly used for process development, laboratory experiments and Regional Training Course (RTC). It was reported that there is no serious problem with regard to the operation of EBM during that time. Process development which is now being done : coating on ceramic, metal, gipsum, marble etc.

Table 5 Total hours of operation of EBM for process development, laboratory experiment and services

YEAR	Operation, hours
1984-1985	40
1986	45
1987	27
1988	30
1989	133
1990	85
1991	48
1992	21
Total =	429

A number of customer had sent thousands square meter of wood parquet mosaic and wood panel to the pilot plant. The materials were coated using the available equipments. A lot of experiences were obtained by giving this radiation services. Based on this experience, an optimum process for a typical application has established and an economic analysis can be done with a higher accuracy. The results have been published anywhere.

It was concluded that the available pilot plant was unsuitable to be used as a commercial production of coated wood parquet flooring or pigmented wood panel, although the size is a commercial size: the cost of coating will be very high which mainly due to the liquid nitrogen cost. This is true because the irradiation system of EBM is uncontinuous system, while the inert gas should flowing continuously. It was estimated that the inert gas consumption (N2) can be much reduced (to one third) by using a continuous irradiation system.

Example :

The consumption of liquid nitrogen of the present EBM for surface coating is about 150 liter/hour. In the present system (uncontinuous), the speed of irradiation is about one piece/min. of wood panel (1.2 x 2.4m). Then the liquid nitrogen consumption is about 2.5 liter/piece of wood panel. If continuous system is applied, the speed of irradiation will be about 7.5 m/min.,or about 3 pieces of wood panel/min., and the liquid nitrogen consumption is about 0.8 liter/piece of wood panel.

REGIONAL TRAINING COURSE

Four times of RTC on radiation curing had been implemented in this facility. The courses were followed by participants from RCA Member States (Table 6). The participants from the last of the course were requested to make an economic analysis of the technology based on the condition available in each country. They concluded that the technology itself was superior technically compared to the conventional one, but for many developing countries they have some difficulties in marketing due to the high cost of production and high cost of investment and supply difficulty of radiation curable materials and liquid nitrogen.

Table 6 Regional Training Course (RTC) on radiation curing of surface coating on wood panel in Jakarta

Country	Number of participants I	II	III	IV
Bangladesh	1	1	1	-
China	-	1	1	2
India	1	1	1	1
Indonesia	3	2	2	2
Korea, Rep. of	-	-	-	1
Malaysia	-	1	1	3
Pakistan	1	1	-	-
Philipine	-	-	-	1
Singapore	-	-	1	-
Sri Lanka	1	1	1	1
Thailand	1	1	1	2
Vietnam	-	-	-	-
Total	8	9	10	14

Note :
I *01 November 1984 - February 1985*
II *11 November 1985 - December 1985*
III *29 September 1986 - 24 October 1986*
IV *04 June 1990 - 22 June 1990*

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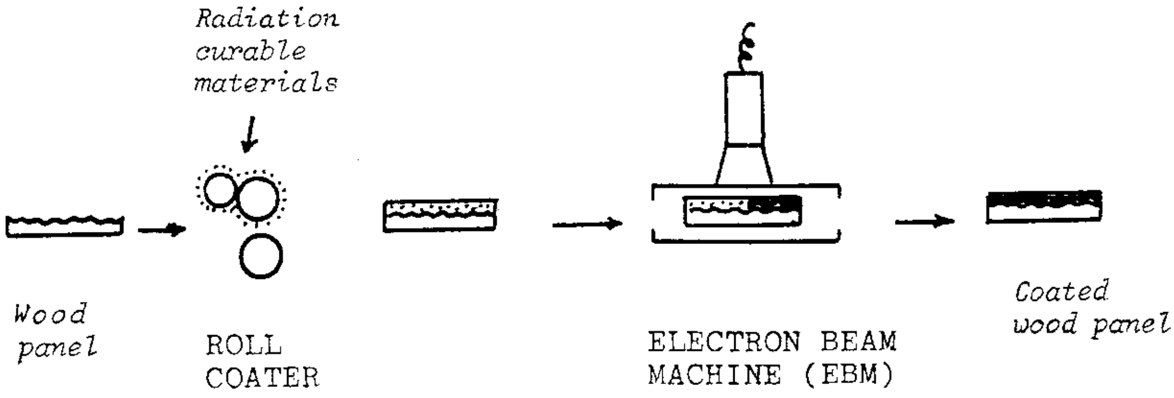

Fig. 1 Basic flowsheet of EB curing of surface coating process

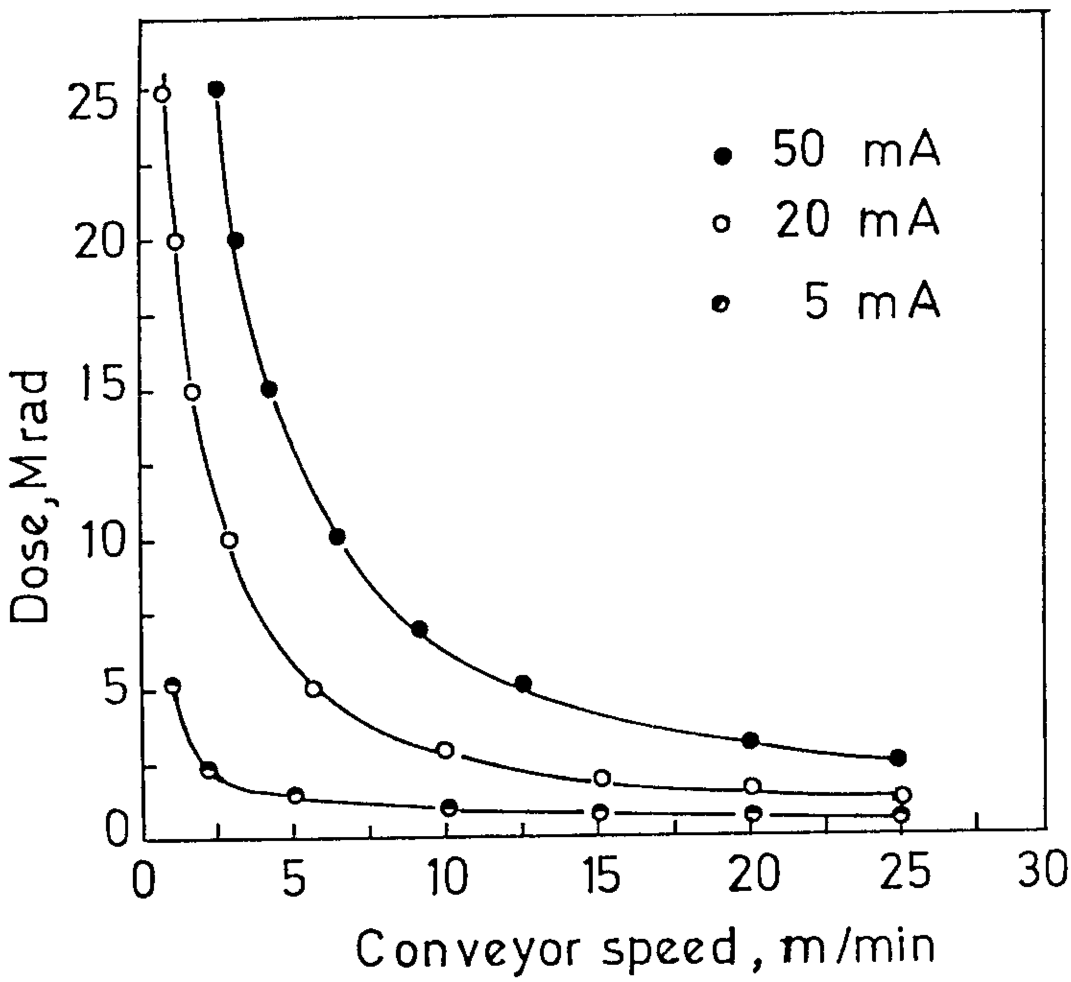

Fig. 2 Relation between EB irradiation dose and conveyor speed or beam current

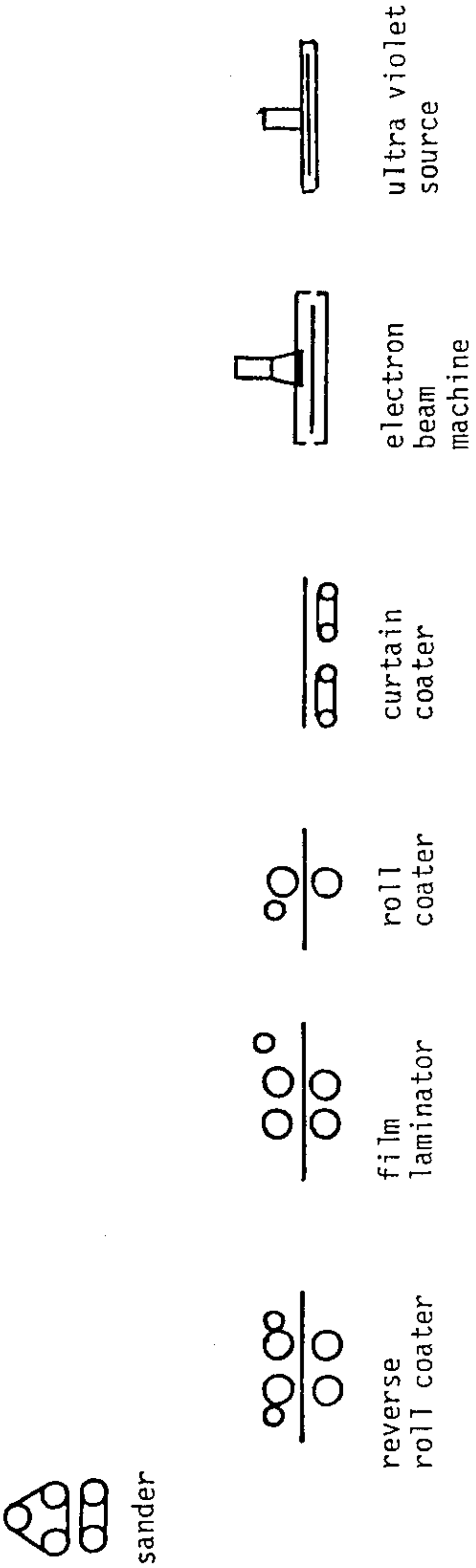

Fig. 3 Equipments lining in the pilot plant

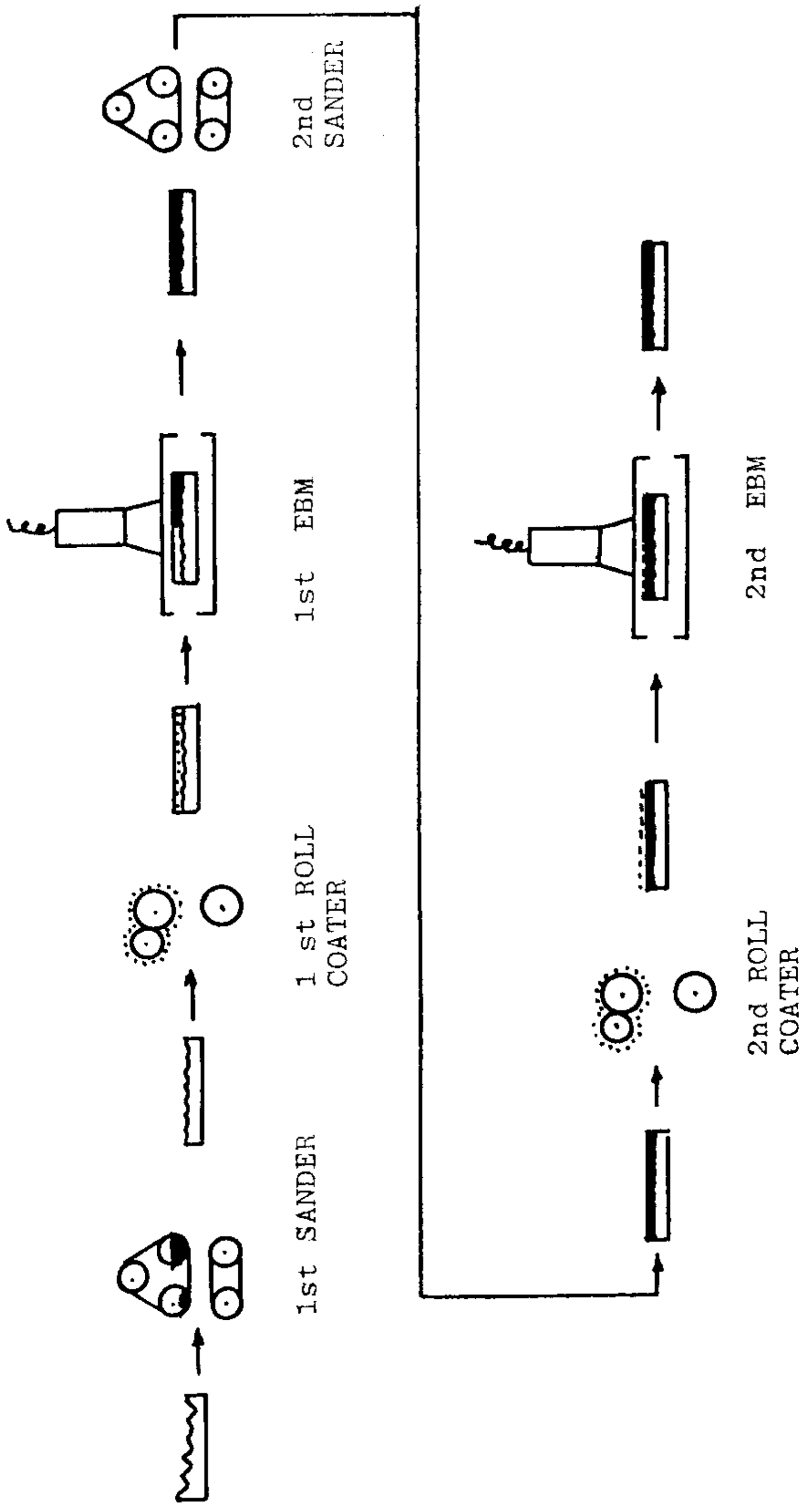

Fig. 4 Flowsheet of EB curing of surface coating on wood parquet flooring

2.11. Sterilization with Electron Accelerators

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Radia Ind. Co. Ltd.

TREND OF RADIATION STERILIZATION IN JAPAN

Radiation sterilization of medical devices has been continuously increasing in Japan for last 20 years, the main items was initially hypodemic needles, and now is dialyzers. There are other items such those hypodemic syringes, surgical knives, sacarpels, catheters, and so on. The advantages of radiation sterilization is well known in Japanese device manufactures, but still more than 50% of the products are sterilized with use of ethylene oxide gas mainly due to the cheaper cost.

Large medical device manufacturers settled their own radiation facilities (in house) with use of Co-60 source. Table 1 shows the radiation facilities used for medical device sterilization.

Table 1 Commercial γ irradiation facility in Japan (as of 1991/12)

Company	Established	Location	Capacity kCi	Activity kCi	Note
JRIIC	1969	Tochigi	600	320	Contract
Radia	1972	Gunnma	1000	500	Contract
Radia	1984	Gunnma	2000	1200	Contract
Koka RI	1987	Shiga	2000	1200	Contract
JMS	1987	Hiroshima	6000	800	In-house
Nishoo	1988	Akita	3000	1100	In-house
Terumo	1988	Yamanashi	6000	5000	In-house
Asahi Md	1988	Ohita	1500	600	In-house

Presently two high power 5 MeV electron beam facilities for contract irradiation are in operation by SHI and RIC. However, application to medical device sterilization is in infant stage in Japan. One company, Hogy medical, has just started a sterilization of non-woven fabric products, which is not medical devices in Japan and is classified as miscellaneous products, with use of 10 MeV linac in-house facility this year.

Table 2 shows trend of gamma-sterilization field in RIC, which shows increase in radiation sterilization of non-medical devices. The electron beam sterilization will also follow the trends in near future.

Table 2 Trend of radiation sterilization in Radia
(trend as of 1990)

Field	Examples	Share (%)	Trend in 1990	Background
Medical Device	Dialyzer, Lancet, etc.	30-40	Decrease	Increase in In-house
Bio-exp. Apparatus	Ptetri Dish, Culture Flask, etc.	25-30	Increase	Disposable, Residual EO
Container, Packaging	Container, Plastic Bag etc.	20-25	Increase	Need Aseptic Residual EO
Ex. Animal Feeds	Sterile, SPF	20	Balance	Exp. Improve SPCA Press.

CHARACTERISTICS OF ELECTRON BEAM STERILIZATION

The characteristics of electron beam sterilization is compared to gamma sterilization, because it will compete each other in the future. Tables 3 and 4 shows the characteristics from technical, and economical & social view points for the high power direct current electron beam machines.

Presently, several hundreds of direct current EB machines are in industrial operation in the world, but most of them are generating up to 3 MeV EB for polymer processing. Only several machines are used in sterilization purpose together with polymer processing in contract irradiators.

Less than ten linear accelerators are used, mostly in European countries, for sterilization with a energy level of 10 MeV. So far the powers are not competitive to direct current machines. Linear cathode low energy machines are proposed to sterile a surface of containers but practical application is not so broad.

Table 3 Technical comparison of EB and γ sterilization

	EB	γ
Radiation source	electrically	radioisotope
Sterilization effect	same	same
Process capacity	large (10 MCi)	small
Dose rate	high	low
Material deterioration	small	large
Penetration	small	large
Dose uniformity	large	small

Table 4 Economic & social comparison of EB & γ sterilization

	EB	γ
Public acceptance	easy	difficult
Source investment	advantage in large	in small
Conveyor	expensive	cheap
Process cost	cheap	expensive
Product bulk density	low (< 0.2 g/cc)	high (>0.2)
Product quantity	need large batch	small batch

Tables 3 and 4 clearly show that the EB and γ sterilizations have supplementary nature, and should be chosen according to a character to the products to be sterilized or amount of products per batch from customers in the service area.

In the case of 10 MeV class EB with use of linear accelerators the penetration will be similar to the gamma irradiators in a practical application, but the author does not have personal experiences to discuss in detail.

A bird's eye view of 5 MeV, 30 mA (150 kW) electron beam facility which can also be used as a x-ray facility of RIC is shown in Fig. 1.

A joint research (JAERI - RIC) on an evaluation of EB sterilization of surgical gloves with use of 5 MeV EB show that the RIC's facility can be sterilized 36,000 pairs of surgical gloves at 25 kGy sterilization dose, corresponding 0.86 Million pairs per day at 24 hrs operation. The product unit is 12 gloves in one box and the dose uniformity is 3.3. The dose uniformity is larger than γ radiation and the material degradation should be studied. The processing capacity is 5 times larger than 1 MCi γ irradiator.

The example demonstrate that 150 kW EB facility has a tremendous capability if the products meet EB sterilization.

DOSE SETTING METHODS FOR MEDICAL DEVICE STERILIZATION

Historically 25 kGy has been widely used to attain a sufficient dose to achieve the sterility assurance level (SAL) of 10 to the -6. This is based on an experience of gamma sterilization and is applied to the EB sterilization too. The efficacy of sterilization was considered to be the same for both EB and γ sterilizations but Scandinavian countries was regulated the different doses for EB and γ sterilizations, 35 and 32 kGy.

At present the formulation of the International Standard of medical device sterilization is under progress in the ISO technical committee (ISO/TC198) and is in the final stage. For radiation sterilization, the revised Draft International Standard is under circulation and will be finalized within a year. In the international standard, the sterilization dose is not differentiated in either gamma, X-ray, and EB. However, the dose setting tests needs more difficult techniques in EB for large medical devices.

The recommended dose setting consists of 2 methods.

a) dose setting using bioburden information
b) dose setting using fraction positive information from incremental dosing

Methods a) and b) are well known methods as AAMI (Association of Advancement Medical Instrumentation) B1 and B2 methods. These are popularly used in North America, but those are rarely used in our regions due to the regulations and resource oriented method of these. In the near future we can not use the on going dose setting method using biological indicator with B. pumilus for export products. Sterility test is also not recommended due to high false positive probability, 0.001, than SAL of 0.000001.

Table 5 Recommended dose setting methods

Method 1. dose setting from bioburden information

(1) Bioburden consists of known distribution of radiation resistance (obtained from D-value distribution mainly in North America)
(2) measure the bioburden
(3) irradiate the sample to SAL=0.01 dose, confirm radiation resistance of the bioburden is weaker than that of the standard radiation resistance distribution by sterility test of 100 samples
(4) determine the sterilization dose according to the bioburden
(5) audit should be made every 3 months

bioburden	1000 -> sterilization dose	24.9 kGy	at (SAL=10^{-6})
	100	21.2	
	10	17.7	

Method 2. dose setting using fraction positive information from incremental dosing

(1) not required bioburden measurement
(2) determine SAL=0.01 dose by incremental dosing combined with sterility tests
(3) determine sterilization dose with extrapolation method at smaller SAL region than 0.01
(4) require 640 samples for sterilization dose determination and audit

strong point - less assumption, measure with natural bioburden
weak point - need large number of samples

The detail of dose setting are outside of the scope but we have to establish reasonable method with scientific backgrounds.

For EB sterilization two problems for dose setting tests are:

1) correct dosing to test sample for incremental dosing in the target dose of several kGy range within +/- 10 %
2) irradiation of a medical device sample with small Dmax/Dmin, recommended for gamma-sterilization is in the range of 1.0 to 1.05, which will practically prohibiting EB sterilization for large medical devices and will require the dose setting test for small samples by dividing into small pieces with use of SIP (sample item portion) concept.

X-RAY STERILIZATION PRODUCED BY BREMSSTRAHLUNG OF EB

A potential application of EB sterilization of large medical devices, dense and/or thick products can be achieved by use of X-ray by bremsstrahlung of high energy electron beam. The EB can be converted into X-ray by impinging EB to plate of high Z materials. The conversion efficiency of EB energy into X-ray for forward direction is about 8% with use of 5 MeV EB. Table 6 shows characteristics of the bremsstrahlung irradiation.

Table 6 Characteristics of X-ray (bremsstrahlung)

1) Machine generated photon radiation,
   - ease of operation for wide dose range without use of radionuclides
2) High penetration than Co-60 gamma-ray,
   - homogeneous dose distribution
   - can be processed large and/or high bulk density products
3) High dose rate,
   - short processing time
   - less material degradation
4) Processing cost of x-ray with gamma-ray irradiation
   - comparable cost to gamma-ray for dual purpose facility
   - bargaining power for Co-60 price rise
   - no disposal problem for decayed radioisotope source

Bremsstrahlung Facility of RIC

Fig. 2 shows x-ray converter located below a beam window of RIC's EB machine. 5 MeV, 30 mA electron beams are converted into x-ray in the high Z target made of tantalum. The x-ray dose rate 40 cm below the target is shown in Fig. 3 together with experimental measurement by CTA and computer simulation using APEX-P. Discrepancy in conveyor direction between dosimetry and the calculation is due to shadowing to diagonal x-ray by target structure. It is noteworthy that x-ray by bremsstrahlung gives very high dose rate photon irradiation than Co-60 gamma source. We started the commercial activity of the new technology just this year .

Conclusion

Many EB machines in the world are used for polymer processing most of which generate medium energy electron beam in the range of 0.8 to 3 MeV. With use of relatively high energy, 4.5 MeV, high power electron beam machine sterilization of health care products are realized in the United States. It is not yet popular in the other countries due to small scale production of such products. The market size is smaller in Japan than the U.S. and it is not commercially feasible to do sterilization only for medical devices and health care products. We have to give contract irradiation to the other fields such as polymer application. It is assumed that the industrial infra-structures here are similar to Japan in this sense. Best way here might be construction of the dual purpose EB facility for sterilization and polymer applications.

Discussion

Questions from Mrs. Nazly Hilmy, Director of PAIR

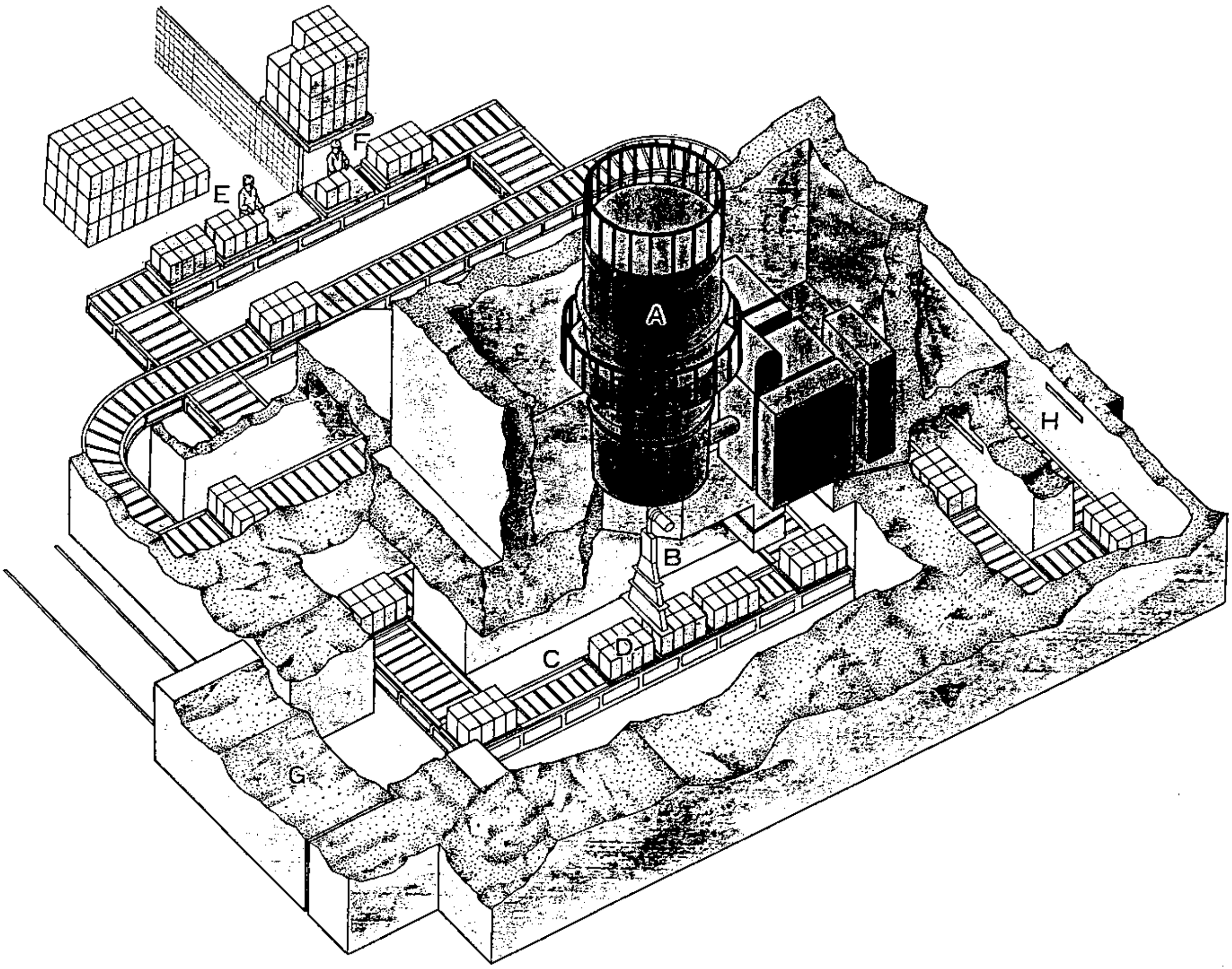
1) Method of validation in irradiation with use of electron beam machine.

2) How do you carried out dosimetric validation ?

Answers from Dr. Takehisa

1) Sterilization of medical devices and food irradiation are obligatrily to validate the routine processing. The validation include facility, and routine processing. Most important point is to deliver a correct dose to the product. In this sense, the difference of electron beam and gamma rays is that the gamma ray can be validated to dose distribution in the product box for bulk density. But in the case of electron beam overall bulk density can not validate a delivered dose to each product in the product box, and needs measuring dose distribution on/in a represented each product. Then the product configuration in a box should be determined in the electron beam application.

2) We use CTA dosimeter to find a detailed dose mapping in/on the each product in a carton box. With use of long strip of CTA dose distribution can be measured in detail and minimum and maximum dose points are obtained conveniently.



A: Electron Beam Generator B: EB Scan Horn
C: Irradiation Conveyer D: Product
E: Unloading from Conveyer F: Loading to Conveyer
G: Shielding Door H: Slit for Long Object
Note: X-ray Converter is not shown in Bird's Eye View

Fig. 1 Bird's eye view of RIC's EB and X-ray facility

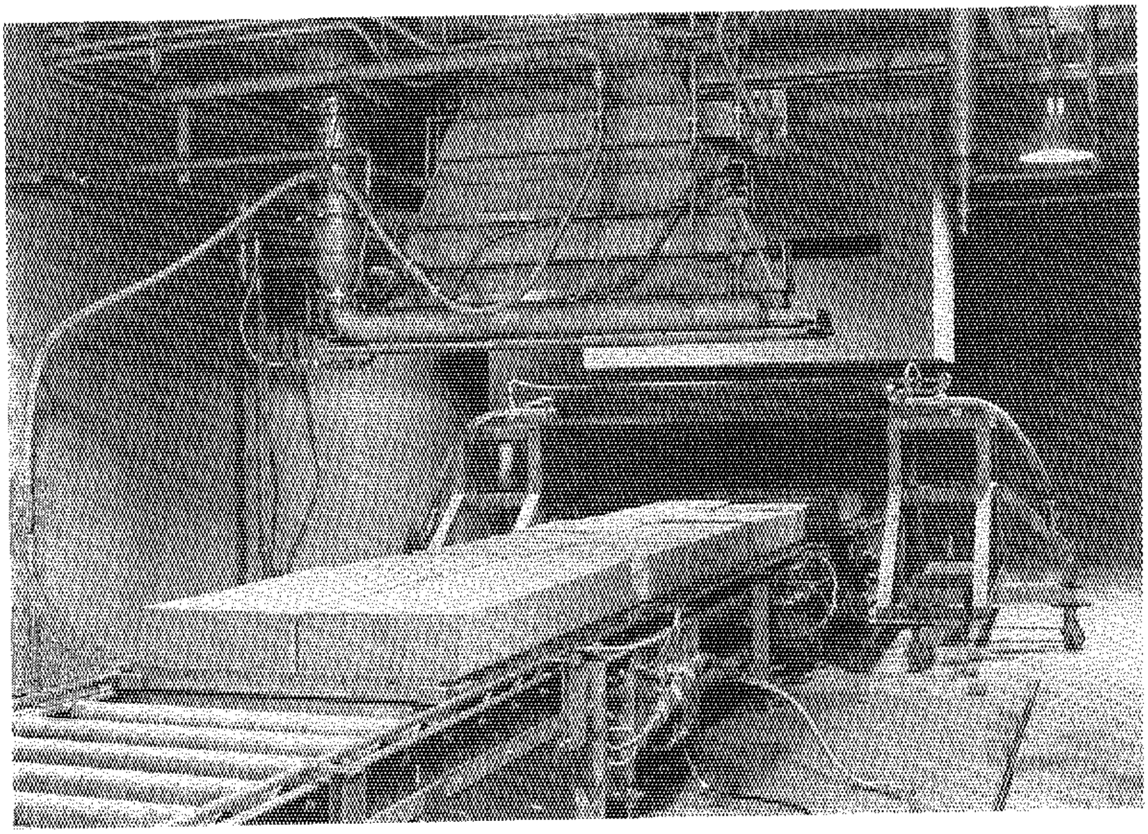


Fig. 2 Product under EB irradiation

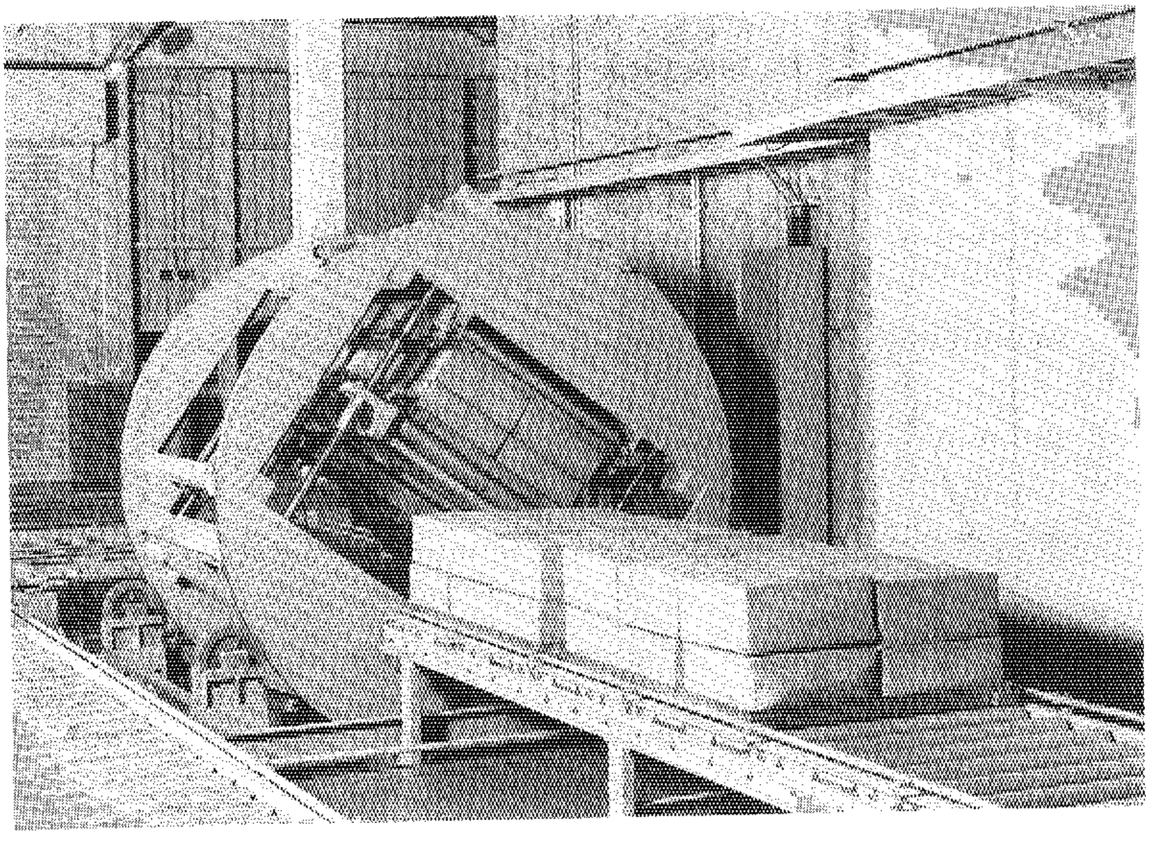


Fig. 3 Turn over machine for dual side irradiation

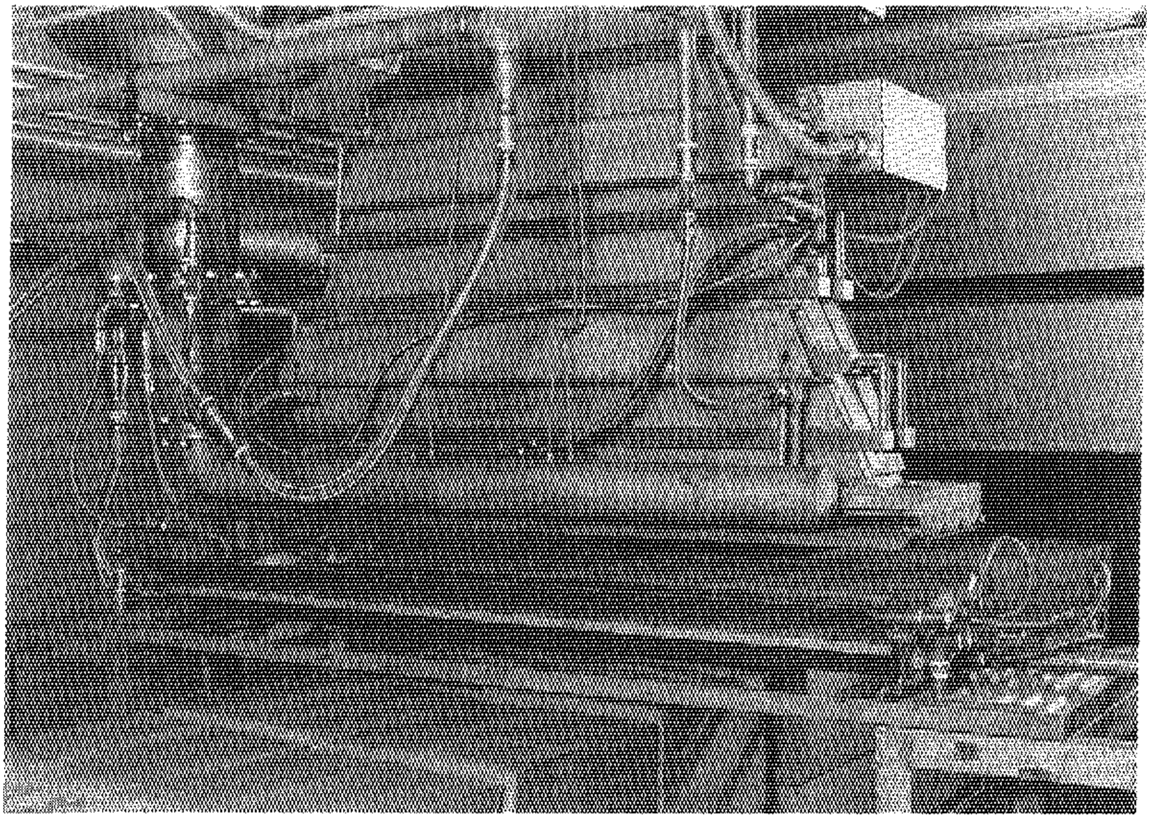


Fig. 4 X-ray converter and product under x-ray irradiation

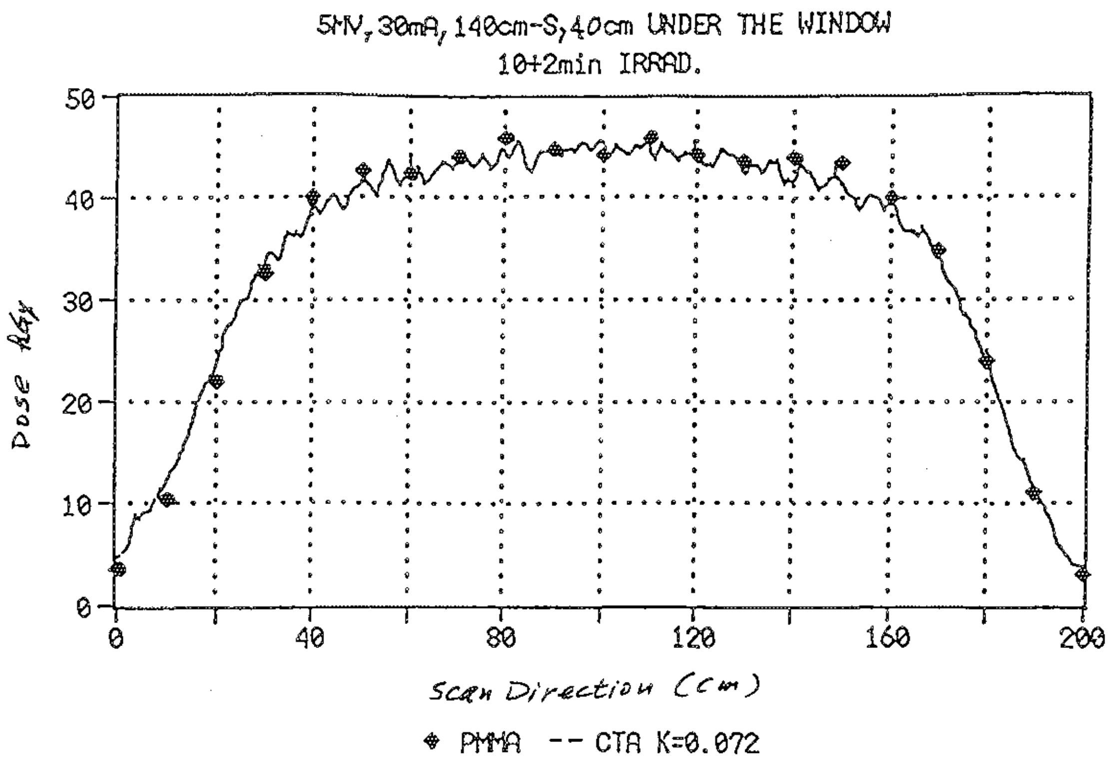


Fig. 5 Dose distribution of x-ray

2.12. The Possibility of using Electron Beam Machine for Food Preservation in Indonesia

Nazly Hilmy

Center for the Application of Isotopes and Radiation, BATAN

INTRODUCTION

The first industrial-sized Electron Beam Machine was built by Raychem Company in March 1957. It was a 1 MeV 6 m A General Electric resonant transformer. The first three products of Raychem Company were miniature coaxial cable, heat-shrinkable tubing and high-performance hook-up wire. The total cost of the first beam cell was US $ 7.000. In 1976 the value of the company become US $ 175 million at a growth rate of 25 % per year (1).

At present Electron Beam Machine have also been used for sterilization of medical health care items,beside others technology such as Etylene oxyde gas and gamma radiation. The market share of the application can be seen in Fig. 1. From an estimated 10 million cubic meters of disposable medical products and related health care items currently being sterilized around the world Ethylene oxide gas (ETO) is used to treat approximately 7.1 million m^3, gamma radiation is used approximately 2.8 million m^3, and EBM is used to treat on approximately 0.3 million m^3 . The estimation future growth of EBM applications for sterilization of medical items is uncreasing as can be seen in Fig. 2 (2).

The Codex Alimentarius Commission's (1984) proposed international standard for irradiated foods, permits three types of ionizing radiation to be used i.e. gamma rays from the radionuclides Co-60 or Cs-137, electrons from EBM with energies of 10 MeV or less, and X-rays with energies of 5 MeV or less. On the molecular level, these three types of radiation have similar effects. The effects of electron beam and gamma rays on microbes and materials exposed are similar,but they have different properties that effects their technical, social and economic desirability such as energy efficiency, absorption efficiency, reliability and maintainability, cultural fit, product flow and dose quality assurance (3-4).

This paper will not be assessed in any detail of economic issues.

THE CHARACTERISTICS OF RADIATION

The characteristics of the three types of radiation can be seen at Table 1. The low penetration of electron particles in water compared to gamma -rays or X-rays can be seen in Fig. 3 and the penetration of 10 MeV electron in water can be seen in Fig. 4.Penetration of 5 Mev bremstrallung in water (x-rays) can be seen in Fig.5.

RADIATION PENETRATION

One of the most important difference between the three types of radiation sources is penetration.Gamma rays from Co-60 and x-rays can penetrate pallet load of foods.Depending on foods density, 10 Mev electrons cannot penetrade more than 2.5 up to 8.0 cm when irradiated from one side (Table 2).The calculation was based on the formula (5):

Voltage = 2.63 TD + 0.32 (single sided treatment)

Voltage = 1.19 TD + 0,32 (double sided treatment)

where: T = Thickness of product
D = Density of product

Caused by the low penetration of electron particles,the calculation is based only on 5 up to 10 Mev EBM.
The limited penetration of electron beams restricts their use only to treating food surface,thin packages or a shallow stream of grain,powder or liquids.A bulk irradiator using electron beams would need to be part of a processing or packing plant to treat the food before it is packed for shipping.
One of the important advantages of EBM compared to gamma facilities is operation condition.The operation of the machine can be arranged based on the availability of materials to be irradiated.It is very useful to be used to treat seasonal products which have peak season.

COMMODITIES TO BE IRRADIATED

Indonesia has approved the food irradiation technology for commercial purposes since December 1987,consisting of three kinds of food commodities i.e. spices,tubers and grains.The commercial application of radiation technology on spices and mixed herbs for local consumtion was increasing in Indonesia i.e. about 90 m^3 in 1989 and 180 m^3 in 1990.Spices are one of the important Indonesian export commodity where radiation technology can be used.Export of Indonesian black pepper, white pepper,nutmeg and cassia vera to countries that have accepted irradiated spices are increasing,but sometimes a part of the commodities was detained by the importing countries,since the quality did not meet the requirements in the importing countries.It is hoped that in the future all important countries will accept irradiated spices from Indonesia (6).

MAINTENANCES AND POWER OF ELECTRICITY

In operating the EBM,maintenance and electricity are two main problems in developing countries like Indonesia. Spare-parts have to be imported and the facility has to have skill labours in handling and maintained the machine.The EMB need higher power of electricity compared to Co-60 facilities.If the problems of maintenance,electricity and skill-labours could be overcome,the EBM will be an alternative technology for food preservation in Indonesia.

CONCLUSIONS

It can be concluded that an EBM with energy between 5 to 10 Mev has a good prospect to be used for food preservation in Indonesia if problems on maintenance , electricity and human resources could be overcome.

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Table 1 Characteristics of Radiation

TYPE OF RADIATION	CHARACTERISTICS
Electron Beam (e-particle)	- Electrical Generation - Ease of Control - High Power & High Dose Rate - Quick Processing - Low Penetration
X-ray (electro magnetic) ray	- Electrical Generation - Ease of Control - High Power & High Dose Rate - Quick Processing - High Penetration
Gamma-rays (electro magnetic)ray	- High Penetration - Uniform Irradiation - Ease of Control

Table 2 Penetration of electron beam in several densities of packaged food and bulk

Energy of EBM / Density	5 MeV		10 MeV	
	One side (bulk)	Two sides (packaged)	One side (bulk)	Two sides (packaged)
0,4 (spices)	4.45 cm	9.83 cm	9.20 cm	20.73 cm
0,8 (grains)	2.28 cm	4.91 cm	4.60 cm	10.17 cm

MARKET SHARE
BY STERILIZATION METHOD

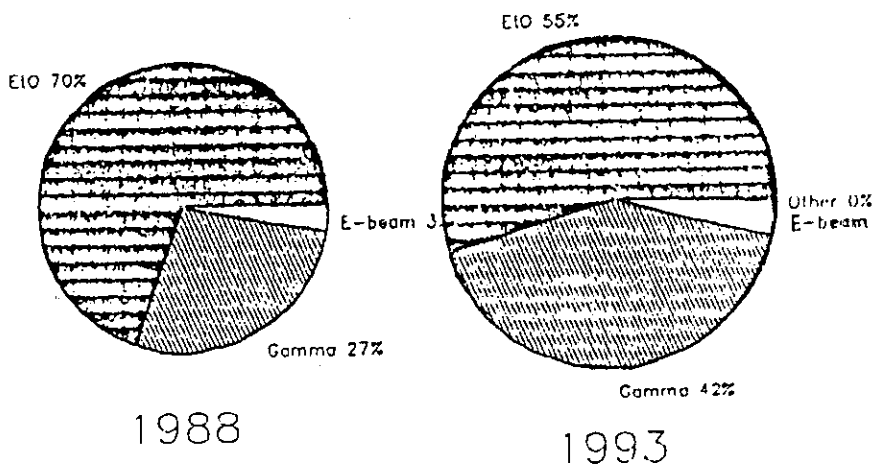

Fig. 1 Market share of ETO, Gamma-ray and E-beam, for sterilization of medical products (2)

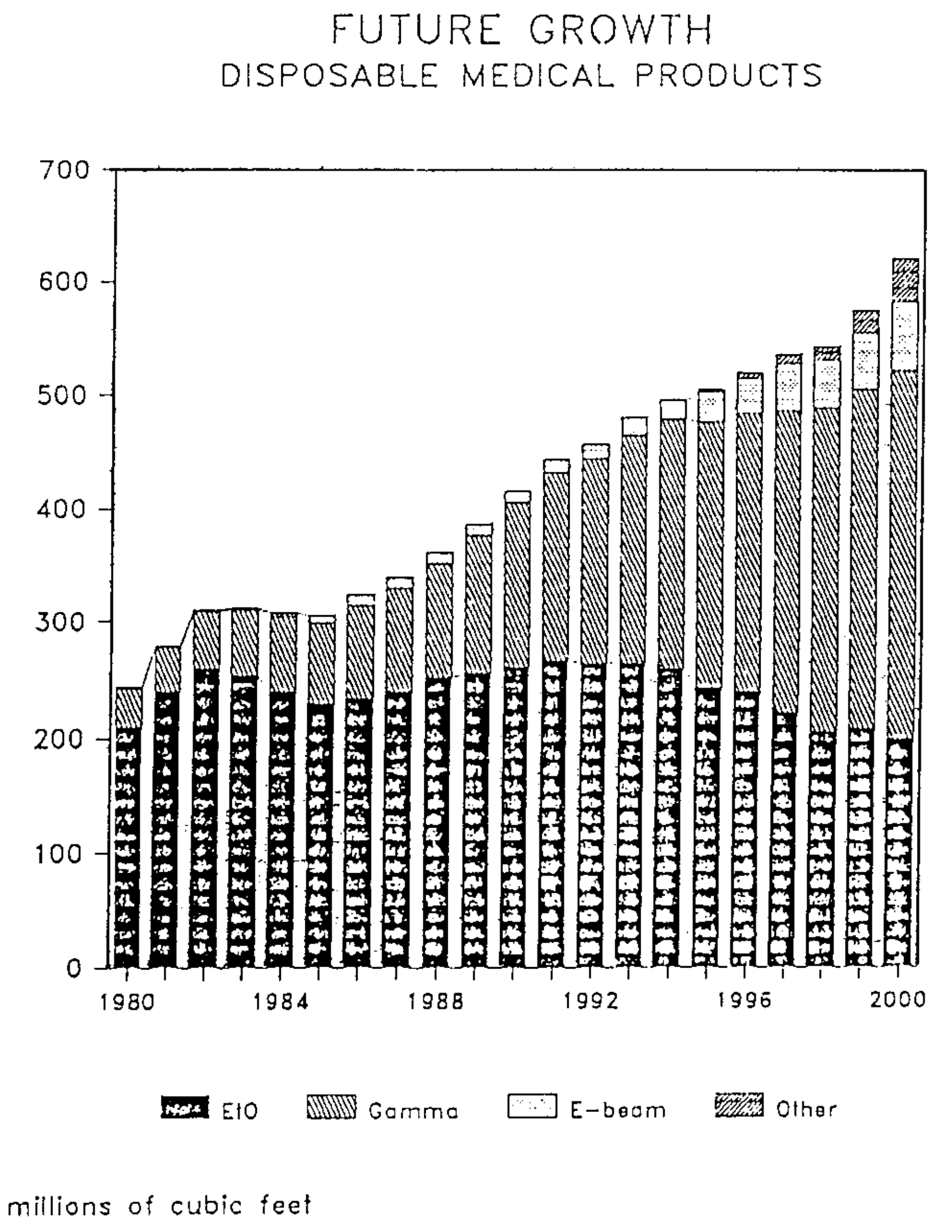

Fig. 2 Future growth of application of E-beam, ETO, and Gamma-rays for sterilization of medical item (2)

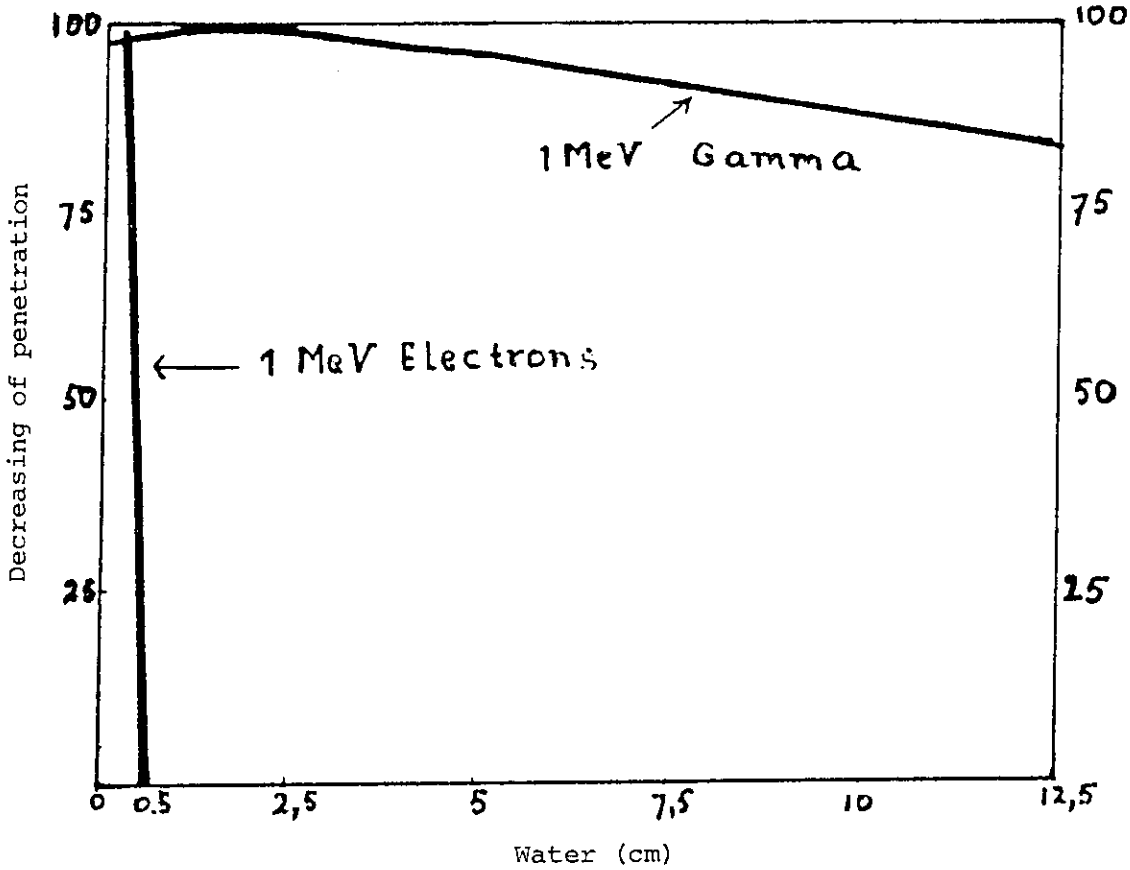

Fig. 3 Penetration of electron beam in water compared to Gamma-rays

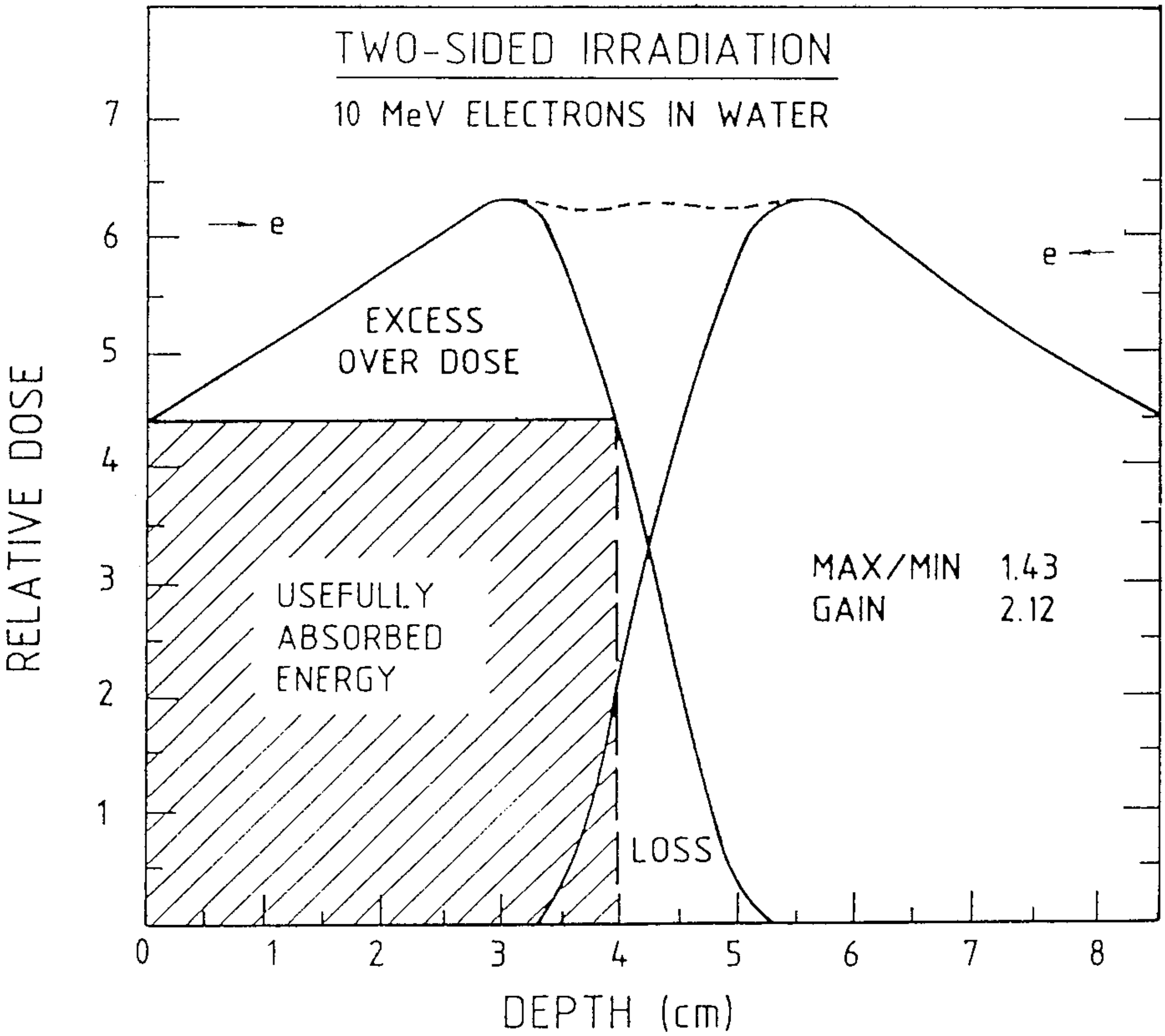

Fig. 4 Penetration of 10 MeV electron beam in water

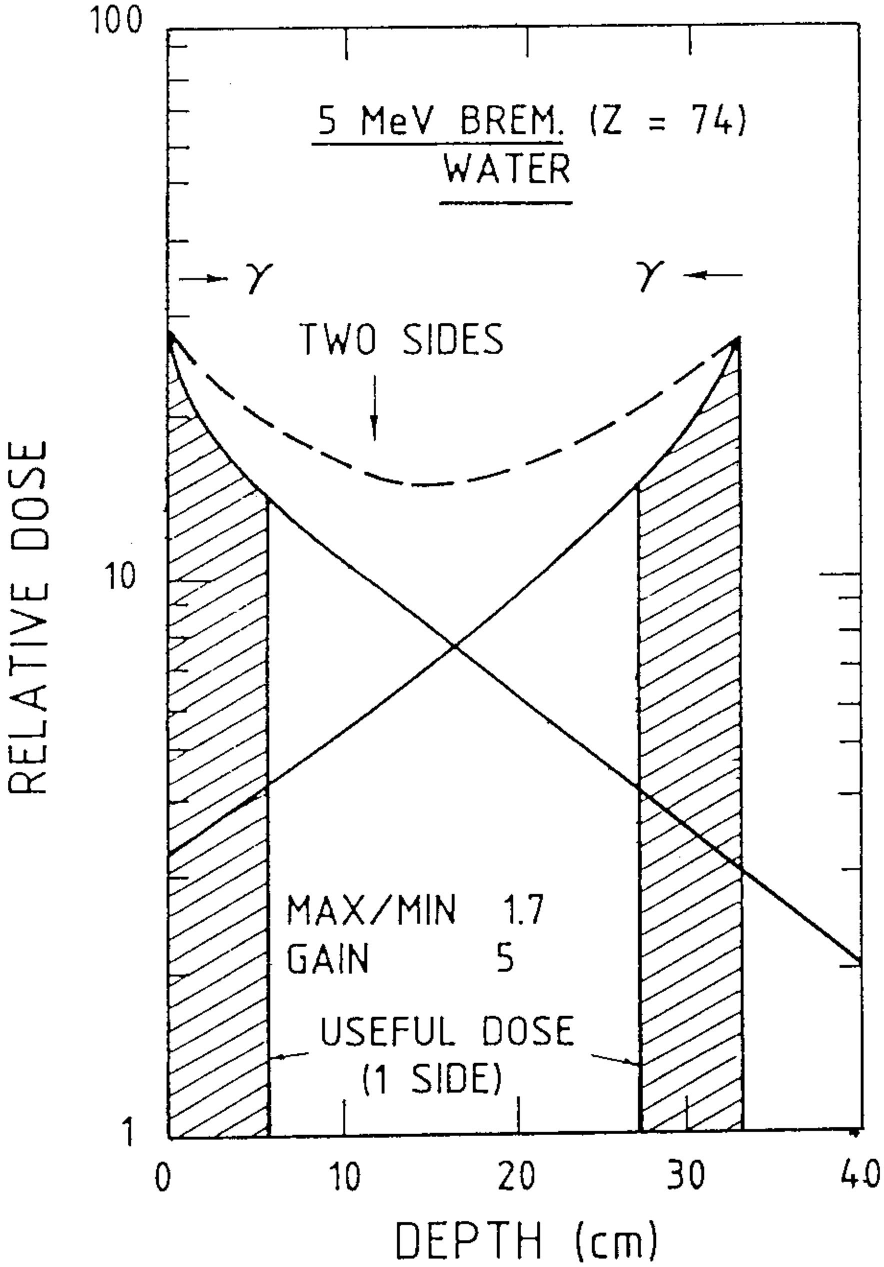

Fig. 5 Penetration of X-rays (5 MeV Brem) in water

2.13. Application of Electron Accelerators to Bio-Resources

T. Kume

Takasaki Radiation Chemistry Research Establishment
Japan Atomic Energy Research Institute

1. Introduction

Radiation processing on biological materials has been developed and the commercial application is specially increasing in the field of food irradiation and sterilization of medical supplies. The radiation processing on bio-resources has been applied for various purposes, such as sprout inhibition, disinfection of insect, decontamination of microorganisms, inactivation of virus, enzymes and other bioactive materials, and degradation of cellulosic wastes. The effective doses are varied in wide range of 0.01 - 1000 kGy according to the purpose (Table 1).

Two types of radiation source, γ from Co-60 and electron accelerator, are commonly used for the radiation processing. The radiation processing by EB can be expected to have various advantages as shown in Table 2 (high dose rate of 500,000 kGy/hr compared to 20 kGy/hr of γ-ray and penetration control by changing energy, 0.2 - 50 mm in water). Radiation processing of bio-resources in the following cases can be performed effectively to utilize the advantages of EB treatment.

2. Faster Processing

Faster processing is required for the irradiation of frozen samples. EB processing avoids a long time exposure which causes the melting of samples. At SPI (Societe de Proteines Industrielles) in France (1), packed frozen boneless poultry meat (5.5 x 55 x 36.5 cm) has been commercially processed using 7 MeV Linear accelerator. For the elimination of salmonella, the samples are irradiated within 1 sec for 5 kGy irradiation whereas the processing by γ-ray needs 30 min - 1 hr (Table 3). The treatment cycle of frozen meat by EB with both sides irradiation takes about 10 minutes. The facility has been operated for several years.

3. High Dose Processing

As the bioactive materials such as virus and enzymes are generally radioresistant, high dose processing up to 1000 kGy is required for their inactivation. Figure 1 shows the inactivation curves of various bioactive materials. The activity decreased exponentially and the higher doses were necessary for the inactivation of small molecules according to the following empirical equation

$$D_{37} = 6.4 \times 10^4 / Mr$$

where D_{37} is the dose (kGy) necessary to inactivate an activity to 37% of its initial level, and Mr is the molecular size (2). As shown in Fig. 2, the molecular weight of ovomucoid is 28,000 but the D_{37} dose for inactivation is 627 kGy because ovomucoid consists of three domains with small molecular size (Mr = 10,200). This result shows that the long time irradiation of 50 - 100 hr is necessary for the inactivation of ovomucoid by γ-ray with the dose rate of 10 - 20 kGy /hr whereas it can be inactivated within a few minutes by EB irradiation with high dose rate.

4. Large Scale Processing

A huge amount of agro-resources such as cellulose, starches are discarded or under-utilized. We have been studying the radiation processing on upgrading of these wastes into useful end-products not only to recycle the bio-resources but also to reduce pollution. Empty fruit bunch (EFB) and palm press fiber (PPF) are major cellulosic wastes of the palm oil industry. The current availability of EFB and PPF in Malaysia is estimated to be 3 million tones (dry weight bases) per year, respectively (Table 4). Animal feeds and mushrooms can be produced from oil palm cellulosic wastes by radiation and fermentation treatment. The process is as follows: decontamination of microorganisms in fermentation media of EFB by radiation, inoculation of useful fungi, and subsequently production of proteins and edible mushrooms. Table 5 shows the throughput capasity of EFB by EB and γ-ray. Maximum throughput capasity with ^{60}Co (3.0 MCi) γ-ray is estimated as 6000 ton/year whereas the thrhoughput capasity with EB (3MeV, 25mA) is 100,000 ton/year. The estimation suggests that EB irradiation is easier and cheeper to process such a large amount of EFB as 100 thousand - 3 million ton/year.

5. Surface Disinfection

EB with low energy can be utilized for disinfection of mold on the surface of fruits. Organoleptic properties of mandarin orange was significantly changed by γ-ray but the hedonic score was not decrease by EB (Table 6). When the mandarin oranges were irradiated by EB of 0.2 - 1.5 MeV, 0.5 MeV was the best to prevent the spoilage. When the oranges were stored at 3°C for 3 months followed by storage at room temperature (16 - 25°C) for one week, fungal growth was effectively inhibited by irradiation of 5 kGy (Table 7). However, if the oranges were irradiated by EB energy of more than 0.5 MeV, their browning of skin and rotting were increased.

For the engineering study of EB on the surface of mandarin orange, a conveyor system was installed (Fig. 3). The dose uniformity ratio of overall samples at 0.5 MeV EB was best when the slope of the side of the sample pallet was 18° (Fig. 4) and the overall dose uniformity was less than 2.0 (Fig. 5).

6. Conclusion

Electron beam irradiation has various advantages for the treatments of bio-resources specially in following cases;

1) *Faster processing* for the elimination of salmonella (5 kGy) in frozen poultry meet

EB: less than 1 second (5.5 x 55 x 36.5 cm, 10 kg)

γ : 30 min - 1 hr (cooling system is necessary)

2) *High dose processing* (- 1000 kGy) for the inactivation of bioactive materials

EB: within a few minutes

γ : 50 - 100 hr

3) *Large scale processing* for a huge amount of agricultural wastes such as EFB

EB: 100,000 tons/year (3 MeV, 25 mA)

γ : 6,000 tons/year (3 MCi, ^{60}Co)

4) *Low penetration irradiation* for surface decontamination of Mandarin orange

EB: 2.3 mm of water(500 keV)

γ : 11 cm of water (half value layer, ^{60}Co)

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Table 1 Effective doses for bio-resources

	Dose (kGy)
Sprout inhibition	0.01 - 0.1
Disinfestation of insect	0.1 - 1
Decontamination of microorganisms	1 - 30
Inactivation of virus	10 - 500
Inactivation of enzymes	50 - 1000
Degradation of cellulosic wastes	100 - 1000

Table 2 Advantages of radiation processing by electron beam to bio-resources

High dose rates: 50 - 500,000 kGy/hr
(γ : - 20 kGy/hr)

* Faster processing
* High dose processing
* Large scale processing

Penetration control: 0.2 - 50 mm in water

* Surface disinfection

Table 3 Irradiation conditions of frozen poultry meats by electron beam at SPI (France)

Accelerator: Linac
- Energy: 7 MeV
- Power: 5 kW

Purpose: Decontamination of Salmonella
- Dose: 5 kGy

Conditions
- Sample size: 5.5(thick) x 55 x 36.5 cm
- Operation: 14 hr/day (2 shift)
- Production: 2,000 ton/year
- (Throughput: 5 packs/min)

Table 4 Oil palm production in Malaysia

Year	Cultivated area (x 1000ha)	Crude oil (x 1000t)	PPF* (x 1000t)	EFB** (x 1000t)
1970	291	431		
1980	1043	2573	12[illegible]0	1360
1986	1599	4544	2120	2400
1987	1672	4800	2220	2540
1988	1786	5030	2330	2660
1989	1951	6050	2800	3200

* Palm Press Fibre

** Empty Fruit Bunch Calculated at 53% of Crude Oil

Table 5 Irradiation of EFB by electron beam and γ-ray

EB (3 MeV)			
Current (mA)	1	2.6	25
Power (kW)	3	7.8	75
Throughput	4,000	10,000	100,000
^{60}Co γ-ray			
Activity (MCi)	0.05	0.5	3.0
Throughput (ton)	100	1,000	6,000

Operation: 6,000 hr/year

EFB package size: 16 x 53 x 43 cm, γ=0.16 g/cm^3

Moisture content of EFB: 60%.

Table 6 Effect of γ or electron irradiation on organoleptic properties of *Citrus unshiu* tested immediately after irradiation

Radiation	Dose (kGy)	Hedonic score (five-point scale)				
		Appearance	Odor	Taste	Hardness	Over-all
Unirradiated		2.93	2.84	3.00	2.73	2.78
γ - rays	0.5	3.20	2.63	1.89**	3.00	2.11**
	1.5	3.00	2.21*	1.10**	2.36	1.33**
Electrons	1.5[a)]	2.93	3.11	3.79**	3.00	3.50**

Appearance and hardness were tested on peel of fruits, and odor and taste were judged as changes in flesh of fruits. Samples were judged by nineteen persons.

a) The samples were irradiated with a surface dose of 1.5 kGy by 1.0 MeV electrons.

* Significance from unirradiated fruits by 95% of probability.

** Significance from unirradiated fruits by 99% of probability.

Table 7 Effect of electron energies on browning and rotting of fruits *Citrus unshiu* stored at room temperature (16 - 25°C) after storage at 3°C for 3 months

Energy(MeV) (Mev)	Total number of sample	Percent of browned and rotted fruits			
		Storage time (days)			
		3		7	
		browned	rotted	browned	rotted
Unirradiated	40	3	20	5	48
0.2	40	3	35	13	60
0.5	20	0	0	5	5
0.9	20	0	20	5	40
1.5	20	5	25	15	55

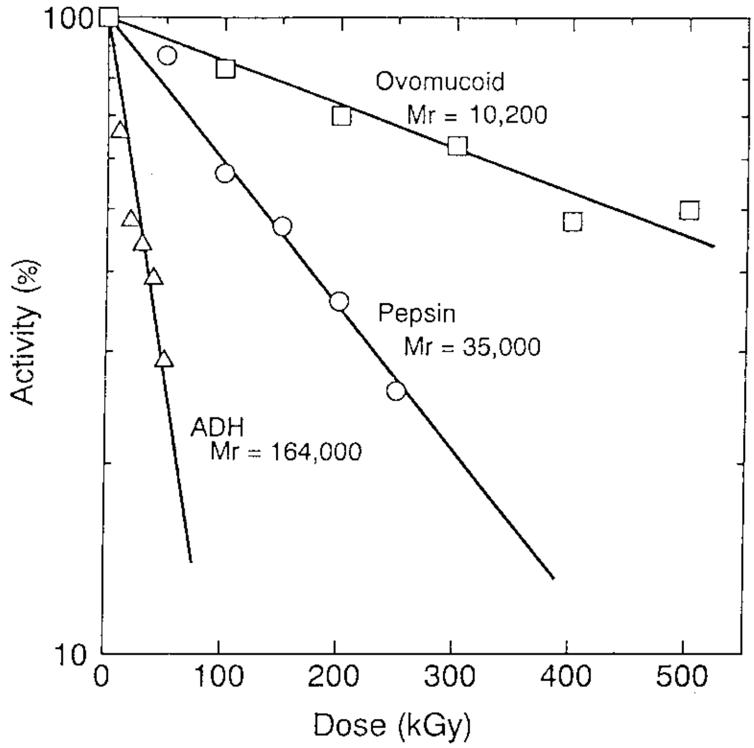

Fig. 1 Inactivation of bioactive materials by irradiation

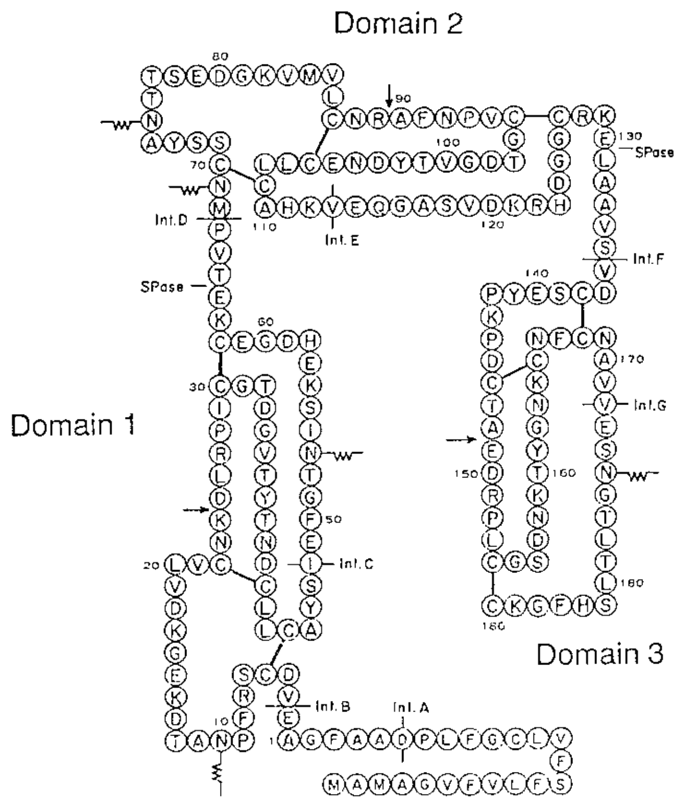

Fig. 2 Structure of ovomucoid
MW = 28,000
Mr(active domain 2) = 10,200 D_{37} = 627 kGy

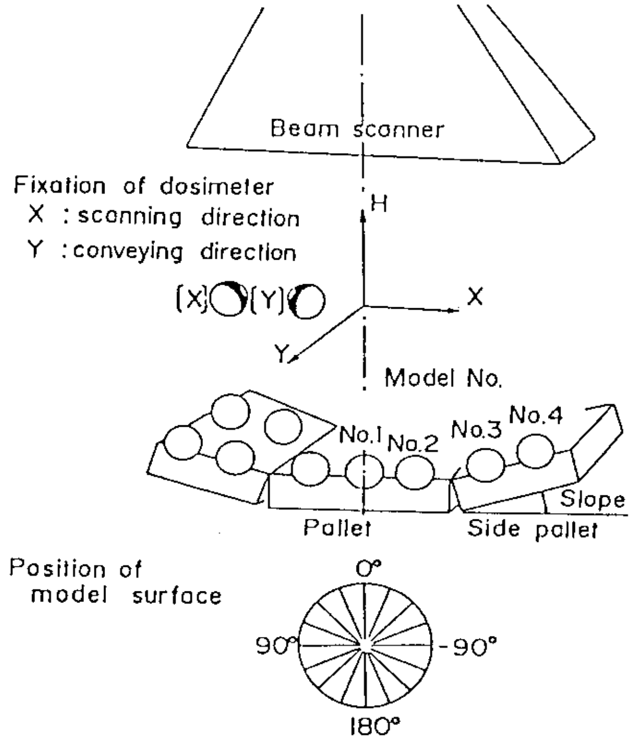

Fig. 3 Geometry of irradiation apparatus and model samples

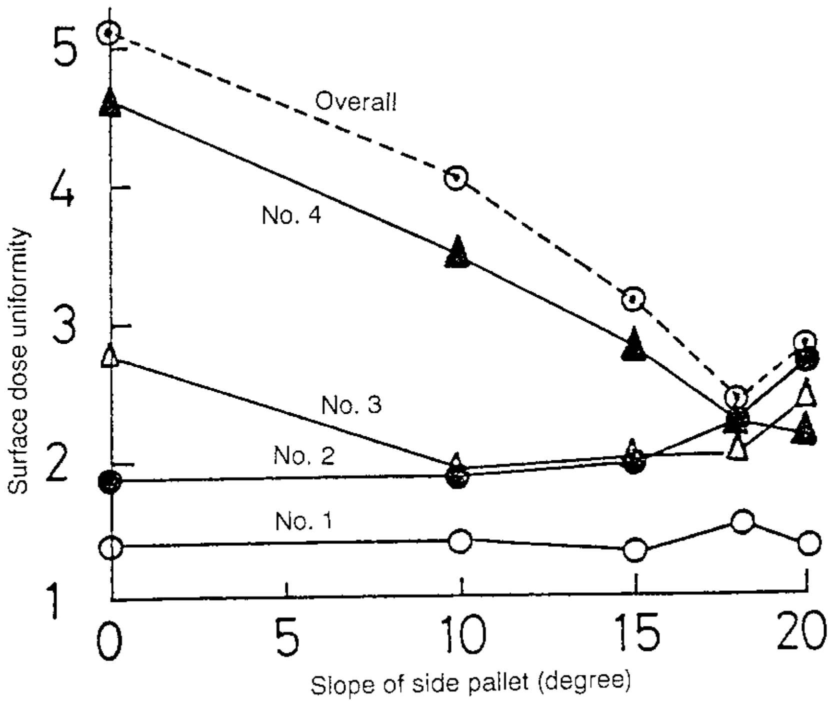

Fig. 4 Surface dose uniformity on one side irradiation at various positions

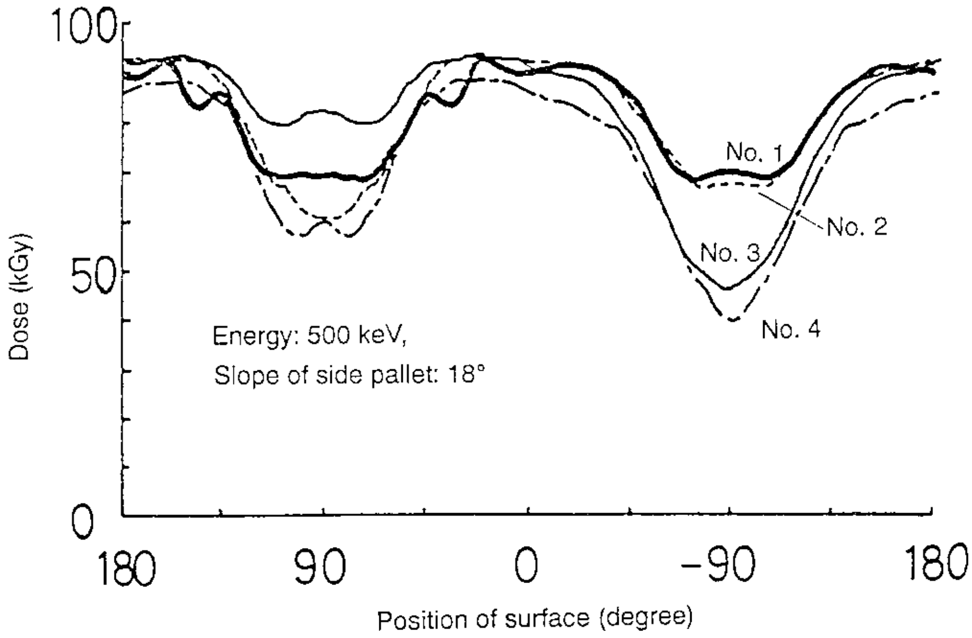

Fig. 5 Surface dose distribution on both side irradiation at various positions

3. CLOSING

3.1. Closing Remarks with Summary of the Workshop

Suchat Mongkolphantha

Secretary-General, OAEP

Dr. Sato,

Mr. Takahashi,

Honored Guests

Ladies and Gentlemen,

The importance of electron accelerator utilization to the development of our countries and people hardly need emphasizing. I am very much pleased that the need to promote this technology has been acknowledged. And I trust that with this in mind, participation of experts, scientists and decision-makers from various government and private sectors will help satisfy the potential demands more effectively.

Although it is well aware that for their great advantages and effectiveness, electron accelerators have been widely accepted and utilized all over the world, the uses are still limited to only in the developed countries. It is in this light that we welcome the various initiatives to promote the transfer of this technology to the developing countries, such as Thailand.

My Government is honored and pleased to host this workshop in Bangkok. I believe that this opportunity provided a wealth of experience and knowledge from which all of us can share. With most sharing similar problems and constraints, one country can learn from the experiences of the other. This will help each in the search for appropriate way and means to deal with its own internal situation and requirements.

I am, therefore, submitting that we must constantly promote and develop technical cooperation between our countries. In particular, we must aim at doing the utmost to take advantages of electron accelerators. In this regard, we hope that the Government of Japan will be able to assist Thailand in her industrialization efforts by applying this high energy technique.

At this opportune moment, on behalf of the Royal Thai Government, I wish to express our deep appreciation to the Government of Japan, JAERI and JAIF for their kind contribution and excellent cooperation extended to our country and to be extended in the future. And I would like to assure them of our full and continued support in generating very active inputs to promote the fullest possible opportunity for the transfer of electron accelerator technology ensuring the prosperity of our nations and the region as a whole.

Thank you.

3.2. Closing Remarks with Summary of the Workshop

Nazly Hilmy

Director, CAIR, BATAN

Ladies and Gentlemen,

We have discussed several aspects on the application of EB Accelerators in Industry. From the discussions, we would like to conclude as follows:

1. EB Accelerators have been widely used in Japanese industries, particularly to produce different kinds of high quality polymer cross-linked product, such as wire & cable insulations, heat-shrinkable tubing and films, PE foam and the treatment of parts of radial rubber tire. The application of EB Accelerators in the field of sterilization of medical products, food irradiation and flue gas treatment are under explored.

2. The potential application of EB Accelerators in Indonesia seems to be great, particularly when the Indonesian industrial society intends to introduce Radiation Technology in their industrial line to produce high quality and high performance products which is needed to fulfill the requirement of technology development.

3. The present workshop is very useful to energize our idea to improve industrial capability in the production technology and also to invite our attention on a new production tool such as EB Accelerators.

4. BATAN is the only research institute who is doing a lot of work on radiation processing in Indonesia, therefore BATAN is ready to provide further information about the application of EB Accelerators.

5. Bilateral cooperation between JAERI and BATAN is expected to maintain exchange information system, especially in the field of Radiation Technology such as the application of EB Accelerators by seminar, workshop and scientist exchange program.

Thank you to you all and on behalf of Organizing Committee I would like to express my gratitude to JAERI and JAIF for the nice cooperation and to all of participants for their attention. I hope such kind of workshop can be carried out regularly for every two years.

Thank you.

SUPPLEMENT

Supplement 1. Agenda (1)

OAEP/JAERI/JAIF WORKSHOP ON INDUSTRIAL UTILIZATION OF ELECTRON ACCELERATORS

9 July 1992
at Central Plaza Hotel. Bangkok, THAILAND

Opening Seession

9:30 - 9:40 Welcome Remarks by
Mr. Suchat Mongkolphantha
(Secretary-General, OAEP)

9:40 - 9:50 Opening Adress by
Dr. S. Sato
(Director General, TRCRE, JAERI)

9:50 - 10:00 Speech by
Dr. Y. Sasaki
(Advisor, Yazaki Co., JAIF Representive)

10:00 - 10:30 Coffee break

Session 1

Chairpersons: *Mr. A. Kuroyanagi (Nisshin)*
Dr. S. Chonkum (OAEP)

10:30 - 11:15 General View of Electron Accelerator Utilization
Dr. S. Sato (JAERI)

11:15 - 12:00 Introduction to Industrial Electron Acceleratrors
Mr. M. Suzuki (NHV)

12:00 - 13:30 Lunch

Session 2

Chairpersons: *Dr. Y. Sasaki (Yazaki)*
Mr. T. Na Chieng Mai (STA GROUP)

13:30 - 14:00 Economical Aspects of Industrial Electron Accelerators
Mr. T. Doi (NKK)

14:00 - 14:30 Polymer Processing with Electron Accelerators
Dr. K. Makuuchi (JAERI)

14:30 - 15:00 Potential Application of Electron Accelerators in Thailand
Mr. C. Siri-upathum (Chulalongkorn Univ.)

15:00 - 15:30 Coffee break

Session 3

Chairpersons: *Dr. S. Sato (JAERI)*
Mr. S. P. Kasemsanta (Thai A.E.C. Commissioner)

15:30 - 16:00 Food Irradiation with Electron Accelerators
Dr. C. Banditsing (OAEP)

16:00 - 16:30 EB Treatment of Wastewater and Sewage Sludge
Dr. S. Hashimoto (JAERI)

16:30 - 17:00 Flue Gas Purification with Electron Accelerators
Dr. W. Kawakami (JAERI)

17:00 - 17:15 Closing Remarks with Summary of the Workshop
OAEP

Supplement 2. Agenda (2)

BATAN/JAERI/JAIF SECOND WORKSHOP ON INDUSTRIAL UTILIZATION OF ELECTRON ACCELERATORS

13 July 1992

at Hotel Indonesia, Jakarta, Indonesia

	Opening	
	OC Report by	
		Dr. Mirzan T. Razzak (BATAN)
9:30 - 10:00	Remarks by	
		Dr. S. Sato
		(Director General, TRCRE, JAERI)
		Dr. M. Takehisa
		(Exec. Director, Radia Ind. Co. Ltd.)
		Dr. Nazir Abdullah
		(Act. Director General, BATAN)
10:00 - 10:30	Coffee break	
	Session 1	
	Chairwoman: *Mrs. Nazly Hilmy (BATAN)*	
	Co-chairman: *Dr. Y. Sasaki (Yazaki)*	
10:30 - 11:00	General View of Electron Accelerator Utilization	
		Dr. S. Sato (JAERI)
11:00 - 11:30	Introduction to Industrial Electron Acceleratrors	
		Mr. M. Suzuki (NHV)
11:30 - 12:00	Economical Aspects of Industrial Electron Accelerators	
		Mr. T. Doi (NKK)
12:00 - 13:30	Lunch	

Session 2

Chairman: *Dr. Soleh Kosela (Univ. Indonesia)*

Co-chairman: *Mr. K. Tomita (Radia)*

13:30 - 14:00 Potential Industrial Application of Electron Accelerators in Indonesia
Dr. Mirzan T. Razzak (BATAN)

14:00 - 14:30 Polymer Processing with Electron Accelerators
Dr. K. Makuuchi (JAERI)

14:30 - 15:00 Progress in Electron Beam Curing in Indonesia
Ir. F. Sundardi (BATAN)

15:00 - 15:30 Coffee break

Session 3

Chairman: *Dr. Moch. Sholichin (PT. KIMIA FARMA)*

Co-chairman: *Mr. A. Kuroyanagi (Nisshin)*

15:30 - 16:00 Sterilization with Electron Accelerators
Dr. M. Takehisa (Radia)

16:00 - 16:30 The Possibility of using Electron Beam Machine for Food Preservation in Indonesia
Mrs. Nazly Hilmy (BATAN)

16:30 - 17:00 Application of Electron Accelerators to Bio-Resources
Dr. T. Kume (JAERI)

17:00 - 17:30 Flue Gas Purification with Electron Accelerators
Dr. W. Kawakami (JAERI)

Closing

17:30 - 17:45 Closing Remarks with Summary of the Workshop by
Mrs. Nazly Hilmy
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