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T-6

Treatment of Municipal and Industrial Waste by Radiation Processing

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ABSTRACT

In recent years the effort in science and technology is shifting from conventional technologies preventing the pollution of air, water and soil, towards processing by gamma or by electron beam (EB) irradiation in order to prevent pollution, rather than curing the problems caused by production processes, which are not optimized with regard to pollution control.

Radiation processing may help to improve the environmental situation in two aspects : It provides alternatives to conventional technologies for the cleaning of air, flue gases and water,....etc, and it also helps to realize "clean processes " for preventing pollution in the first place.

This paper will outline the basic principles of radiation processing for waste streams of environmental relevance, will summarize the state - of - the - art in environmental applications of radiation processing to show both the advantages and the limitations of the radiation processing of waste streams, and to highlight the environmental and economic benefits of "clean processes " made possible by radiation processing applied to municipal and industrial waste. Reference is made to gamma and EB radiation sources, and description of new technologies is presested.

Key Words : Gamma Irradiator / Accelerator / Radiation Processing / Curing / Crosslinking

I.INTRODUCTION

Conventional technologies preventing the pollution of air, water and soil by anthoropogenic waste streams have been developed in the past. Despite a rather high state of maturation, these technologies cause substantial investment costs and complicated process modifications. There are sometimes serious environmental effects as well as disposal problems.

As an example, there has been a great concern for the environment from sewage and its hazards on water pollution, on plants, and consequent health effects on the public. One of the problems in this respect is the dumping of sludge in rivers, seas and oceans. Accordingly, efforts have been made to clean up process effluents. On the other hand, the efficient use of the limited water resources, and the protection against pollution, has become of great national concern in every country.

Radiation processing by gamma rays from cobalt-60, or by electron beams may help to improve the environmental situation in both aspects : it not only provides alternatives to conventional technologies for the cleaning of hazardous waste, but it also helps to realize " clean processes " for preventing pollution in the first place.

The radiation process induces chemical changes which are responsible for its ability to modify the material components, a property which is exploited during radiation processing (polymerization, cross-linking, sterilization, disinfecting,... etc).

The objectives of this lecture is to outline the basic principles of radiation processing for waste streams of environmental relevance, and to summarize the state - of - the art in environmental applications of radiation processing, as well as to show the advantages and the limitations of radiation processing of hazardous waste.

II.RADIATION SOURCES

Radiation sources include cobalt-60 gamma irradiators, electron beam (EB) accelerators, and X-rays. A brief description will be given for the sources most widely used in radiation processing, just as examples of the big variety of radiation sources.

Cobalt -60 Gamma Irradiators

The activity of gamma sources ranges from few hundreds of curies to 3 megacuries. Usually, safety recommendations are primarily concerned with facilities with the larger activities, but they also apply, with appropriate modifications, to facilities with relatively low activities.

Four general categories of irradiators are defined according to the design of the facility and particularly the accessibility and shielding of the radioactive source [(1)]. Our main interest will be in Category IV :

Category IV: A controlled human access irradiator in which the sealed source is contained in a water filled storage pool, is fully shielded when not in use and is exposed within a radiation volume that is maintained inaccessible during use by an entry control system (Fig.1).

The industrial irradiator used in radiation processing is designed in various forms of Category IV, one of these is the Pallet Irradiator -Automatic shown in (Fig.2) [(2)].

It consists of a room with concrete walls two meters thick which contains the radiation source (Co-60). A conveyer system automatically moves the products in the room for irradiation, and then removes them. When personnel must enter the room, the source is lowered to the bottom of a pool, where water absorbs the radiation energy and protects the workers.

The basic requirements for gamma irradiators include simplicity, ease of operation and maintenance, dose uniformity within the carrier, high cobalt efficiency, flexibility in terms of ability to process more than one product at a time, reliability, and safety.

Electron Beam Accelerators

Electron accelerators of energies less than or equal to 10Mev are used in radiation processing.

For these energies there is no induced radioactivity in any part of the equipment. There are many types of electron beam (EB) accelerators; the main differences between the types of accelerators are in the mode of accelerating the E.B. and in the method of producing the high voltage needed for acceleration. As in gamma irradiators, there are different categories dependent on the shielding and safety features of the accelerators. Of the many different types of E.B. accelerators [(3)], we will give a d.c. EB accelerator, and a radio frequency accelerator as examples : the First is shown in Fig.3[(4)], it is featured by being small and compact, having high stability and homogenity. Beam energy is 3 MeV and power 200KW.

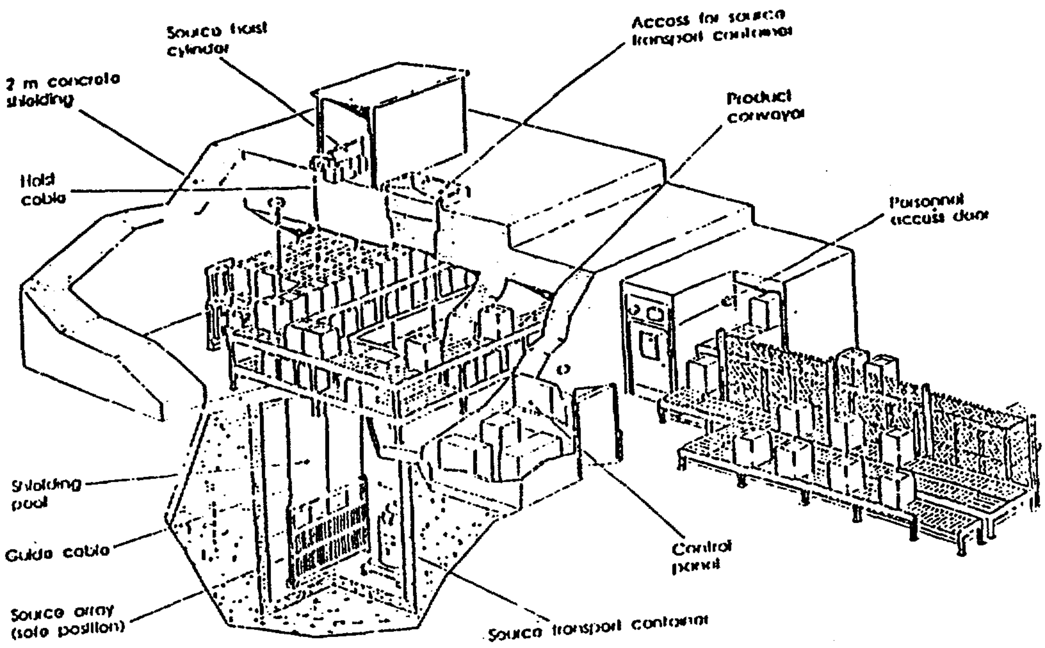


Fig.1 Category IV Gamma Irradiator. A Panaromic Wet Storage Type

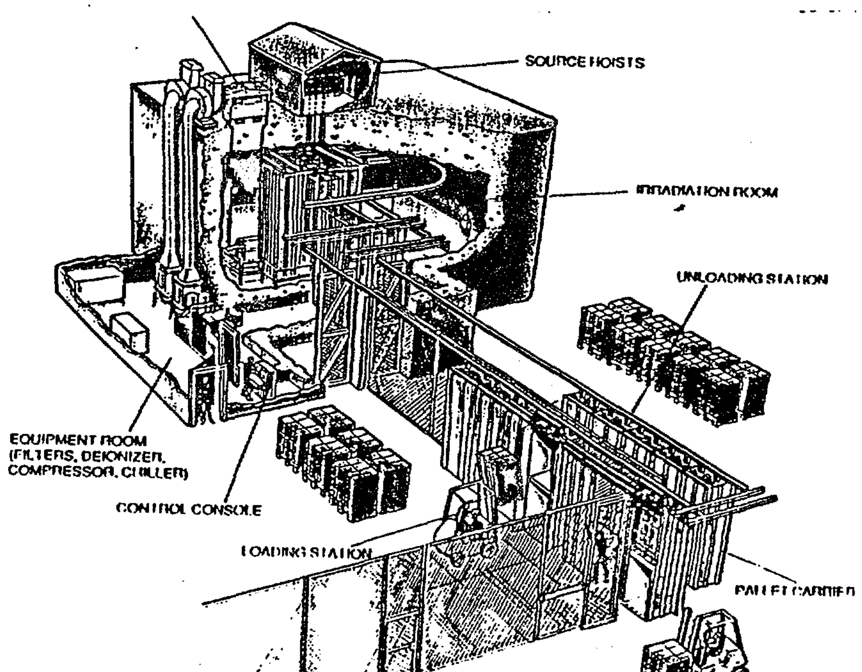
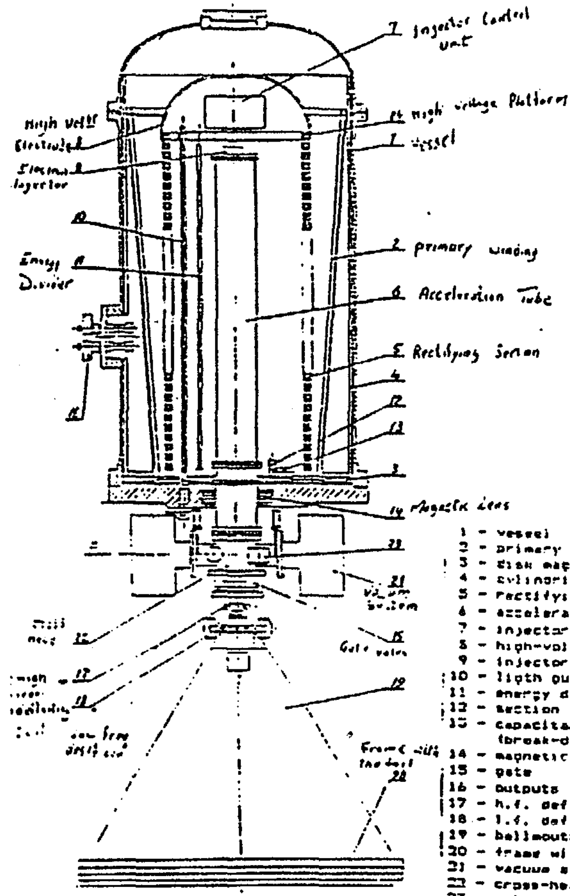


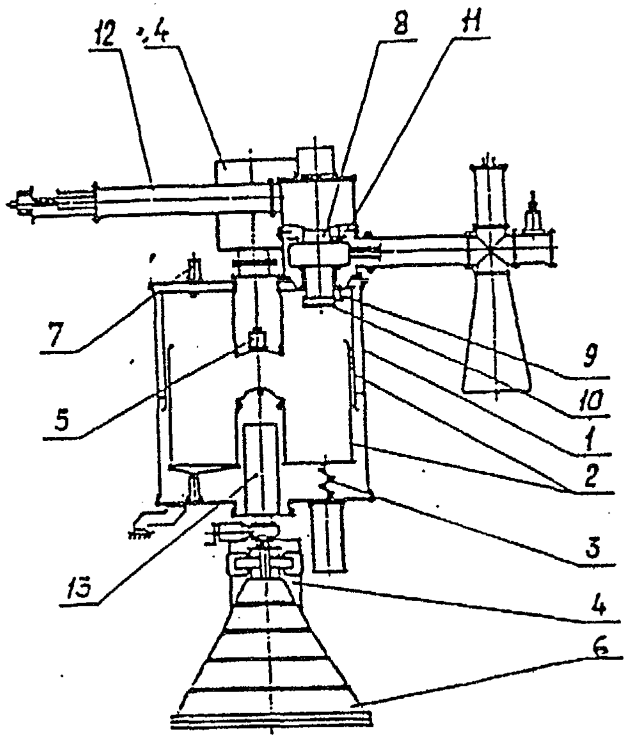
Fig.2 Industrial Pallet Irradiator-Automatic



1 - vessel
2 - primary winding
3 - disk magnetoguide
4 - cylindrical magnetoguid
5 - rectifying section
6 - accelerating tube
7 - injector control unit
8 - high-voltage electrod
9 - injector
10 - ligth guide unit
11 - energy divider
12 - section voltage divider
13 - capacitance unit (break-down probe)
14 - magnetic lens
15 - gate
16 - outputs
17 - h.f. deflecting coil
18 - l.f. deflecting coil
19 - bellmouth
20 - frame with the foil
21 - vacuum system
22 - cross-head
23 - sylphon gate
24 - base of high-voltage electrod

Electron Accelerator Based on High voltage Rectifier

Fig.3



Schematic of the Single-Resonator d.c. Accelerator

1—vacuum tank; 2—resonator; 3—inductive coil of the bias at the lower half of the resonator; 4—magnetodischarge pumps; 5—electron injector; 6—extraction device; 7—measuring loop; 8—generator tube; 9—base of the coupling loop; 10—vacuum capacitor of the coupling loop; 11—movable plate of the feedback capacitor; 12—cathode stub; 13—focusing lens.

Fig.4

The acceleration tube and extraction device are located in the biological shield.

The second type is a radio frequency EB accelerator; linear single gap accelerator, Fig.4[5] .in which acceleration of electrons is accomplished in a high frequency resonator gap, which means that none of the accelerator components has a potential relative to the housing, thereby eliminating the acceleration tube, rectifying section, insulating gas and pressure vessel,...etc.

X - Rays as Radiation Sources

X-rays are produced whenever electrons strike against a target material. This radiation is also called Bremstrahlung and results from the conversion of some of the electrons kinetic energy into electromagnetic radiation.

Table 1 gives comparison between the three types of radiation sources.

III.APPLICATIONS TO HAZARDOUS WASTE

III.A.TREATMENT OF MUNICIPAL WASTE

Gmma irradiation and EB-processing may serve for disinfection of solid and liquid wastes for the degradation of persistant chemicals. In the following some examples for the treatment of wastes are discussed.

III.A1. Disinfection of Municipal sewage Sludge

Recent worldwide trends on the recycling and reuse of wastes have had an impact on the way in which municipal sewage sludge is perceived. A growing concern for the environment, coupled with immediate access to news of world events, has focused global attention on water pollution and the to plants and wildlife caused by it. As a result, ocean and river dumping of sludge is rapidly being discontinued and efforts are being made to clean up process effluents. The European Union environment regulations prohibit the dumping of such waste at sea. Especially in semi-arid countries ,the efficient use of the limited water resources and the protection thereof against pollution, has become a national strategic issue. At the same time, awareness of the potential use of sludge as an organic soil conditioner and horticultural product has lead to an increased need for waste disinfection or sterilization technologies. A potential hazardous product can thus be converted into a very valuable asset. Especially in semi-arid regions, very valuable land rehabilitation programmes can be instituted through the beneficial use of safe sewage sludge as a soil conditioner and fertilizer - the latter being created with the necessary nutrient augmentation of the disinfected sludge.

Sludge is a natural by-product of the treatment of effluent waters which have been contaminated by humman or animal excreta and wastes. Sludges can broadly be categorised into raw and stabilised sludges. The essential difference between them is that raw sludge putrefies, omits offensive odours, hosts numerous potentially lethal (to humman beings) pathogens and encourages fly breeding, which has a significant nuisance factor and potential health risk. Stabilised sludge has none of the above characteristics except that the pathogens are still present. Should any of the other characteristics of raw sludge be present in stabilised sludge, then the sludge is considered as not being fully or complerely stabilised.

Comparison between irradiation processes

	Advantages	Disadvantages
Gamma-rays	• good penetration • high reliability • relatively simple operation	• low intensity • low power utilization • long process time • continous emission • potential nuclear hazard • bad public perception
Electron beams	• high intensity • high thoughputs • high power utilization • adjustement of beam energy, intensity and scanning • beam shut-off	• limited penetration • package size restrictions
X-rays	• excellent penetration • beam shut-off • product flexibility	• low conversion efficiency

Table .2

Irradiation facilities for treatment of water, wastewater, and sludge that have been or are operating

	Irradiator type	Waste type processed	Reason for treatment
Austria	Electron-beam	Drinking water	Reduction of chemical contaminants
	Cobalt-60	Wastewater	Reduction of phenols
Canada	Cobalt-60	Sludge	Disinfection prior to fertilizer use
Czech Republic	Cobalt-60	Drinking water	Disinfection
Germany	Cobalt-60	Sludge	Disinfection prior to land use
	Cobalt-60	Well water	To prevent biological fouling
India	Cobalt-60	Sludge	Disinfection
Japan	Cobalt-60	Sludge	Disinfection prior to composting
	Cobalt-60	Landfill leachate	Destruction of toxics
Norway	Cobalt-60	Sludge	Disinfection
	Electron-beam	Effluent	Disinfection
South Africa	Electron-beam	Sludge	Disinfection
United States	Electron-beam	Wastewater, sludge	Disinfection

Of particuler concern are wastes that present problems in two areas . those containing potentially infectious microoganisms (sewage sludge, biomedical wastes, wastewater) and those contaminated with toxic chemicals.

The gamma irradiators have been widely used since the early 1996 in the sterilization of medical products and consumer goods. Their use in the disinfection of sewage sludge has been demonstrated on a full-scale basis at a plant near Munich, Germany; and at a biomedical waste sterilizer in Arkansas, U.S.A. for the treatment of hospital wastes.

Similarly, E.B. accelerators have seen decades of use in industrial processes. This technology has been proven effective in the disinfection of drinking water and wastewater.

Irradiation facilities for treatment of water have been constructed in many countries of the world [6], as shown in table 2. The first large – scale plant was the Geiselbullach Gamma Sludge Irradiator, constructed in Germany in 1973. Another commercial application, also in Germany, is the use of irradiation to reduce biological fouling of drinking water wells.

India's sludge Hygenization Research Irradiator (SHRI) is the second such plant in the world, formally commissioned in the city of Baroda in early 1992. SHRI treats the entire sludge output of ablut 110 cubic meters per day. The hygenized sludge is used as a safe fertilizer.

Studies have been carried out [2] on the effect of high-energy E.B. irradiation on the removal (ultimate destruction) of the toxic organic chemicals in aqueous solutions and the factors that have been identified as important in efficiently destroying the chemicals . The results of these studies are applicable to waste treatment and the remediation of hazardous waste sites. E.B. accelerator 1.5 MeV energy delivering 50 mA bean current yields doses from 0 to 8 KGY and is capable of scanning at a rate of 200 Hz to give a coverage of 1.2 meters wide and 5 centimeters high [2] ,the maximum penetration in water is approximately 7 mm for 1.5 MeV electrons .

Irradiated sludge as a fertilizer product

Particular emphasis in many of the earlier studies was placed on the agricultural advantages that can be gained from the safe use of irradiated sewage sludge-converting a problem waste product into a highly valuable asset.

Sewage sludge is rich in nutrients and provides valuable soil conditioning properties. Because it is organically based, it offers long-term soil improvement, unlike chemical fertilizer which provide nutrients but have few soil-enhancement propreties. A typical analysis of an irradiated and dried sludge product is as follows: [6]

Major Nutrients	%
Total Nitrogen	3,0
Available Phosphoric Acid	0,5
Soluble Potash	0,4
Minor Nutrients	
Calcium	0,29
Magnesium	0,05
Boron	0,008
Iron	1,8
Manganese	0,05
Zinc	0,015
Molybdenum	0,00035
Other Components	
Organic Matter	44,5
Moisture	30,0

III.A2. Municipal Sludge Irradiators

Radiation disinfection of sludge is accomplished be E.B. irradiation, or by gamma-ray cobalt-60 irradiators . In the first case, sludge cake(water content 80%) is spread on a stainless steel conveyer through a flat nozzle and disinfected by E.B. which is injected from upside of the system fig.5 [7] . The width of the nozzle is 20 cm and sludge thickness is variable from 1 to 10 mm.

The maximum feed rate of sludge is 300 kg/hr. Any type of the big variety of E.B. accelerators could be used, including those previously described in section II, E.B. energy being in the range 1.5 to 3.5 MeV, and beam current could reach 30mA. The applied dose of 10KGY is sufficient to reduce the bacteria counts by 5 orders of magnitude (Fig.6) (8) .

If the sterilized waste does not contain other toxics such as heavy metals or dioxins, it is suitable as an agricultural fertilizer . A combination-process of irradiation and composting has been proven to be most suitable for minimizing the composting time.

Gamma irradiators are also used . There are more than 170 of these full scale industrial irradiators operating around the world used in radiation sterilization in various fields of applications .

A sludge gamma disinfection system, like the one used in Canda (Fig.7) [9], consists of three main components :

- A concrete – walled disinfection room which houses the irradiator and cobalt – 60
- A product handling mechanism which houses the sludge into and out of the room, and
- A cobalt-60 energy source for disinfection

It is worth mentioning that in some cases,more research and testing is required before the technology can be widely used on a commercial scale, in other instances, however, the technology is already being used on a full – scale basis .

IV.USE OF ELECTRON ACCELERATORS IN ENVIRONMENT-RELATED TECHNOLOGIES

The objectives of this survey about radiation processing is to summarize the state-of the-art of environmental effects of radiation processing to show its advantages and limitations and to highlight the environmental benefits of clean processes made forcible by E.B. processing.

IV1.PURIFICATION OF FLUE GASES BY ELECTRON BEAMS (E.B.)

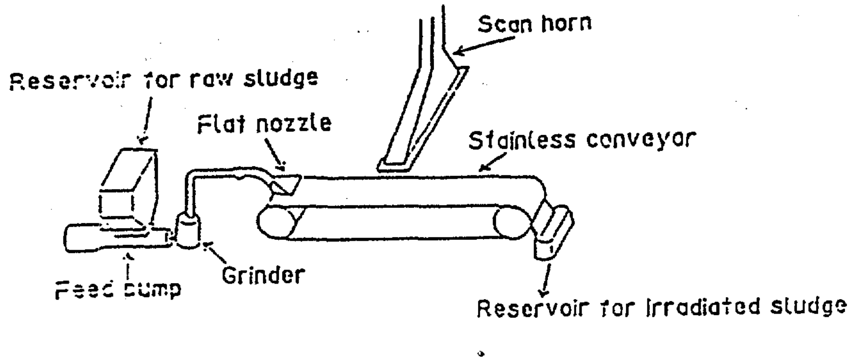
Conventional air pollution control technology for power plants (e.g.wet scrubbing) has been developed to a high state maturity. Lower costs for emission control are expected from second generation processes, among them the Electron Beam Dry Scrubber (EBDS)-process. Besides the cost of the process, the usefulness of the by-product obtained from SO_2 and NO_x removal is of importance with respect to the long term application of flue gas cleaning.

Flue gas from coal fired power plants may be efficiently cleaned by the EBDS process. In the presence of ammonia a mixture of ammonia sulphate and ammonium nitrate is obtained which may be used for the production of fertilizer. Several pilot plants using the EBDS process (flow rates up to 20 000 M^3/hr) have been operated meanwhile in Japan, Poland, U.S.A and Germany. These have proved the feasibility of the process and utilization of the product, Table 3 [10] .

On the other hand it has been shown [10] that the energy consumption of the process may be reduced significantly by multiple irradiation and intermediate scrubbing.

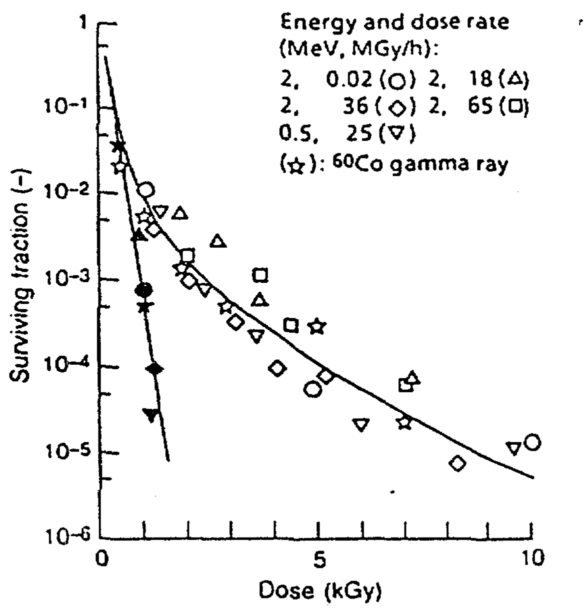
Table 3 [10]

Year	Institution		Flow Rate	Accelerator	Type of Flue Gas
	Name	Country	[Nm^3/h]	[kW]/MeV	
1970-71	Ebara	Japan	0.02	1.2/2-12	simulated
1972-74	JAERI	Japan	60	15/1.5	simulated
1974-77	Ebara	Japan	1.000	30/0.750	heavy oil
1977-78	Ebara	Japan	10.000	90/0.750	sinter plant
1981	University of Tokyo	Japan	84	0.12/1.0	simulated
1984-85	Research Cortrell	USA	5.300	80/0.800	coal
1984-88	Ebara	USA	24.000	160/0.800	coal
1981-91	JAERI	Japan	0.9	/1.5	
1984-88	KfK	FRG	300–1.000	3.6/0.300	heavy oil
1984-91	University Karlsruhe	FRG	1.000	22/0.220	nat. gas
1985-88	Badenwerk	FRG	20.000	180/0.300	coal
1990	KfK	FRG	1.500	16.5/0.550	light oil
1991	INCT	Poland	20.000	100/0.700	coal
1992	NKK/JAERI	Japan	1.000	50/<1.000	incinerator
1992	Ebara	Japan	50.000	80/0.800	tunnel
1993	Ebara/JAERI	Japan	12.000	108/0.800	coal
Project	KfK/INCT	FRG/Poland	150.000	600/0.800	coal
Project	Ebara	Japan	1.750.000	?/?	coal



Apparatus for electron beam irradiation of sludge

Fig.5



Sterilization of sewage sludgeby irradiation: Surviving fraction of bacteria for various beam energies and dose rates (sludge thickness: 1mm; open symbols: bacteria; filled symbols: coliforms; (--): dimensionless (Sato et al., 1992)

Fig.6

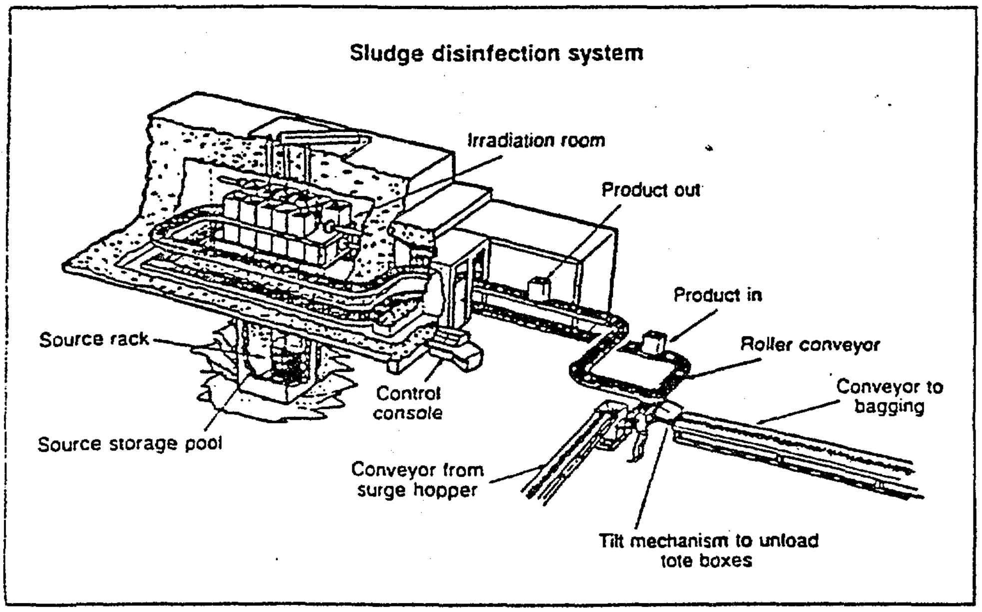

Sludge disinfection system
Irradiation room
Product out
Product in
Roller conveyor
Conveyor to bagging
Source rack
Control console
Source storage pool
Conveyor from surge hopper
Tilt mechanism to unload tote boxes

Fig.7

The flow diagram of the EDBDS-process is shown in (Fig.8). It consists of three main steps:

- Flue gas conditioning
- Irradiation
- Aerosol filtration

It works as follows (Fig.8)

1.Flue gas at 140 °C(284 °F) is cooled to 70 °C(158 °F) in a spray cooler .The fine mist of water from the spray nozzles in the cooler is totally evaporated by a heat exchanger with the hot flue gas .

2. Prior to entry into the process vessel, the flue gas is injected with gaseous ammonia . In the process vessel, the flue gas is irradiated by the electron beams causing free radicals to be generated. These free radicals readily oxidize the SO_2 and No_x to form their acid counterparts which react with the ammonia to form ammonium sulfate and ammonium nitrate particulates.

3.Before its release to the atmosphere via the smoke stack, the flue gas passes through a by-product to remove the ammonium sulfate and ammonium nitrate particulates, these particulates are automatically removed and transported to a by-product storage vessel for later off-site removal.

The SO_2 and No_x are removed from the flue gas in three [11] sequential steps in less than one (1) second as follows [11]

a) Under the influence of electron-beam irradiation, nitrogen (N_2), oxygen (O_2), water (H_2O), other molecules in the exhaust gas are converted into active, free-radicals with high oxidation potential, such as OH,O and HO_2.

b) These free-radicals oxidize the SO_2 and No_x in the flue gas to produce sulfuric acid ($H_2 SO_4$) and nitric acid (HNO_3) as intermediate products.

c) These intermediate products then react with the stoichiometric quantity of ammonia (NH_3), previously injected to form ammonium sulfate $(HN_4)^2 SO_4$ and ammonium nitrate ($NH_4 NO_3$).

The E BDS process has the following advantages:

a) High removal efficiencies, 95% for SO_2, and 80% for No_x, (Fig 9).

b) Easy to operate,

c) Dry versus wet mode of operation,

d) Valuable fertilizer by-product; ammonium sulphate and ammonium nitrate,

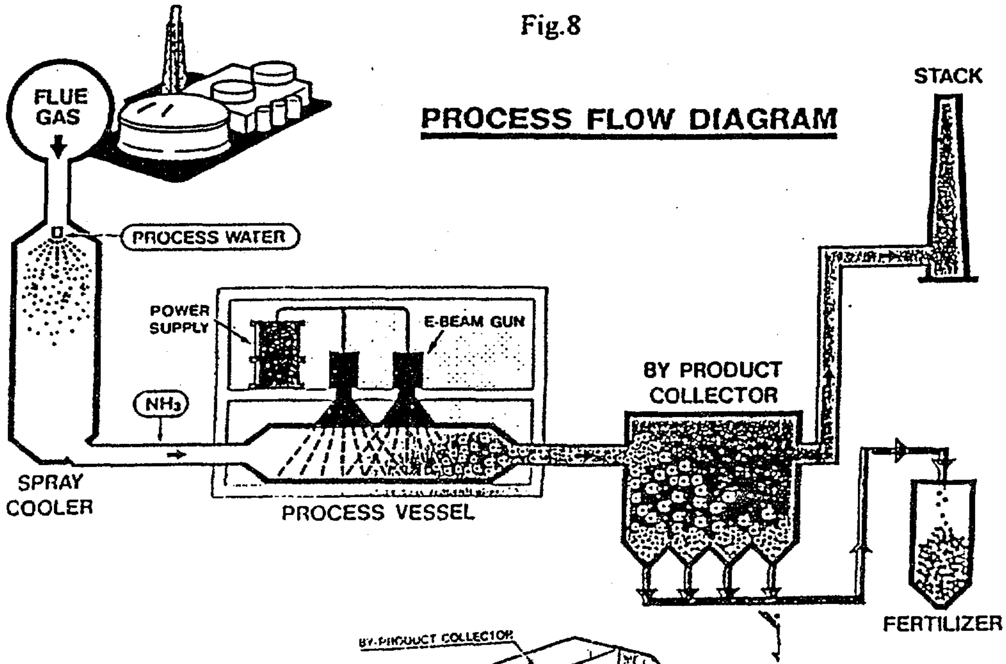
e) Low capital requirement and low operating expenses.

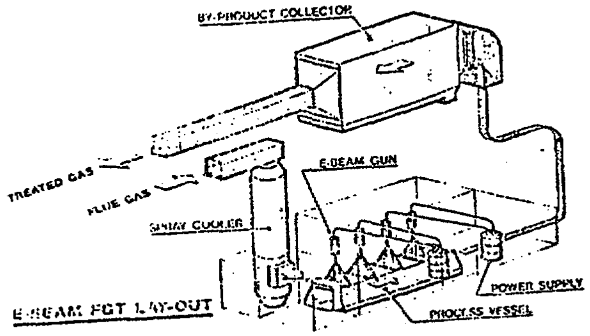
IV.2. ELECTRON BEAM TREATMENT OF WASTE STREAMS

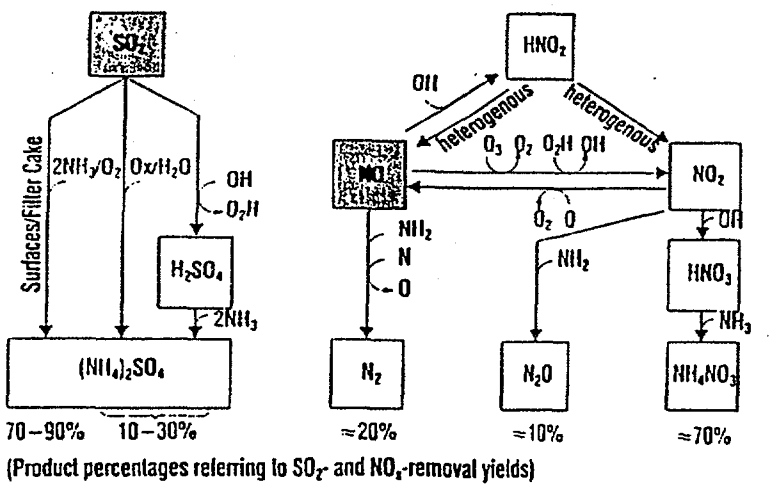
1.Waste Incinerators

The flue gas generated by the incineration of municipal wastes contains acidic trace gases usch as H CL, SO_2 and No_x.These Compounds may be treated by EB-processing and neutralization by lime addition (Fig .10). Pilot plants have been in operation during recent years [12] , H CL and SO_2 were removed to over 90% from the gas and sufficiently high efficiencies were obtained for No_x removal, even at higher temperatures,(Fig11).

Fig.8







Pathways for Removal of SO_2 and NO_x in the EBDS Process

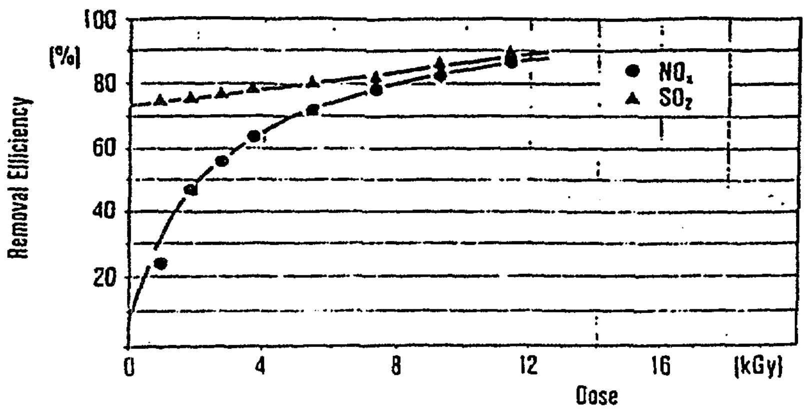


Fig.9 SO_2 and NO_x Removal Efficiencies in the EBDS-Process

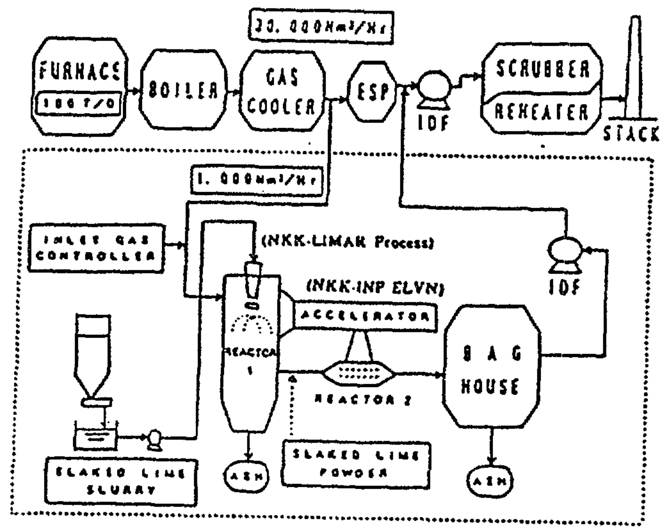


Fig.10 Flow chart of the 1000 m^3/h pilot plant for radiation processing of flue gas from a waste incinerator (Doi et. al. 1993)

The product of this process is a mixture of fly ash and soluble organic salts, which must be disposed of. The method might be useful as a low-cost retrofit for existing incinerators.

2.Industrial Ventilation System

Slow Technical progress has been made up to now in the control of emissions which are low in concentration and contain several components (organic, inorganic and aerosols). Usually, these emissions are characterized by large volumes due to specific process requirements. Typical off-gases of this kind are emitted from industrial processes, (e.g... coating of metal parts with solvent containing paints) and from automobile tunnels.

Removal of Volatile Organic Compounds (V.O.C.)

E.B. irradiation provides a simple and safe method for the simultaneous removal of organic trace gases from air; OH-radicals are produced in the off gas, which subsequently oxidize the pollutants. The removal efficiencies for an industrial solvent mixture as determined downstream of the accelerator depend on several parameters: dose, concentration and chemical composition of the mixture. As shown in Fig 12, efficiencies up to 90% were measured for low concentrations (20,40 mg/m3) in the dose range between 1 and 5 KGY, lower-yields were noticed for a VOC concentration of 110 mg/m3 in the same dose range.

Gas purification by E.B. is also used in tunnel of gas cleaning where large volumes of air are emitted from automobile tunnels. These contain low concentration of No_x (<10PPmV) and smelly VOC, some of which even might be harmful (e.g.benzene), during long term exposure to neighbouring residents. Especially for tunnels within residential areas a cleaning technology having low energy consumption and low space requirements is desirble. A large plant for a flow of $50000m^3/h$ of tunel off gases is meanwhile operated successfuly in the Tokyo bay [13] ,(Fig.13).

. This process closely resembles the EBDS-process for flue gas cleaning , Fig13. The tunnel gas is spiked with traces of ammonia and subsequently irradiated with electrons. The particulate products (ammonium nitrate), dust and soot from the tunnel are trapped in a wet electrostatic precipitator. Finally, traces of excess ozone are decomposed by an activated carbon filter. The product, a solution of ammonium nitrate is cleaned from toxic exhaust components and may by used as valuable liquid fertilizer.

V. Waste Management

Radiation disinfection of solid and liquid wastes

Direct E.B. processing of waste may serve for the disinfection of wastes for the degradation of persistent chemicals in solid and liquid wastes. The state-of-the art of radiation treatment of such wastes has been summarized by Waite [14] . Typical examples are considered in the following :

V.1 Sterilization of Airline Wastes

Airline wastes consist of food wastes, plastics, celluloses, glass and liquids. These wastes may contain pathogenic bacteria, parasites and viruses. This creates a difficult disposal problem and it must be sterilized to prevent international transmission of plant and animal disease. The traditional approach to the problem is to incinerate the wastes, but this creates a public acceptance problem. An alternative way is to irradiate the wastes and dispose of them via landfilling. Such a process has to be approved by appropriate regulatory authorities, On the basis of chemical and biological considerations, irradiation of airline waste to a dose of about 90 KGY poses no significant toxicological hazard. The only effect of irradiation is the gas evolution, primarily hydrogen, at a rate much smaller than gas emission produced by incineration [15] .

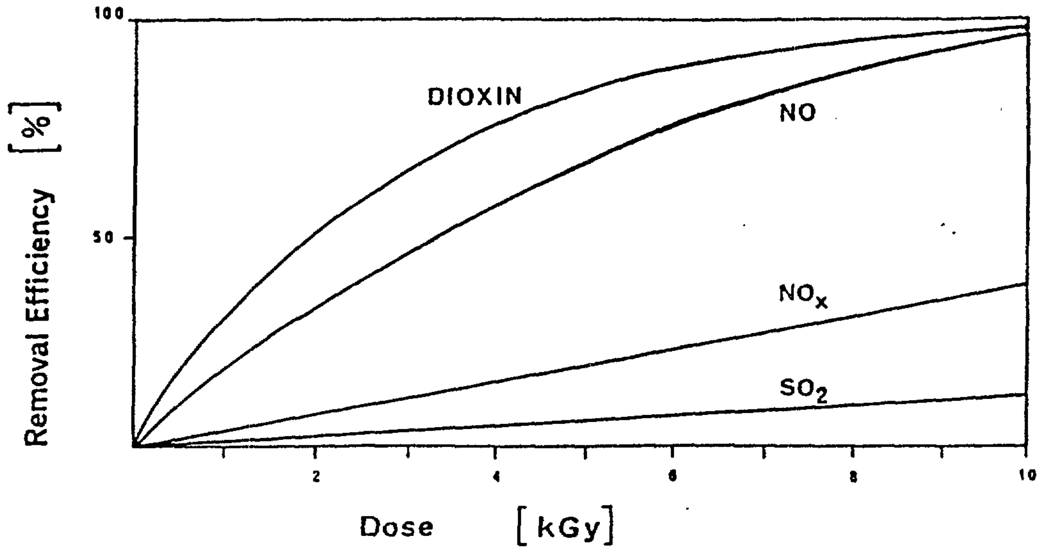


Fig.11 Calculation of the EB induced decompositionj of dioxin (2,3,7,8-TCDD), SO_2 and NO_x in incinerator flue gas

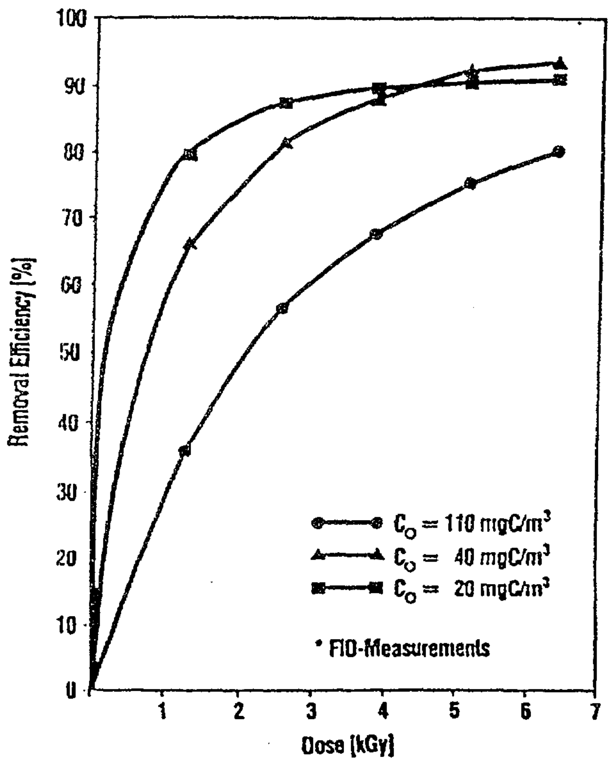


Fig.12 Removal of VOC from a simulated off gas stream

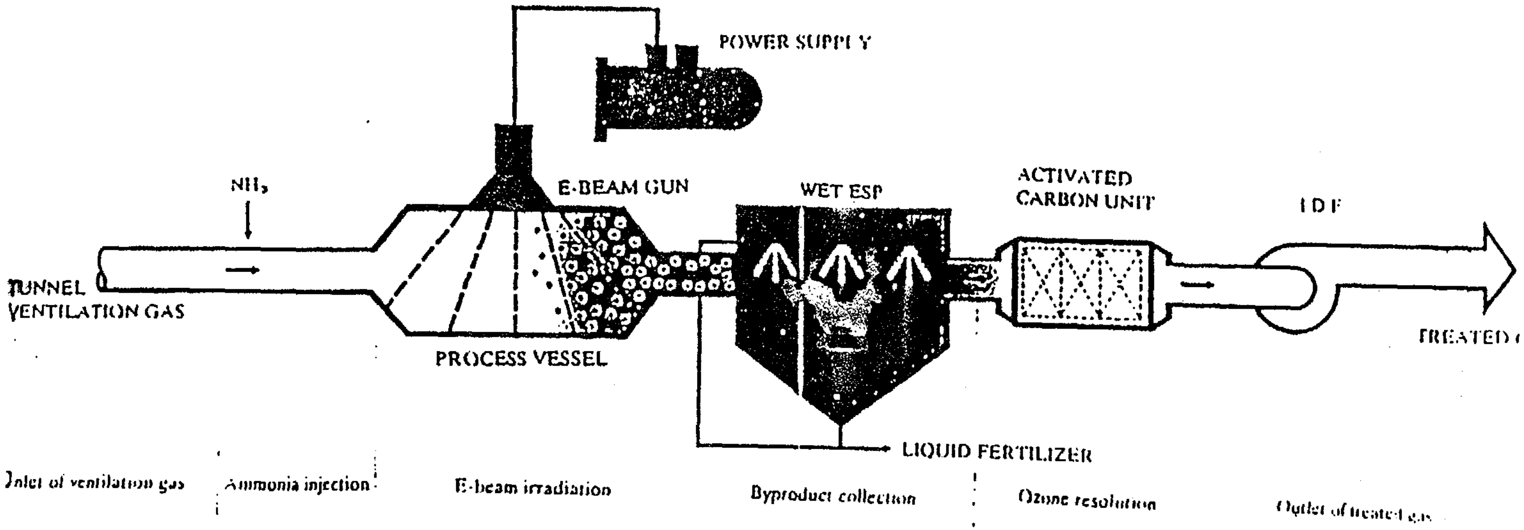


Fig. 13 Flow diagram of the tunnel off gas cleaning facility at the Tokyo Bay

V.2 Biomedical Wastes

This type of waste originates from hospitals, diagnostic and research laboratories . In hospitals, about 1 ton of waste is produced by 1000 beds per day. Although about 85% of this quantity is non-infectious refuse, risks involved in separation of refuse from actual contaminated waste makes it advisable to treat the total mass as potentially infectious material. Because of its contamination with pathogenic micro-organisms, there is potential hazard for public. Accordingly, such wastes have to be disinfected before being disposed of in landfills. Because incineration creates hazards to public health since biomedical wastes contain 20% plastic materials which produce toxic combustion gases , sterilization by E.B. irradiation is environmentally preferable.

VI. Applications to Waste Prevention ("Clean Technologies") Production of FUELS

VI.1. Desulfurization of natural gas :

Natural gas contains considerable amounts of hydrogen sulphide. Prior to the transport of the gas the H_2S must be removed to avoid corrosion of the pipeline ducts. This is usually achieved by the Claus-process. Intensive work regarding the application of radiation for the cleaning of natural gas was performed in Russia and Azerbaijan [(16)] ; The G-value of the H_2S radiolysis was measured to 3 molec /100 eV. Since one radiolysis product is molecular hydrogen, the rather high energy consumption of the process is somewhat decreased. Nevertheless it seems not realistic to apply the method to natural gas having high sulpher content. A more promising application of radiation technology might be final cleaning of natural gas in the receiving countries.

VI.2. Desulphurization of Coal

A process [(17)] has been investigated to reduce the inorganic and coal organic sulfur content of coal by irradiation of a slurry of fine coal particles in sulphuric acid. Results yielded S-removals of up to 80% for coal having sulfur contents of 2-3%. The optimized process was proposed which combined conventional coal desulfurization (magnetic separation, washing) with the radiation approach. Thereby significant energy savings have been reached and the dose was reduced down to 100KGY. Considering the flue gas composition, this translates into almost the same dose range as required for flue desulphurization by electron beam.

VII. Radiation Processing of Industrial Materials

The EB treatment of the different types of materials gains steady position in the various fields of industrial production. The success of this technology is based on its economic efficiency, technological flexibility and ecological safety. The advantages of the EB processing are clearly seen in comparison with conventional technologies. This will be illustrated in the brief survey given below in such processes as curing, crosslinking and polymerization.

The main advantage of radiation processing is the possibility of direct energy transfer into the treated material for chemical reactions initiation . The uniqueness of this technology is based on the fact that all the transferred energy is converted into free radicals, so no catalyst or initiating agent is used.

Production of Polymers

i) Curing and Crosslinking

A difficult problem of environmental technology is the control of low concentrated pollutants (VOC). These are emitted frequently in many coating and printing processes. By application of low-voltage electron beam irradiation, the curing and crosslinking of surface coatings and inks is possible without the use of solvents. The products are at least of similar or higher quality and may be stacked immediately after production [18].

An important industrial application of the EB-irradiation is the production of heat resistant cables by crosslinking of cable isulations. In addition to high quality produced by this process, an important argument for using this technology come from the fact that use of dangerous chemicals may be avoided and no waste is produced during the start-up phase of the process.

Intensive work [19] has quantified the environmental advantages of radiation curable composites. It was found that for manufacturing of typical products the energy consumption of the radiation process was only 13% of equivalent thermal processes. For a given production rate autoclaves use 10-20 times the energy to cure composites as compared to 50KW EB's. Tupically VOC emission from thermal curing processes are in the order of 3-4-g/kg of polymer. In order to meet typical safety standards the VOC emissions are diluted with 3.5-5 m^3 of fresh air. Compared to the substantial emission of thermal curing processes no VOC is detected during the EB curing at 25-50 °C and doses between 50-100 KGY. Even more important than the environmental benefit seems the potential to minimize the exposure of workers to carcinogenic compounds during industrial curing. Table 4 summarizes some industrial applications for electron beam processing inducating the advantages of E.B. processing in each case.

ii) Vulcanization

The radiation vulcanization of natural rubber latex [20] process consists of mixing natural rubber latex with 5% of n-butyl acrylate and irradiation of this mixture at 15 KGY. The advantage of this technology is that the vulcanization is achieved without sulphur or ditiocarbonates, which are commonly used.

The new rubber does not contain nitrosamine which is found in ordinary rubber. Since this rubber does not contain antioxidants it is easily biodegradable in the natural environment. Furthermore, the EB-processed rubber is featured by higher strength and more flexibility.

iii) Emission-Free Lacquering, Glueing, Printing

In order to protect our environment in the Future, it is essential to reduce ecological damages, users of lacquers, printing inks and adhesives containing solvents should look for environmentally harmless processes. Solvent-free converting system is achieved by using electron-beam curing (EBC) which has the following advantages:

- EBC is heat free and works absolutely without emission
- Substantial production increase compared with conventional heat-treatment methods and UV-technology
- Immediate further treatment of converted products without posturing
- Low space requirement and integration into existing production lines without problems
- No waste when starting up and shutting down the plant. (Fig 14) shows the electron accelerating device (Used by POLYMER - PHYSIK corporation) in EBYC solvent free technology.

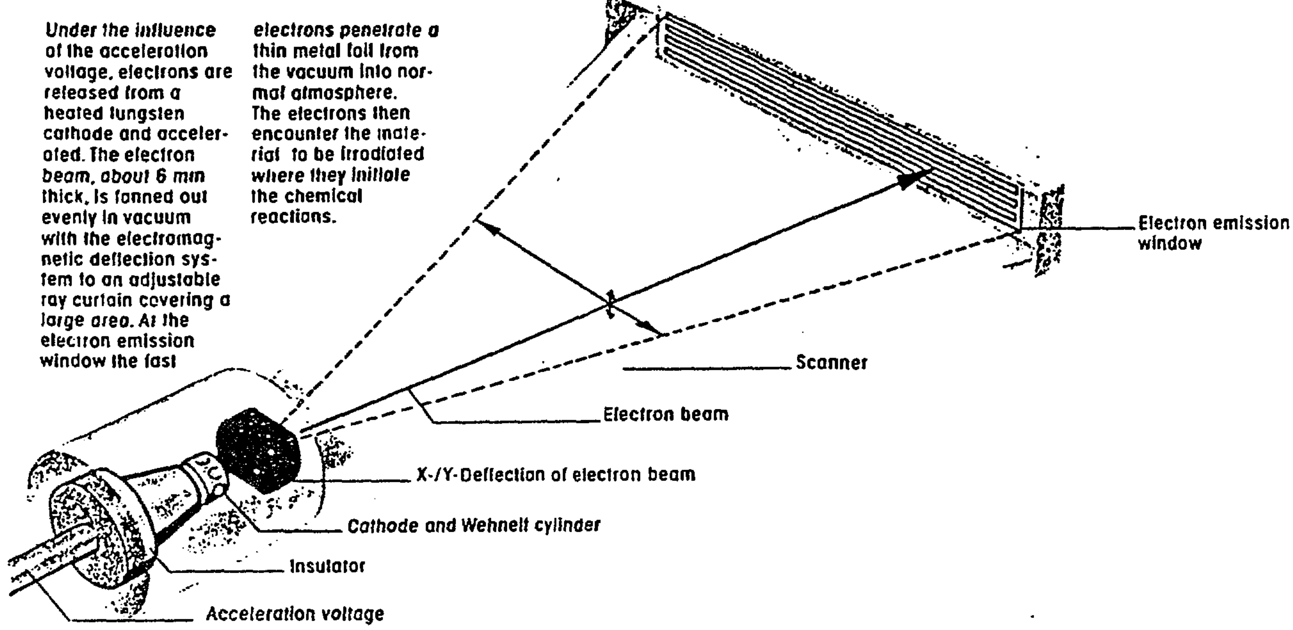
Other techniques for EB-processing are: pre-treatment of wood chips with high energy electrons which result in great saving in energy needed for pulping, and in the viscose industry where great progress has been achieved by irradiating cellulose pulp by electrons to yield several products of economic significance, (Fig 15).

The benefits of electron pre-treatment of wood chips using IMPELA E.B. acelerators are the following [21] (Fig 16) :

جدول رقم (٤)

INDUSTRIAL APPLICATIONS FOR ELECTRON BEAM PROCESSING		
Product	**Product Improvements and EB Process Advantages**	**Process**
Wire and Cable Insulation; Plastic Insulating Tubing; Plastic Packaging Film	Shrinkability; tensile strength; heat, solvent, stress-cracking resistance; low dielectric losses	Cross-linking, Vulcanization
Foamed Polyethylene	Compression; tensile strength	
Natural and Synthetic Rubber	Abrasion resistance; elimination of vulcanizing agents	
Stack Gases	Precipitation of SO_2 and NOx eliminating pollution hazards	Chemical Reaction
Precious and Semiprecious Gems; Crystal; Glass	Permanent coloring	Crystalline Alteration
Adhesives: Pressure sensitive; Flock; Laminate	Elimination of solvents; high-speed cure; low energy consumption; room-tempertaure cure; no limitation on colors	Curing, Polymerization
Coatings, Paints and Inks on: Woods Metals Plastics		
Wood and Organic Impregnates	Mar, scratch and abrasion resistance; surface uniformity; upgrading of softwoods	
Cellulose	Enhanced chemical combination	Depolymerization
Potatoes; Wheat; Rice Flowers; Onions; Cod and Redfish; Chicken; Strawberries	Extended storage and shelf-life	Pasteurization, Disinfection
Sewage	Safe disposal and agricultural use of sewage sludge	
Medical Supplies and Disposable Containers	Processing of heat-sensitive materials; high-speed in-line production; low energy consumption	Sterilization
Hospital Waste	Safe decontamination of biologically contaminated waste	

Fig .14



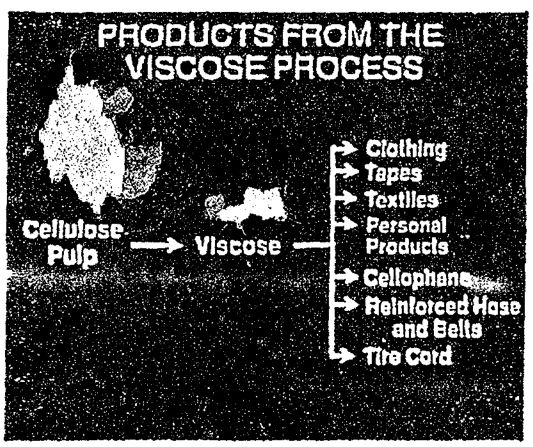


Figure 15 A

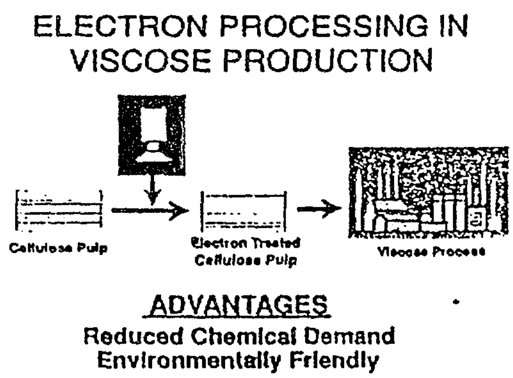


Figure 15B

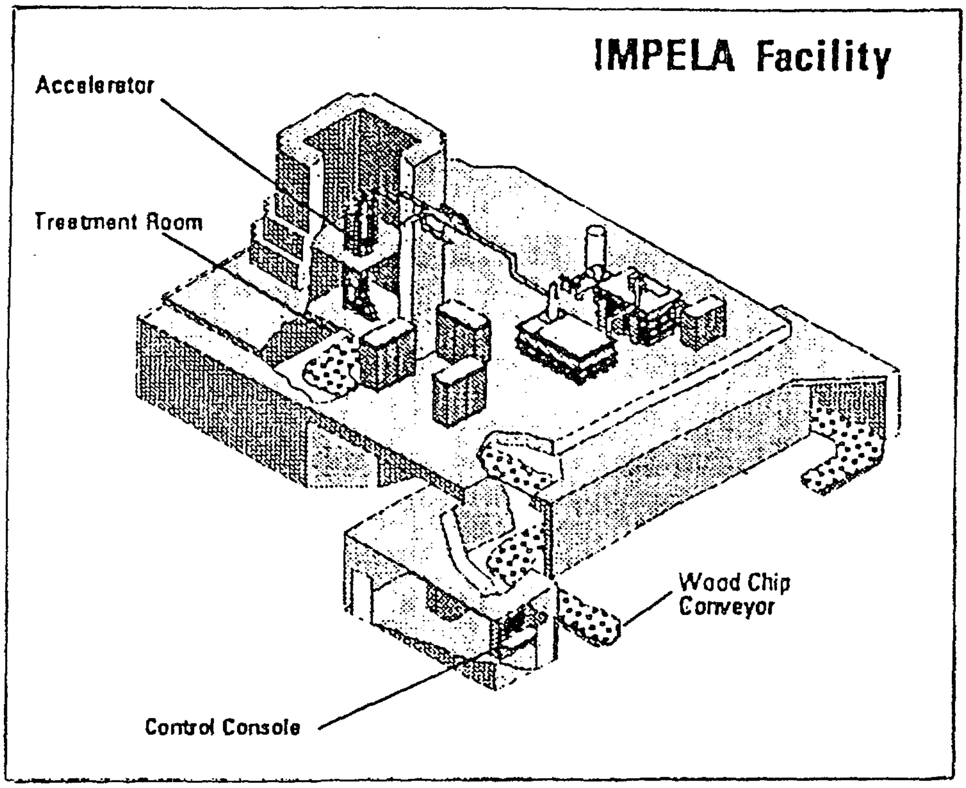

IMPELA Facility
Accelerator
Treatment Room
Wood Chip
Conveyor
Control Console

Fig 16

- Induces chemical changes in wood chips resulting in net electrical power savings of 20% to 40%,
- No chemicals are used, and no pollutants or effluent disposal,
- Equipment is off-line, could be located in the woodyard using lees than 1,600 square feet of space
- Effects wood chip disinfestation prior to storage in woodyard and prevents microbial attack which reduces yield loss during pulping,
- Payback can be in one year.

Strength properties of Some pulps are affected, thus, optimization is required to maximize energy savings against strength loss

CONCLUSIONS

Development work during the last 20 years has shown that radiation processing has a high potential to solve environmental problems by either treating or avoiding waste streams. The radiation processes work at ambient temperatures, and often produce valuable compounds or byproducts. They promise significant space and energy savings due to the high processing speeds. A solid theoretical knowledge has been acquired regarding the chemical reaction mechanisms of the processes.
Nevertheless during past R&D -work also limitations of EB-processing were realized in some projects. They are sometimes not cost-effective when applied to high pollutant concentrations. The oxidizing species in most of these processes is the OH-radical.
Therefore the energy consumption of these processes is roughly proportional to the oxidized amount of pollutants unless chain reactions occur. However, in many applications, radiation processing has significant benefits in the treatment of hazardous waste.

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