## Industrial Application of Electron Beam Acclerators

#### Masakazu WASHIO

#### Introduction

The interaction of electrons with materials has been studied in the field of "Radiation Chemistry". In recent 10 years, extensive works have been done in this field about the primary processes and the analyses of final products induced after the irradiation. We are now in the position to use the new knowledge of the Radiation Chemistry for new application of radiation processing.

In this paper, it is described how accelerated electrons are useful and powerful tool to induce an expected change in materials, and typical examples of practical applications for the industrial processing using ionizing radiation are shown briefly.

In the last part of this paper, current status of our Electron Beam Service and Application Research Center located in Tsukuba is also described.

#### What is the electron?

Ever since J.J.Thomson identified electrons through his experiments on cathode ray in late 19th century, electron has been important items(or objectives) for studies of quantum physics.

After the World War II, electron technology has become more and more faimiar to us through the devices such as television sets and oscilloscopes. In the field of chemistry, such electron beam accelerators as Van-De-Graafs, Dynamitrons®, Cockcloft-Waltons and linear accelerators(Linac) have become tools for study.

Now we can expect that we are in threshold of promising age of EB applications using these electron beam accelerators.

### Why electrons are convenient for us?

Generally, materials which are to be modified are composed of many molecules, which are combined and characteristics are dominated by the electronic interactions. Hence, the materials can be modified by inducing change of electronic states by interaction of electrons of the energy around several eV.

The methods to give chemical changes onto the materials are heating, chemical reagents, photons and electrons. Among them the most direct method to induce changes on molecules is the injection of electrons into materials. With this method, one can get very quick and effective modifications of materials and the modification efficiency is much higher than other conventional methods, such as heating and chemical reagents.

#### What is the radiation chemistry?

The knowledge obtained in the studies of radiation chemistry gives us very valuable information for the understandings of "primary processes of electron-molecule interactions", "the successive reaction mechanism", and "the final products", Therefore, understanding of the radiation chemistry is very important for achieving a desired new radiation process successfully.

The radiation chemisty gives us following important knowledge such as:

- Physics of primary processes of reactions in the chemical system such as geminate ion recombination.
- · Ion-Molecular reactions
- Processes of polymer crosslinking and degradation
- · Polymerization mechanism
- Reaction rate constants of above reactions
- · Identification of reactive intermediates
- Identification of final products.

# What happens in materials after the electron irradiation?

The major phenomena after the electron irradiation are ionization and excitaion. Injected primary electrons with relatively high energy (in the industrial processing, the energy of electrons are between 150 keV and 10 MeV) will generate a number of secondary electrons.

The major initiators for inducing chemical reactions are not the primary electrons but these secondary electrons.

Energy absorption of electrons are almost proportional to the electron density of materials. This is completely different from photon (not X-ray but UV and Visible lights) energy absorption. In the case of electrons, mass collision stopping power (MeV /(g/cm²)) dominates the energy absorption, but in the case of photons, the molecular extinction coefficients of molecules dominate the photon energy absorption.

Another aspect of energy absorption of electrons are the depth-dose distribution in the materials. This characteristics are very important and should be taken into account by the processing of relatively thick materials with certain energy electons. The depth-dose relations can be calculated by use of computer code named EDMULT.

# Advantages and some Applications of Electron Beam(EB) Processing

Typical EB accelerators and their applications are shown in Fig. 1.

Fig 1. TYPICAL LAYOUT OF ELECTRON BEAM ACCELETOR & APPLICATIONS

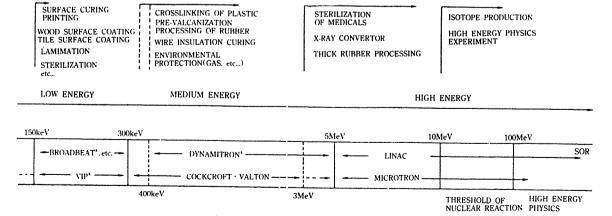


Table 1 shows the list of advantages of EB processing very briefly.

Table 1 ADVANTAGES OF EB PROCESSING

- 1. REACTION CAN START AT VERY WIDE TEMPERATURE RANGE

  REACTION STARTS AT ROOM TEMPERTURE!

  2. REACTION CAN START FROM OUTSIDE OF THE SYSTEM:

  CATALYST FREE!
  - ⇒ CONTAMINATION FREE PRODUCTS, A SIMPLE PROCESS
- 3. EASY ON/OFF CONTROL OF REACTION
  - ⇒ SAFETY SYSTEM, LESS LOSS OF ENERGY
- 4. EASY REALIZATION OF HIGH SPEED PROCESS
  - ➡ HIGH THROUGHPUT PRODUCTION
- 5. POISONOUS GAS FREE AT THE STERILIZATION. FOOD PROCESSING ETC.
  - SAFETY, EASY TO CONTROL
- 6. NO NEED OF STOCK AREA AFTER PROCESSING
  - ECONOMICAL FOR PLANT DESIGN

On line productions using EB processing are now widely applied in many field, such as tire manufacturing, wire and cable insulation improvement, and many types of surface treatments, etc.. Other aspect of EB processing is off line or batch production which is convenient for the customers with small production amounts and for the purpose of medical supply sterilization. For these purposes, there are many established facilities in the world. They are tabulated in Table 2 with some typical applications of each facilities listed in the fourth column.

# Present Status of EB Service and Application Research Center

The center was established by Sumitomo Heavy Industries, Ltd. in June of 1989 at Tsukuba city in Japan. Irradiation service has been performed by using Dynamitron® accelerator with the power of 200kW(5 MeV, 40mA). The present major items of irradiation services at the center are sterilization of laboratory ware, teflon degradation, modification of semi-conductor, and crosslinking of heat shrinkable tube, etc..

Objectives of establishment of this facility are as follows.

- 1. Small Scale Production by Contract Irradiation
- 2. Development of EB Irradiation Oriented Materials
- 3. Development of EB Irradiation Application Technology
- 4. Development of new EB processor with high energy and high power
- 5. Development of new beam source such as X-ray by using converter
- 6. Development of EB sterilization procedure and quality assurance
- 7. Training of operation and maintenance for personnel in charge of operating Dynamitron®
- 8. Better capability for field service in Asia Pacific region by stationing field engineers and stocking spare parts

Recently, the approval that qualifies Tsukuba Center as a facility for sterilizing a medical product (surgical gloves) by electron beam was issued by the Ministry of Health and Welfare

Thus our Tsukuba Center became first facility in Japan to sterilize medical product by EB.

Needless to say, this must be very important milestone in Japan to expand the EB business.

Table 2 ELECTRON BEAM SERVICE FACILITIES

TELEFUNKEN	OPERATOR	EQUIPMENT		IN USE	PRODUCT	REMARKS
BETA-GAMMA SERVICES (WIEHL, GERMANY)	TELEFUNKEN	1.5 MeV,	60 kW	1976	wire, tubing,	
(WIEHL, GERMANY)         3.0 MeV, 110 kW 1986 (DYNAMITRON**)         1986 (DYNAMITRON**)         wire, cable, tubing sterilization         Former RDI (Germany)           CARIC (PARIS, FRANCE)         6.0 MeV, 7.5 kW (CIRCE)         1966 (DIR NAMITRON**)         1986 (DIR NAMITRON**)         sterilization         Former RDI (Germany)           E-BEAM SERVICES (CIRCE)         10 MeV, 10 kW (CIRCE)         1987 (DIR NAMITRON*)         food         Former RDI Service           (CRANBURY, N.Y., USA)         4.5 MeV, 150 kW (DYNAMITRON*)         1986 (DYNAMITRON*)         Sterilization         Division           ELECTRON TECHNOLOGIES (SOUTH WINDSOR, Ct., USA)         3.0 MeV, 3 kW 1965 (DYNAMITRON*)         plastics, molded parts semi-conductors         plastics           (GAITHERSBURG, Md., USA)         12 MeV, 10 kW 1960 (DYNAMITRON*)         1986 (DYNAMITRON*)         sterilization, gems semi-conductors           MEDICAL STERILIZATION (SYOSSET, N.Y., USA)         4.5 MeV, 150 kW 1984 (DYNAMITRON*)         1986 (DYNAMITRON*)         sterilization         Derived from RDI (DYNAMITRON*)           RAYCHEM (COPENHAGEN, DENMARK)         10 MeV, 10 kW 1960 (DYNAMITRON*)         1986 (DYNAMITRON*)         sterilization         Sterilization           SCAN-CARIC (COPERBURG, SWEDEN)         10 MeV, 20 kW 1983 (DYNAMITRON*)         sterilization         sterilization           COPERBURG, SWEDEN)         2.5 MeV, 200 kW 1983 (DYNAMITRON*)         steriliz	(HUMBURG, GERMANY)				plastics	
CARIC	BETA-GAMMA SERVICES	550 keV,	11 kW	1980	coatings, thin films	
CARIC   6.0 MeV,   7.5 kW   1966   Sterilization   Former RDI	(WIEHL, GERMANY)	3.0 MeV,	110 kW	1983	wire, cable, tubing	
CARIC (PARIS, FRANCE)	(BRUCHSAL, GERMANY)	4.5 MeV,	150 kW	1986	sterilization	Former RDI
(PARIS, FRANCE)         (CIRCE)         10 MeV, (CIRCE)         10 kW (CIRCE)         10 kW (CIRCE)         10 kW (CIRCE)         10 kW (CIRCE)         1987 food           E-BEAM SERVICES         3.0 MeV, 90 kW         1974 wire, cable, plastics         Former RDI Service           (PLAINVIEW, N.Y., USA)         (DYNAMITRON*)         1986 sterilization         Sterilization           (CRANBURY, N.J., USA)         4.5 MeV, 150 kW         1965 plastics, molded parts semi-conductors         Semi-conductors           ELECTRON TECHNOLOGIES (SOUTH WINDSOR, Ct., USA)         3.0 MeV, 3 kW         1972 semi-conductors         semi-conductors           IRRADIATION INDUSTRIES (GAITHERSBURG, Md., USA)         12 MeV, 10 kW         1965 plastics         sterilization, gems semi-conductors           (SAN DIEGO, Ca., USA)         12 MeV, 10 kW         1984 semi-conductors         sterilization           MEDICAL STERILIZATION (SYOSSET, N.Y., USA)         (DYNAMITRON*)         1987 sterilization         Derived from RDI           RAYCHEM (COPENHAGEN, DENMARK)         10 MeV, 10 kW         1967 sterilization         sterilization           RISO (ROSKILDE, DENMARK)         10 MeV, 20 kW         1988 sterilization         sterilization           SCAN-CARIC (COPPERBURG, SWEDEN)         (CIRCE)         1988 sterilization         sterilization           STUDER (DANIKEN, SWITZERLAND)         1.		(DYNAMITRON®)				(Germany)
10 MeV,	CARIC	6.0 MeV,	7.5 kW	1966	sterilization	
CIRCE	(PARIS, FRANCE)	(CIRCE)				
E-BEAM SERVICES		10 MeV,	10 kW	1987	food	
(PLAINVIEW, N.Y., USA)         (DYNAMITRON*)         Service           (CRANBURY, N.J., USA)         4.5 MeV, 150 kW (DYNAMITRON*)         1986         sterilization         Division           ELECTRON TECHNOLOGIES (SOUTH WINDSOR, Ct., USA)         3.0 MeV, 3 kW 1972         semi-conductors         semi-conductors           IRRADIATION INDUSTRIES (GAITHERSBURG, Md., USA)         2.5 MeV, 45 kW 1965         plastics           IR.T.         12 MeV, 10 kW 1960         sterilization, gems semi-conductors           (SAN DIEGO, Ca., USA)         12 MeV, 10 kW 1984         semi-conductors           MEDICAL STERILIZATION (SYOSSET, N.Y., USA)         (DYNAMITRON*)         sterilization         Derived from RDI           RAYCHEM (COPENHAGEN, DENMARK)         10 MeV, 10 kW 1967         sterilization, plastics         plastics           RISO (ROSKILDE, DENMARK)         10 MeV, 20 kW 1960         sterilization         sterilization           SCAN-CARIC (COPPERBURG, SWEDEN)         (CIRCE)         1988         sterilization           STUDER (DANIKEN, SWITZERLAND)         2.5 MeV, 200 kW 1983         wire, cable, tubing, sterilization         sterilization           VIRITECH (SWINDON, UK)         4.5 MeV, 90 kW (DYNAMITRON*)         1987         sterilization         (RDI, UK)           CSMITOMO HEAVY IND. (DYNAMITRON*)         5.0 MeV, 200 kW 1989         plastics, sterilization		(CIRCE)				
(CRANBURY, N.J., USA)  4.5 MeV, 150 kW (DYNAMITRON*)  ELECTRON TECHNOLOGIES (SOUTH WINDSOR, Ct., USA)  IRRADIATION INDUSTRIES (GAITHERSBURG, Md., USA)  I.R.T. 12 MeV, 10 kW 1965 plastics  (SAN DIEGO, Ca., USA) 12 MeV, 10 kW 1986 semi-conductors  MEDICAL STERILIZATION (SYOSET, N.Y., USA) (DYNAMITRON*)  RAYCHEM (COPENHAGEN, DENMARK)  RISO 400 keV, 20 kW 1960 sterilization, plastics  (ROSKILDE, DENMARK) (CIRCE)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK) 4.5 MeV, 20 kW (DYNAMITRON*)  VIRITECH (SYOME) (CIRCE)  SUMITOMO HEAVY IND. (DYNAMITRON*)  RAYLHAM (DYNAMITRON*)  4.5 MeV, 20 kW 1987 sterilization  (COPENBAGEN, DENMARK) (DYNAMITRON*)  SEMI-CONDUCTORS (CROBE, USA) (CIRCE)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK) 4.5 MeV, 200 kW (DYNAMITRON*)  5.0 MeV, 200 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (DYNAMITRON*)  SEMI-CONDUCTORS (STERILIZATION (RDI, UK))  5.0 MeV, 150 kW 1989 plastics, sterilization semi-conductors  SECHICAL (DYNAMITRON*)  FORMARY (DYNAMITRON*)  SUMITOMO HEAVY IND. (DYNAMITRON*)  RADIA IND. 5.0 MeV, 150 kW 1991 sterilization etc.	E-BEAM SERVICES	3.0 MeV,	90 kW	1974	wire, cable, plastics	Former RDI
CDYNAMITRON*   Semi-conductors   Semi-conducto	(PLAINVIEW, N.Y., USA)	(DYNAMITRON®)				Service
ELECTRON TECHNOLOGIES	(CRANBURY, N.J., USA)	4.5 MeV,	150 kW	1986	sterilization	Division
(SOUTH WINDSOR, Ct., USA)         3.0 MeV, 3 kW         1972 semi-conductors           IRRADIATION INDUSTRIES (GAITHERSBURG, Md., USA)         2.5 MeV, 45 kW         1965 plastics           IR.T.         12 MeV, 10 kW         1960 semi-conductors           (SAN DIEGO, Ca., USA)         12 MeV, 10 kW         1984 semi-conductors           MEDICAL STERILIZATION (SYOSSET, N.Y., USA)         4.5 MeV, 150 kW         1986 sterilization         Derived from RDI           RAYCHEM (COPENHAGEN, DENMARK)         10 MeV, 10 kW         1967 sterilization, plastics         Hin films, plastics           RISO (ROSKILDE, DENMARK)         10 MeV, 10 kW         1960 sterilization         Sterilization           SCAN-CARIC (COPPERBURG, SWEDEN)         (CIRCE)         10 MeV, 20 kW         1988 sterilization           STUDER (DANIKEN, SWITZERLAND)         2.5 MeV, 200 kW         1983 sterilization         Former RDL (RDI, UK)           VIRITECH (SWINDON, UK)         1.5 MeV, 74 kW         1977 sterilization         Wire, cable, tubing sterilization         Former RDL (RDI, UK)           SUMITOMO HEAVY IND. (DYNAMITRON*)         5.0 MeV, 200 kW         1989 plastics, sterilization semi-conductors         Semi-conductors           RADIA IND.         5.0 MeV, 150 kW         1991 sterilization etc.         Image: conductors semi-conductors		(DYNAMIT	RON®)			
IRRADIATION INDUSTRIES (GAITHERSBURG, Md., USA)	ELECTRON TECHNOLOGIES	3.0 MeV,	3 kW	1965	plastics, molded parts	
CAITHERSBURG, Md., USA)	(SOUTH WINDSOR, Ct., USA)	3.0 MeV,	3 kW	1972	semi-conductors	
I.R.T.	IRRADIATION INDUSTRIES	2.5 MeV,	45 kW	1965	plastics	
(SAN DIEGO, Ca., USA)  MEDICAL STERILIZATION (SYOSSET, N.Y., USA)  RAYCHEM (COPENHAGEN, DENMARK)  RISO (ROSKILDE, DENMARK)  SCAN-CARIC (COPPERBURG, SWEDEN)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  SUMITOMO HEAVY IND. (CSAN DIEGO, Ca., USA)  12 MeV, 10 kW 1984  1986  sterilization  1967  sterilization, plastics  sterilization  plastics sterilization  semi-conductors  sterilization  sterilization  sterilization  yire, cable, tubing, sterilization  (RDI, UK)  (RDI, UK)  SUMITOMO HEAVY IND. (DYNAMITRON*)  (CINCE)  STUDER (DYNAMITRON*) (SWINDON, UK)  5.0 MeV, 20 kW 1983  sterilization  Former RDL (RDI, UK)  1989  plastics, sterilization  SEMi-conductors  SUMITOMO HEAVY IND. (DYNAMITRON*) (DYNAMITRON*)  SOMEV, 200 kW 1989  plastics, sterilization  SEMi-conductors  SEMi-conductors  SEMi-conductors  SEMi-conductors  SEMi-conductors  SUMITOMO HEAVY IND. (DYNAMITRON*) (DYNAMITRON*)  SOMEV, 200 kW 1989  plastics, sterilization  semi-conductors	(GAITHERSBURG, Md., USA)					
MEDICAL STERILIZATION (SYOSSET, N.Y., USA)  RAYCHEM (COPENHAGEN, DENMARK)  RISO (ROSKILDE, DENMARK)  SCAN-CARIC (COPPERBURG, SWEDEN)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  Location  Locatio	I.R.T.	12 MeV,	10 kW	1960	sterilization, gems	
(SYOSSET, N.Y., USA)  (DYNAMITRON*)  RAYCHEM (COPENHAGEN, DENMARK)  RISO (ROSKILDE, DENMARK)  SCAN-CARIC (COPPERBURG, SWEDEN)  (CIRCE)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  (DYNAMITRON*)  (DYNAMITRON*)  (DYNAMITRON*)  (DYNAMITRON*)  (CIRCE)  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  (DYNAMITRON*)	(SAN DIEGO, Ca., USA)	12 MeV,	10 kW	1984	semi-conductors	
RAYCHEM (COPENHAGEN, DENMARK)  RISO (ROSKILDE, DENMARK)  SCAN-CARIC (COPPERBURG, SWEDEN)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  (DYNAMITRON*)  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  (COPENHAGEN, DENMARK)  10 MeV, 20 kW 1970  10 kW 1960  1988 sterilization sterilization  sterilization  sterilization  wire, cable, tubing, sterilization  (RDI, UK)  1988 sterilization  Former RDL (RDI, UK)  1988 sterilization  1988 sterilization  1988 sterilization  1988 sterilization  1988 sterilization  1980 sterilization  Former RDL (RDI, UK)  1980 plastics, sterilization  (RDI, UK)  1980 sterilization  SUMITOMO HEAVY IND. (DYNAMITRON*)	MEDICAL STERILIZATION	4.5 MeV,	150 kW	1986	sterilization	Derived
(COPENHAGEN, DENMARK)  RISO  (ROSKILDE, DENMARK)  10 MeV, 10 kW 1960 sterilizationm semi-conductors  SCAN-CARIC (COPPERBURG, SWEDEN)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  1.5 MeV, 74 kW 1977 wire, cable, tubing sterilization  (DYNAMITRON*)  6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  (DYNAMITRON*)  RADIA IND.  5.0 MeV, 150 kW 1991 sterilization etc.	(SYOSSET, N.Y., USA)	(DYNAMITRON®)				from RDI
RISO (ROSKILDE, DENMARK)  10 MeV, 10 kW 1960 sterilizationm semi-conductors  SCAN-CARIC (COPPERBURG, SWEDEN)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  4.5 MeV, 90 kW 1987 sterilization  (DYNAMITRON®) 6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  RADIA IND.  400 keV, 20 kW 1960 sterilization  1988 sterilization  VIPRIS device in thin films, plastics sterilization  sterilization  Wire, cable, tubing sterilization  (RDI, UK)  1987 sterilization  (RDI, UK)  1988 semi-conductors  Sumiromo Heavy IND. (DYNAMITRON®) semi-conductors  SUMITOMO HEAVY IND. (DYNAMITRON®) semi-conductors	RAYCHEM	10 MeV,	10 kW	1967	sterilization,	
(ROSKILDE, DENMARK)  10 MeV, 10 kW  1960 sterilizationm semi-conductors  SCAN-CARIC (COPPERBURG, SWEDEN)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  4.5 MeV, 90 kW (DYNAMITRON*)  6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  RADIA IND.  10 MeV, 10 kW 1988 sterilization  wire, cable, tubing sterilization  Wire, cable, tubing sterilization  (RDI, UK)  1983 semi-conductors semi-conductors semi-conductors semi-conductors semi-conductors semi-conductors semi-conductors	(COPENHAGEN, DENMARK)				plastics	
SCAN-CARIC (COPPERBURG, SWEDEN) (CIRCE)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK) (DYNAMITRON*) (5.5 MeV, 200 kW 1983 wire, cable, tubing, sterilization (RDI, UK) (DYNAMITRON*) (SUMITOMO HEAVY IND. (TSUKUBA, JAPAN) (DYNAMITRON*) (DYNAMITRON*) (DYNAMITRON*) (DYNAMITRON*) (DYNAMITRON*) (DYNAMITRON*) (Semi-conductors) (RDI, UK) (RDI,	RISO	400 keV,	20 kW	1970	thin films, plastics	
SCAN-CARIC (COPPERBURG, SWEDEN) (CIRCE)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK) (DYNAMITRON*) (5.0 MeV, 200 kW 1983 wire, cable, tubing, sterilization  Former RDL (RDI, UK) (RDI, UK)  SEMI-Conductors  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN) (DYNAMITRON*)	(ROSKILDE, DENMARK)	10 MeV,	10 kW	1960	sterilizationm	
(COPPERBURG, SWEDEN)  STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  1.5 MeV, 74 kW 1977 wire, cable, tubing sterilization  VIRITECH (SWINDON, UK)  4.5 MeV, 90 kW 1987 sterilization (DYNAMITRON*)  6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  SUMITRON*)  (DYNAMITRON*)  SUMITOMO HEAVY IND. (DYNAMITRON*)  SUMITOMO HEAVY IND. (DYNAMITRON*)  SUMITOMO HEAVY IND. (DYNAMITRON*)  SEMI-conductors  Semi-conductors  Semi-conductors  Semi-conductors  Semi-conductors  Semi-conductors  Semi-conductors					semi-conductors	
STUDER (DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  6.5 MeV, (DYNAMITRON*)  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  RADIA IND.  2.5 MeV, 200 kW 1983  wire, cable, tubing sterilization  wire, cable, tubing sterilization  Former RDL (RDI, UK)  1983  semi-conductors  plastics, sterilization semi-conductors  semi-conductors  semi-conductors  semi-conductors  semi-conductors  semi-conductors  semi-conductors  semi-conductors	SCAN-CARIC	10 MeV,	20 kW	1988	sterilization	
(DANIKEN, SWITZERLAND)  VIRITECH (SWINDON, UK)  4.5 MeV, 90 kW 1987 sterilization (DYNAMITRON*) 6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN)  SUMITRON*)  (DYNAMITRON*)  (DYNAMITRON*)  Semi-conductors	(COPPERBURG, SWEDEN)	(CIRCE)				
VIRITECH (SWINDON, UK)  1.5 MeV, 74 kW 1977 wire, cable, tubing sterilization (RDI, UK) (DYNAMITRON®) 6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (TSUKUBA, JAPAN) (DYNAMITRON®) (DYNAMITRON®)  Semi-conductors semi-conductors semi-conductors semi-conductors semi-conductors semi-conductors	STUDER	2.5 MeV,	200 kW	1983	wire, cable, tubing,	
(SWINDON, UK)  4.5 MeV, 90 kW (DYNAMITRON*)  6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. (DYNAMITRON*)  (TSUKUBA, JAPAN)  (DYNAMITRON*)  RADIA IND.  5.0 MeV, 150 kW 1991 sterilization etc.	(DANIKEN, SWITZERLAND)				sterilization	
(DYNAMITRON®) 6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. 5.0 MeV, 200 kW 1989 plastics, sterilization (TSUKUBA, JAPAN) (DYNAMITRON®) semi-conductors  RADIA IND. 5.0 MeV, 150 kW 1991 sterilization etc.	VIRITECH	1.5 MeV,	74 kW	1977	wire, cable, tubing	Former RDL
(DYNAMITRON®) 6.5 MeV, 1 kW 1983 semi-conductors  SUMITOMO HEAVY IND. 5.0 MeV, 200 kW 1989 plastics, sterilization (TSUKUBA, JAPAN) (DYNAMITRON®) semi-conductors  RADIA IND. 5.0 MeV, 150 kW 1991 sterilization etc.	(SWINDON, UK)	4.5 MeV,	90 kW	1987	sterilization	(RDI, UK)
SUMITOMO HEAVY IND. 5.0 MeV, 200 kW 1989 plastics, sterilization semi-conductors  RADIA IND. 5.0 MeV, 150 kW 1991 sterilization etc.		(DYNAMITRON®)				
(TSUKUBA, JAPAN) (DYNAMITRON®) semi-conductors  RADIA IND. 5.0 MeV, 150 kW 1991 sterilization etc.		6.5 MeV,	1 kW	1983	semi-conductors	
RADIA IND. 5.0 MeV, 150 kW 1991 sterilization etc.	SUMITOMO HEAVY IND.	5.0 MeV,	200 kW	1989	plastics, sterilization	
	(TSUKUBA, JAPAN)	(DYNAMIT	(DYNAMITRON®)		semi-conductors	
(TAKASAKI, JAPAN)	RADIA IND.	5.0 MeV,	150 kW	1991		
	(TAKASAKI, JAPAN)					