# 5.1 Low Voltage electron beam Accelerators

Masafumi OCHI
Iwasaki Electric Co., Ltd.

## 1. Introduction

Widely used electron accelerators in industries are low voltage electron beam (e-beam) processors with acceleration voltage at 300 kV or less. In this paper the basic concept of the low voltage e-beam processor and its applications will be introduced.

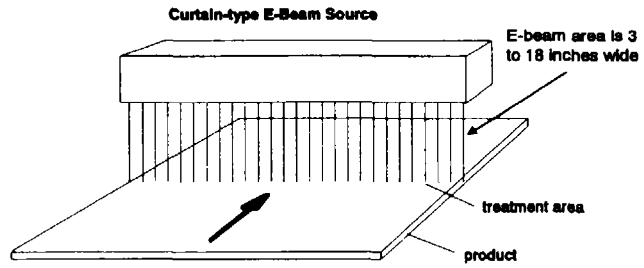
## 2. Type of the beam

Most of the low voltage e-beam processors generate continuous curtain like beam as in Fig. 1. In this curtain-type processor the product receives electrons over its width continuously while traveling under the beam.

In a scanning-type system a beam spot is generated and swing across the product width with relatively high speed so that the product surface can be treated substantially uniform while the product is transported under the swinging beam. The scanning-type system is used mainly in the medium or high voltage accelerators with energy from over 300 keV up to 10,000 keV. The detail of the scanning-type system will also be presented in one of this workshop session.

Curtain-type processors operate at lower voltages than most scanning-type systems, usually at voltages ranging from 120 to 300 kilovolts. When energetic electrons strike the matter, a small percentage of their energy is converted to penetrating (X-ray type) radiation. The lower voltages permit the equipment to be self-shielded against this radiation, with the result that curtain-type processors can be installed and operated safely in unrestricted areas.

For
Low Voltage
accelerators

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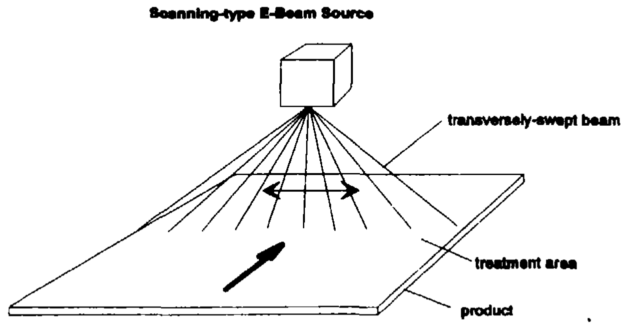



Fig. 1 Type of e-beam, Curtain & Scanning

**3. Low voltage e-beam equipment manufacturers in the market**

The manufacturers of commercially available low voltage e-beam equipment are listed in Table 1. Each manufacture has its unique technology in its products. However, in this paper, hereafter introduced mainly will be the curtain-type low voltage e-beam processors produced by ESI (Energy Sciences Inc.) ma. USA, a group company of Iwasaki Electric Co., Ltd. of Japan. The low voltage electron processing is widely used in the industries of all over the world.

**Table 1**

Manufacturers and distributors of low voltage e-beam in Japan

| Companiy Name | Naming | HV(kV)(*2) | Power(kW)(*2) | Width(cm)(*2) |
|---|---|---|---|---|
| Sumitomo Heavy Ind. | WIPL | 130-250 | 10-50 | 60,70 |
| Nissin-High Voltage CO., LT | Curetron[R] | 100-300 | 5-100< | 15-100< |
| Iwasaki Electric Group (ESI) | Electrocure[TM] | 80-300 | 1.1-100< | 15-100< |
| Ushio Inc. / Toyo Ink Mfg. | Min-EB | 50-70 | 0.01-0.36 | 2.5-22 |
| Others | | | | |

* Voltage is 300kV or less
*2 Assumption was made for some figures .

**4. Curtain-type e-beam processor**

**4.1 Mechanism of electron acceleration**

Typical low voltage e-beam system mainly uses a single gap DC acceleration performed in high vacuum as illustrated in Fig. 2. The hot electrons generated from the filament are extracted by a DC potential applied between the extractor grid and the filament. The electrons gathered at the terminal grid are then accelerated by a high voltage potential applied between the grids and the window. The accelerated electrons increase their speed so that they can penetrate the window foil as electron beam then emerge in the process zone usually at atmospheric pressure.

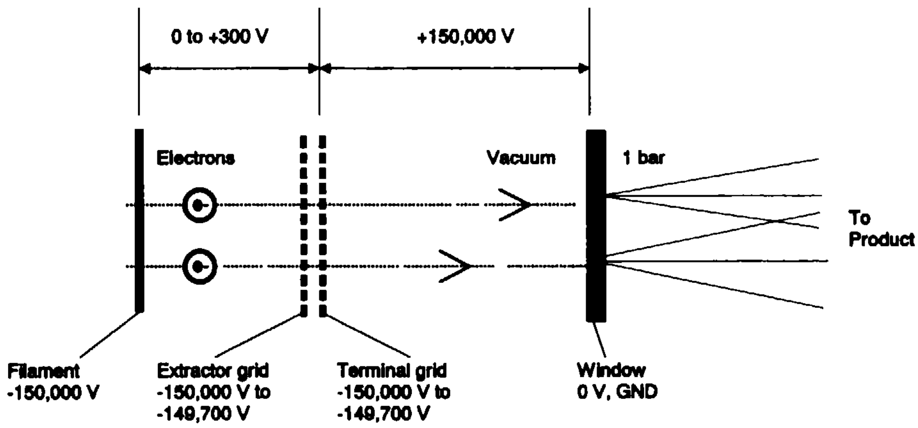



Fig.2 Acceleration mechanism

### 4.2 Equipment configuration of low voltage e-beam processor

Fig. 3 shows an outlook of a low voltage e-beam processor. The product web enters from right entrance and exit from left exit. Fig. 4 shows a cross-sectional view of the e-beam processor acceleration head and process zone. Fig. 5 is a block diagram of the equipment giving another cross-sectional view at acceleration head. Both figures help understand the operation of e-beam processor. The functions of each major unit of the processor will be described below.

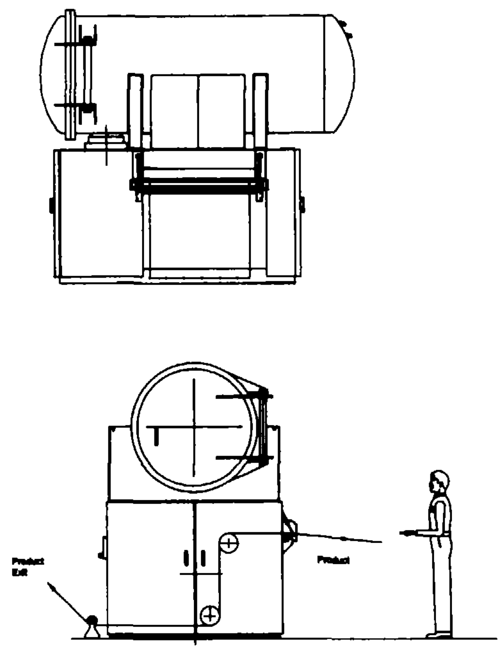


Fig. 3
Typical e-beam Processor

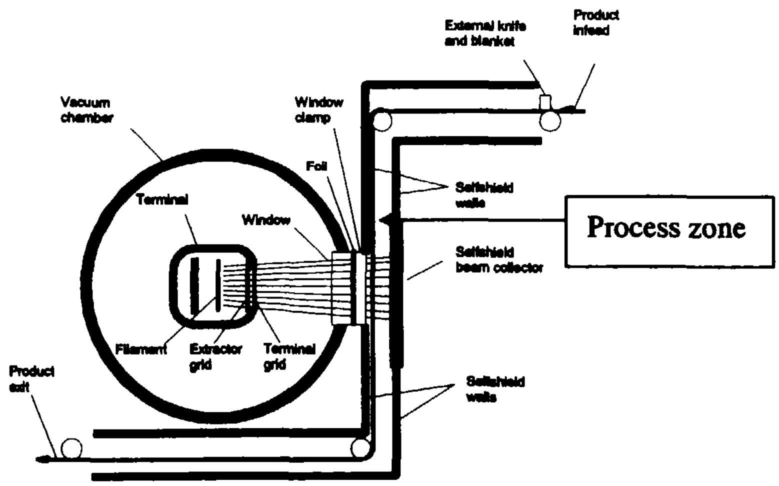



Fig.4
Typical e-beam
processor

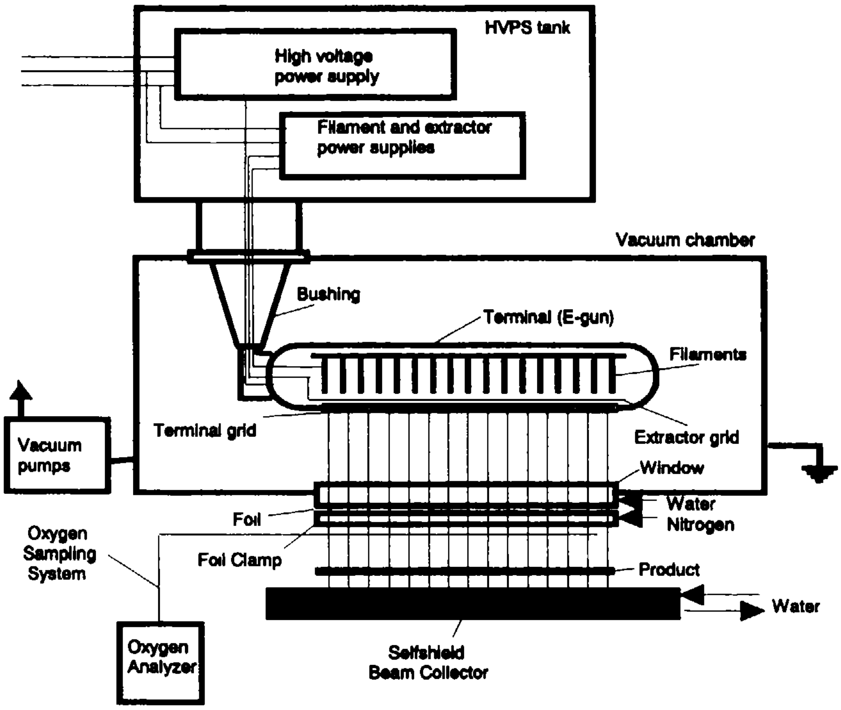



Fig.5 Block diagram of LV e-beam system

***Vacuum chamber with electron window***

Works as an acceleration head of e-beam. It contains high voltage terminal in the center with filament / extractor grid mechanism inside. An e-beam window is installed to the chamber wall opening to introduce the beam to the process zone. The window is a cooled foil-covered opening in the chamber body that determines the "shape" of the electron beam as it begins to traverse the path to the product being treated. The window is water-cooled to offset the heat induced by the electron beam as it strikes the surfaces of the window and the window foil. The outside of the window frame is covered by a metal, usually titanium foil, which acts as a pressure-to-vacuum seal for the chamber. The foil is partially transparent to the electron beam and permits the chamber to operate at a high vacuum. The high vacuum is required in order to minimize oxidation of the filament and also to minimize collisions of electrons with gas atoms within the chamber during acceleration. An excessive number of electron-gas atom collisions would result in electron beam losses and reduce the effectiveness of product treatment.

***High voltage power supply tank***

Supplies acceleration voltage as well as filament power and extraction potential to the high voltage terminal through the bushing in the vacuum chamber. The bushing is usually made of ceramics with good insulation to the high voltage.

*Vacuum system*
Is used to maintain the vacuum chamber at high vacuum typically at pressure lower than 1.33 x 10-3 Pa. Usually two stage evacuating system is adopted employing rotary oil pump for roughing and Turbo molecular pump or cryopump for high vacuum.

*Radiation Shield*
Is designed to contain X-ray generated by electron collision in the processor that no significant amount of X-rays is detected outside the processor and working area. X-ray radiation is generated whenever electrons are stopped or absorbed in matter. The intensity of X-ray radiation depends upon the characteristics of the absorbing material. X-rays scatter in all directions as they interact with atoms and molecules and have a long range in air. In the e-beam system, X-rays are absorbed by the shielding. The selfshield system is designed so that no openings exist in the shielding except for the entrance and exit of the product. These openings are designed in such a way that radiation and leakage are reduced to safe levels.

## 5. Operation of e-beam equipment

### 5.1 Control system
In order to operate the system easier the modern e-beam equipment is provided with process parameter monitor display with keyboard. To control system output, the operator must enter desired parameters (set points) of filament power, beam current, and high voltage. He enters these values through the keypad on the console's control panel. The system computer will then act to maintain the desired values. These performance specifications permit operation with a wide range of product line speeds and quick response to changes in line speed.

### 5.2 Inerting
Presence of oxygen in the product treatment area is usually undesirable because it may interfere with the curing process and result in the generation of ozone when energized electrons collide with oxygen molecules. Means are provided, therefore, to minimize oxygen concentration in the processing zone. Several different techniques may be found in e-beam systems for reducing oxygen concentration in the product treatment area to a level at which the product can be successfully cured. Window cooling gas is the only inerting process common to most e-beam machines. Its purpose is to prevent overheating of the window foil and it removes heat from the foil by convection. If inerting is not required, air may be used for cooling the window foil, provided precautions are taken to prevent condensation of corrosive products ($HNO_3$) in the process zone. If, however, inerting is needed, an inert gas such as nitrogen is used.

### 5.3 Oxygen monitoring system
In combination with the inerting system, most applications of e-beam systems are required constant monitoring of oxygen in the treatment area. If supplied, the oxygen monitor continually samples the gas in the treatment zone and displays the oxygen concentration in PPM (parts per million).

### 5.4 Ozone exhaust system

When the e-beam processing is done in air ozone is generated in the process zone as described above. In this case the processor would be equipped with ozone exhaust system to prevent ozone concentration to the working area

## 6. Determination of process parameters

The radiation dose received by the product may be defined as the energy absorbed in a mass of material. It is dependent on the following factors:

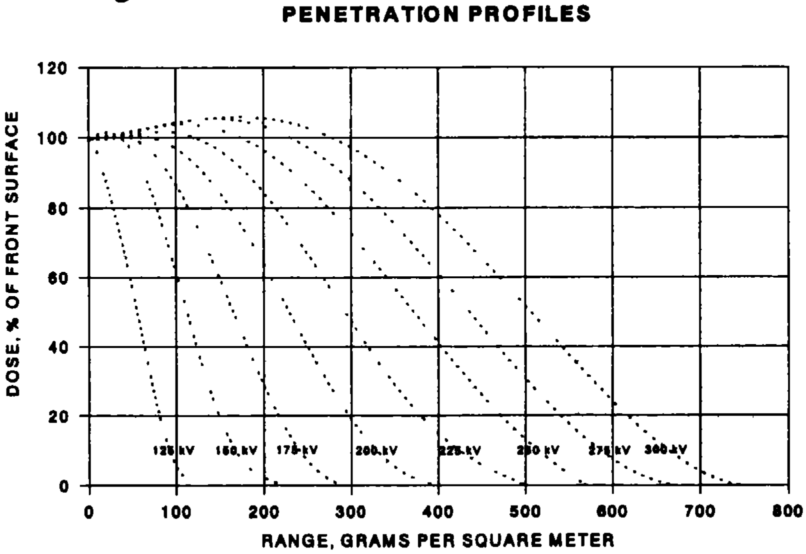
- Beam current (I, in mA)
- Line speed (S, in meters/min )
- Yield factor (K) of the machine at the required high voltage (HV) operating level
- Beam energy or the High Voltage operating level (kV)
- Thickness of the material to be treated
- Density of the material to be treated

The dose is usually measured in kilo Grays (kGy). A 10 kGy dose is equivalent to the absorption of 2.4 calories of energy by one gram of the treated material (4.3 BTU/lb), and 1 MR = 10 kGy. In most cases, determining the proper dose and the proper HV with which to treat a product is a simple matter. To select a proper voltage (kV) a penetration profile data is used. (see Fig. 6 ) One can determine the energy easily from the profile for the thickness to be treated. Then the following simple formula can be used to determine beam current (I) for the required dose (D) and the speed (S) for the production:

$$I = D \cdot S / K$$

Where, D is the absorbed dose of the material.

Fig. 6



**7. Performance of the equipment**

There are three items to evaluate the performance of e-beam processors.

1 Yield factor K as described above
2 Beam uniformity
3 Penetration

These three performances can be measured by dosimetric technique using FWT(*) nylon chips commercially available.

(*) FWT: Far West Technology Inc.

**8. Basic maintenance requirement**

There are some consumable parts that should be replaced periodically. The items are listed in Table 2.

Table 2 Basic Maintenance Requirement

| Item | Typical Lifetime |
|---|---|
| window Foil | 1000 - 2000 hrs. |
| E-gun Filament | 10,000 hrs. |
| O-rings | 2000 - 5000 hrs |

**9. Safety consideration for radiation**

As previously mentioned low voltage e-beam processor is equipped with radiation shield called Selfshield[R] that the user will have no need to install the equipment in the restricted area. In addition, environmental radiation monitors mounted at several locations on the Selfshield[R] system ensure that the system is always operating well within the limits specified by local regulations.

**10. Electron Beam Processing and applications**

In a number of industrial processes, the output products can be physically and/or chemically modified by subjecting them to a controlled beam of high energy electrons. This general technique is described as electron processing, e-beam processing, or as radiation processing. In its basic sense, electron processing may be defined as the technology of using ionizing radiation to cause desired changes in the physical properties of matter. Ionizing radiation has sufficient energy to convert atoms or molecules to ionized or excited states in which free radicals are generated and bond scission occur. These processes lead to several generally useful effects. One effect is the initiation of chemical reactions, primarily polymerization, crosslinking, or grafting reactions; another is the inactivation of microorganisms with consequent sterilization. In Japan various advanced development works are being done using electron beam at JAERI Takasaki and other government research institutions of Japan. These achievements will be presented in one of this work group session.

## 11. Advantage of low voltage e-beam

In the e-beam processing in the existing application field like curing and cross-linking the advantages below have already been proven. (Table 3)

Table 3 Low voltage e-beam advantages

| |
|---|
| High speed cure |
| Hard, scratch resistant finishes |
| Stain, chemical resistant finishes |
| Extremely high gloss finishes |
| Solventless – 100% curing |
| Energy efficient curing |
| Low temperature increase(15°C) |
| Consistent cure |
| Relatively compact equipment |
| Simple equipment operation |
| Very low odor / Low extractable |

## 12. Recent trend of low voltage technology

New e-beam processors with acceleration voltage around 100kV were introduced maintaining the relatively high dose speed capability of around 10,000kGy x mpm at production. The application field like printing and coating for packaging requires treating thickness of 30 micron or less. It does not require high voltage over 110kV. (Fig.7) The reduction of energy made the accelerator compact and economical. (Fig. 8, 9, 10, 11)
Also recently developed is a miniature bulb type e-beam tube with energy less than 60kV. The new application area for this new e-beam tube is being searched.

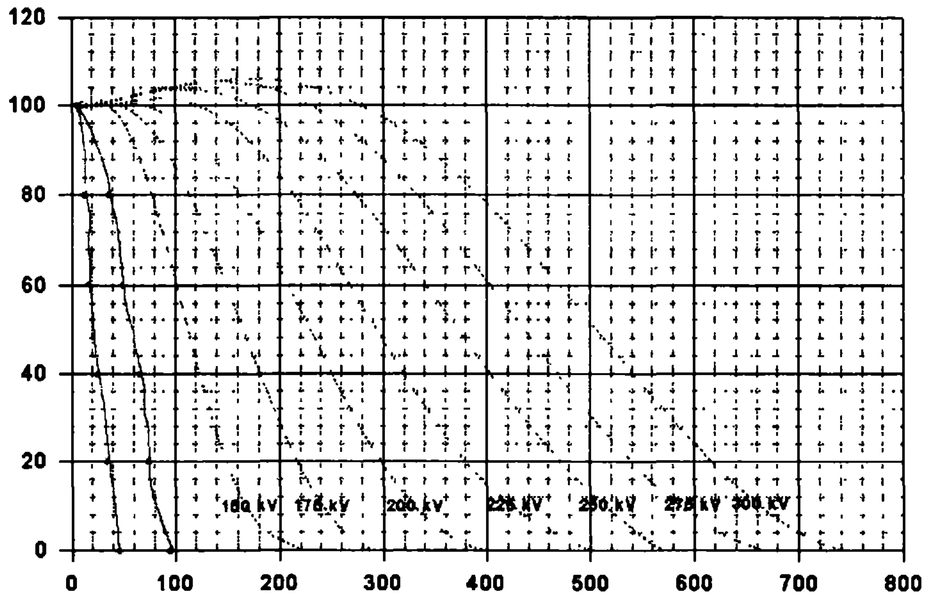



Fig 7. Penetration Profile

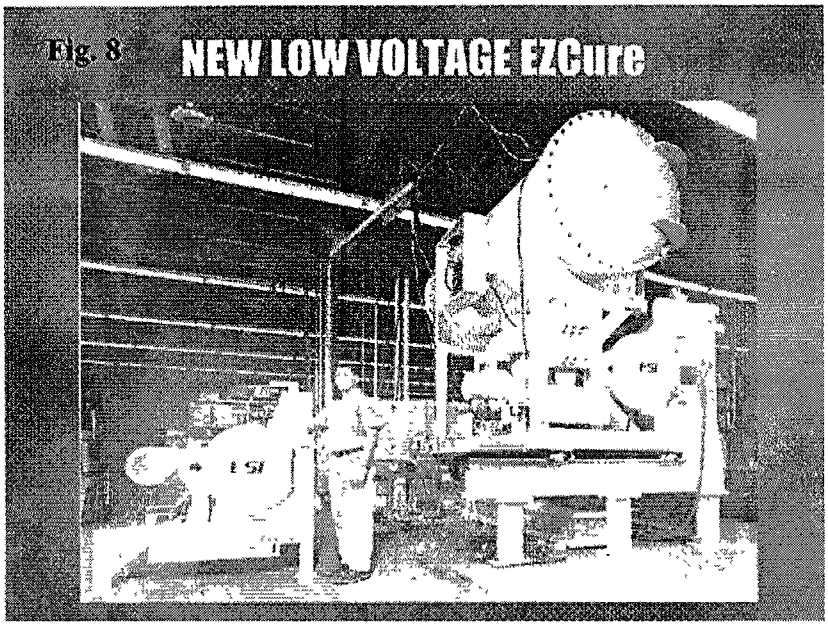


Fig. 8

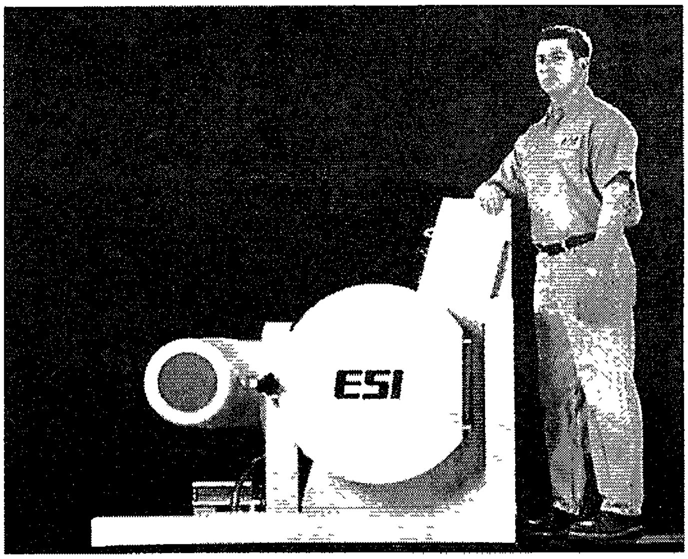
**Fig. 9**

EZCure$^{tm}$ LOW VOLTAGE EB SYSTEM

MAX SPEED
300 mpm @
30 kGy

WEB WIDTHS
50cms to 165cms

DIMENSIONS
1.5m H x 1.5 m L x
WEB WIDTH



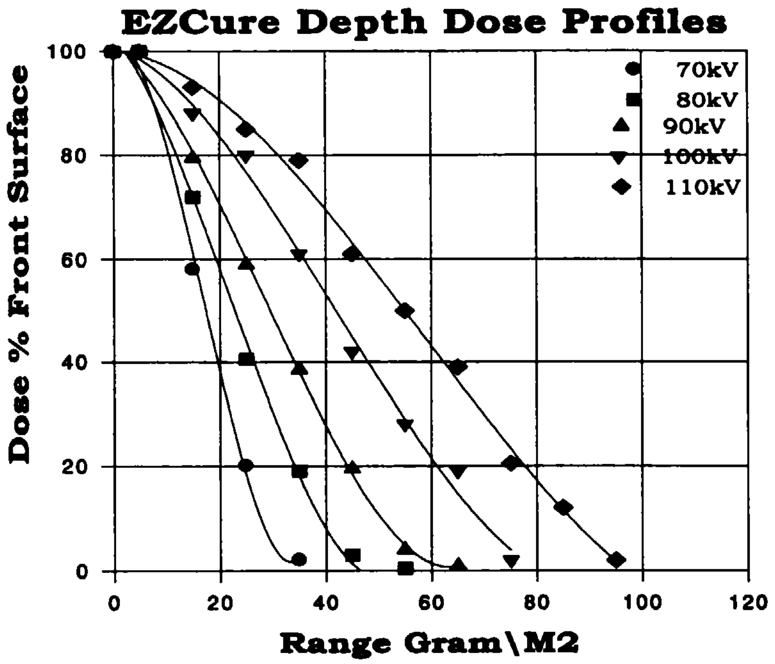

EZCure Depth Dose Profiles
Dose % Front Surface
Range Gram\M2
70kV
80kV
90kV
100kV
110kV
0 20 40 60 80 100 120

Fig. 10

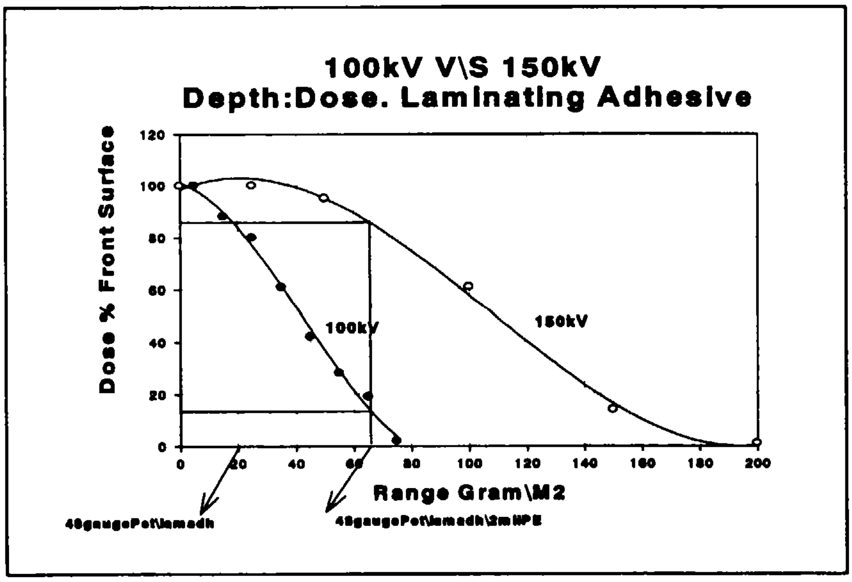

100kV V\S 150kV
Depth:Dose. Laminating Adhesive
Dose % Front Surface
Range Gram\M2
100kV
150kV

Fig 11

## 13. Summary

Low energy electron processor has many advantages as described above. In this workshop recent advanced R & D of Japan will be presented from JAERI Takasaki and the government research institutions of Japan. On the other hand the equipment is becoming compact and less expensive. The author thinks that the drive force of this technology to spread in the industries would be further development of new application, process and market as well as the price reduction of the equipment, upon which further acknowledgment and acceptance of the technology to societies and industries would entirely depend.

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