Industrial Applications of Electron Accelerators

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Ion Beam Applications

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Presentation Outline

Introduction

Basic Concepts of Radiation Processing

Applications of Radiation Processing

Physical Aspects of Radiation Processing

Industrial Electron Accelerators

Conclusion

Introduction

Definition of Radiation Processing

The treatment of products and materials with radiation or ionizing energy to change their physical, chemical or biological characteristics, to increase their usefulness and value or to reduce their impact on the environment.

Introduction

Ionizing Energy Sources

Electrons from Particle Accelerators.
X-Rays from Accelerated Electrons.
Gamma Rays from Radioactive Nuclides.

In absorbing materials, electrons, X-rays and gamma rays transfer their energies by ejecting atomic electrons, which can then ionize other atoms. These radiations produce similar effects.

Introduction

Ionizing Energy Sources

Electrons from Particle Accelerators.
X-Rays from Accelerated Electrons.
Gamma Rays from Radioactive Nuclides.

The choice of a radiation source depends on the practical aspects of the treatment process, such as absorbed dose, material thickness, processing rate, capital and operating costs.

Introduction

Radiation processing was introduced fifty years ago.
Many practical applications have been discovered.
The most important commercial applications are:

Modification of plastic and rubber materials.
Sterilization of medical devices and consumer items.
Pasteurization and preservation of foods.
Reduction of environmental pollution.

Basic Concepts of Radiation Processing

Absorbed Dose Definition

Temperature Rise vs Absorbed Dose

Absorbed Dose Requirements

Absorbed Dose vs M_W and G Value

Basic Concepts of Radiation Processing

Absorbed Dose Definition

Absorbed dose is proportional to the ionizing energy delivered per unit mass of material.

Dose is the most important specification for any irradiation process.

The quantitative effects of the process are related to the absorbed dose.

Basic Concepts of Radiation Processing

Absorbed Dose Definition

Energy Absorbed Per Unit Mass
International Unit Is The Gray

1 Gy = 1 J/kg
1 Gy = 1 W s/kg
1 kGy = 1 kJ/kg
1 kGy = 1 kW s/kg
1 kGy = (1/3600) kW h/kg

Basic Concepts of Radiation Processing

Absorbed Dose Definition

Energy Absorbed Per Unit Mass
Obsolete Unit Is The Rad

1 Gy = 100 rad
10 Gy = 1 krad
100 Gy = 10 krad
1 kGy = 100 krad
10 kGy = 1 Mrad
100 kGy = 10 Mrad

Basic Concepts of Radiation Processing

Temperature Rise vs Absorbed Dose

Temperature rise is proportional to the thermal energy absorbed per unit mass of heated material.

Also, temperature rise is proportional to the absorbed dose in irradiated material (in same units).

Calorimetry is the primary method for measuring absorbed dose and calibrating secondary dosimeters.

Basic Concepts of Radiation Processing

Temperature Rise vs Absorbed Dose

$$\Delta T = H / c$$

$$\Delta T = D / c$$

ΔT = Temperature Rise in °C
H = Heat per Unit Mass in J/g
c = Heat Capacity in J/g °C
D = Absorbed Dose in kGy

Basic Concepts of Radiation Processing

Examples – Temp. Rise per kGy

Material	Thermal Cap.	Temp. Rise
Water	4.19	0.24
Polyethylene	2.30	0.43
Teflon	1.05	0.95
Aluminum	0.90	1.11
Iron	0.44	2.27
Copper	0.38	2.63

Basic Concepts of Radiation Processing

Temperature Rise for EB Processing

Industrial EB processes need less energy than most thermal treatment processes.

Absorbed dose requirements for various industrial processes cover a very wide range from 0.1 kGy to 1000 kGy.

Most of these processes need less than 100 kGy, many need less than 10 kGy, and some need less than 1 kGy.

Basic Concepts of Radiation Processing

Absorbed Dose Requirements

Sprout Inhibiting	0.1 – 0.2 kGy
Insect Disinfesting	0.3 – 0.5 kGy
Parasite Control	0.3 – 0.5 kGy
Delay of Ripening	0.5 – 1.0 kGy
Fungi Control	1.5 – 3.0 kGy
Bacteria Control	1.5 – 3.0 kGy

Basic Concepts of Radiation Processing

Absorbed Dose Requirements

Sterilizing	15 - 30 kGy
Polymerizing	25 - 50 kGy
Grafting	25 - 50 kGy
Crosslinking	50 - 150 kGy
Degrading	500 - 1500 kGy
Gemstone Coloring	> > 1500 kGy

Basic Concepts of Radiation Processing

Absorbed Dose vs Molecular Weight M_W and G Value

$$D = N_A \, (100 / G) \, e / M_W \text{ joules / gram}$$

$$D = 9.65 \times 10^{6} / (G \, M_W) \text{ kGy}$$

$$N_A = 6.022 \times 10^{23} \text{ molecules / mole}$$

$$e = 1.602 \times 10^{-19} \text{ joules / electron volt}$$

$$G = \text{number of chemical reactions / 100 eV}$$

Basic Concepts of Radiation Processing

Absorbed Dose vs M_W and G Value

High molecular weight means acceptably low dose.

If $M_W = 100{,}000$ and $G = 1$, then $D = 100$ kGy.

Low molecular weight means excessively high dose.

If $M_W = 100$ and $G = 3$, then $D = 32{,}000$ kGy.

Basic Concepts of Radiation Processing

Absorbed Dose vs M_W and G Value

Polymeric materials with high molecular weights are good candidates for radiation processing.

Inorganic compounds with low molecular weights are poor candidates for radiation processing.

Dilute solutions are exceptions. Ionizing a small fraction of the solvent will affect most of the solute.

Applications of Radiation Processing

Modifying Polymeric Materials
- Curing Monomers and Oligomers
- Grafting Monomers onto Polymers
- Crosslinking Polymers
- Degrading Polymers

Biological Applications
- Sterilizing Medical Products
- Disinfecting Consumer Products
- Pasteurizing and Preserving Foods

Applications of Radiation Processing

Environmental Applications
- Reducing Acid Rain
- Treating Waste Materials

Solid State Applications
- Modifying Semiconductors
- Coloring Gemstones

Applications of Radiation Processing

Modifying polymeric materials

Curing

Grafting

Crosslinking

Degrading

Applications of Radiation Processing

Curing Solvent-Free Coatings, Inks and Adhesives

- Oligomers
  - Acrylated epoxies
  - Acrylated polyethers
  - Acrylated urethane polyesters
- Multifunctional monomers
  - Trimethylolpropane triacrylate

Dose = 10 to 30 kGy

Low-Energy EB Curing of Colored Coatings

Laboratory Test Panels

Applications of Radiation Processing

Curing Composite Materials for Spacecraft and Missiles

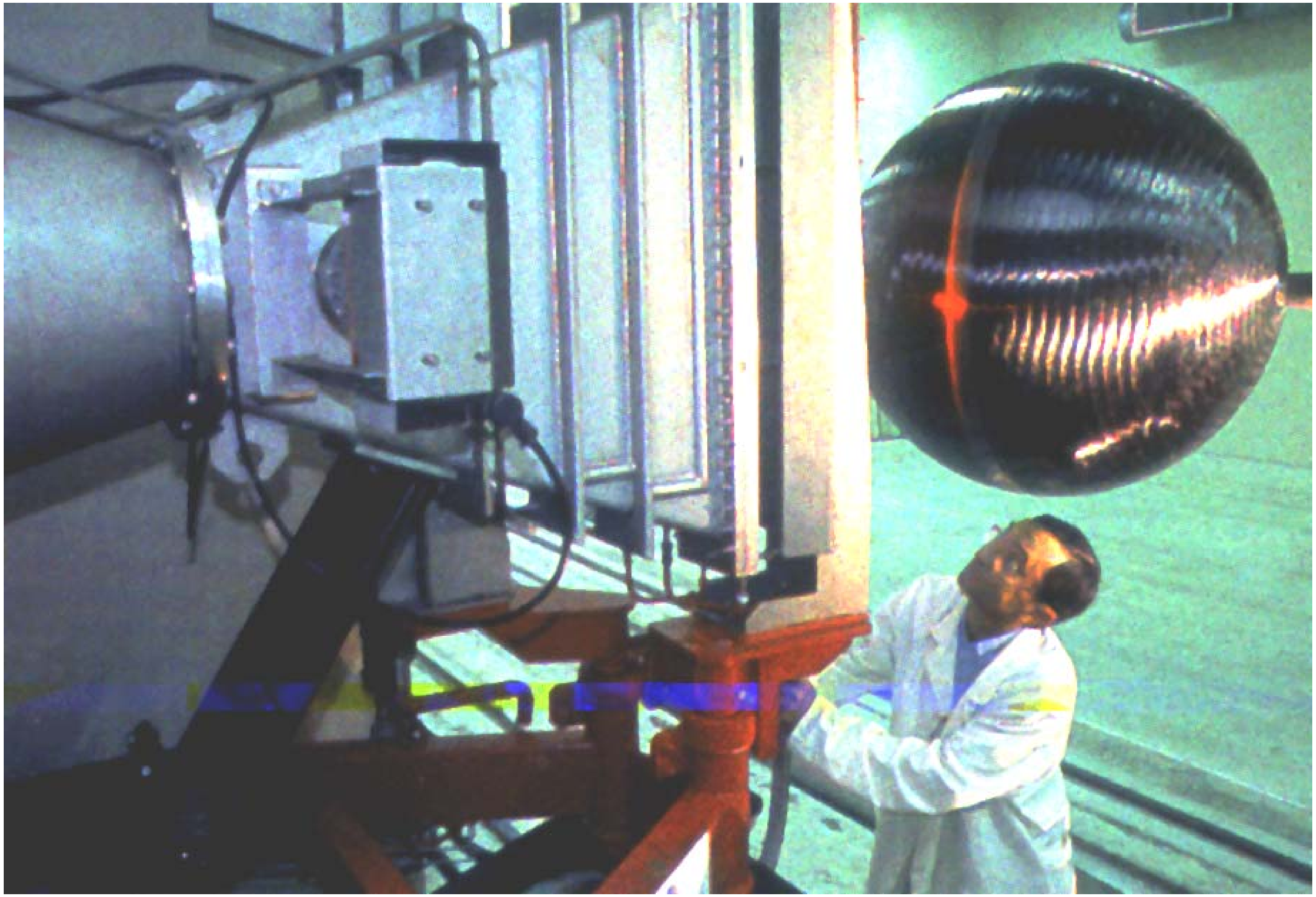
Oligomers

Modified epoxies with
special properties

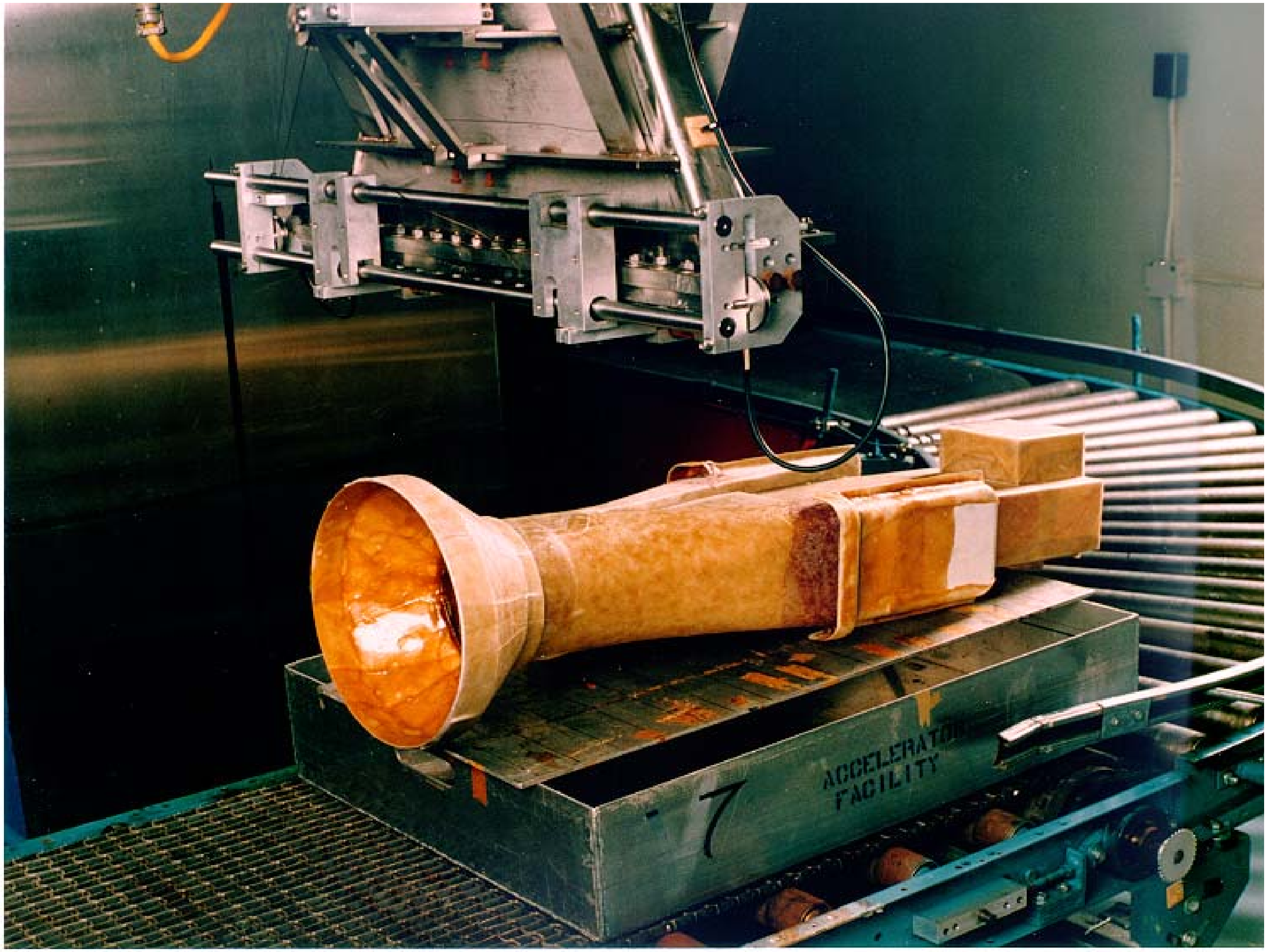
Carbon fiber reinforcement

Dose = 150 to 250 kGy

EB Curing of Carbon Fiber Composite Tank



EB Curing of Composite Missile Component



Applications of Radiation Processing

Materials Suitable for Grafting

A variety polymeric materials

- Polyethylene, Polypropylene
- Polyvinyl Chloride, Fluoropolymers
- Cellulose, Wool

A variety of hydrophilic monomers

Dose = 10 kGy

Applications of Radiation Processing

Property Improvements by Grafting

Addition of hydrophilic surfaces on hydrophobic polymers to make permselective membranes.

Fuel cell and battery separator films.

Improvement of surface adhesion properties.

Biocompatible materials for medical applications.

Applications of Radiation Processing

Typical Materials for Crosslinking

Polyethylene
Polyvinylchloride
Polyvinylidene fluoride
Ethylene-propylene rubber
Ethylene vinylacetate
Polyacrylates

Dose = 50 to 200 kGy

Applications of Radiation Processing

G value: yield in number of molecules per 100 eV
G_x = cross-linking, G_s = chain scission
G values at room temperature in the absence of O_2

Polymer	G_x	G_s	Polymer	G_x	G_s
Nat. Rubber	1.3-1.5	0.1-0.2	PTFE	0.1-0.3	3.0-5.0
Polyethylene	0.3-1.3	0.4-0.5	Butyl Rubber	<0.5	2.9-3.7
Polypropylene	0.3-1.1	0.3-1.8	PMMA	<0.5	1.1-1.7

Applications of Radiation Processing

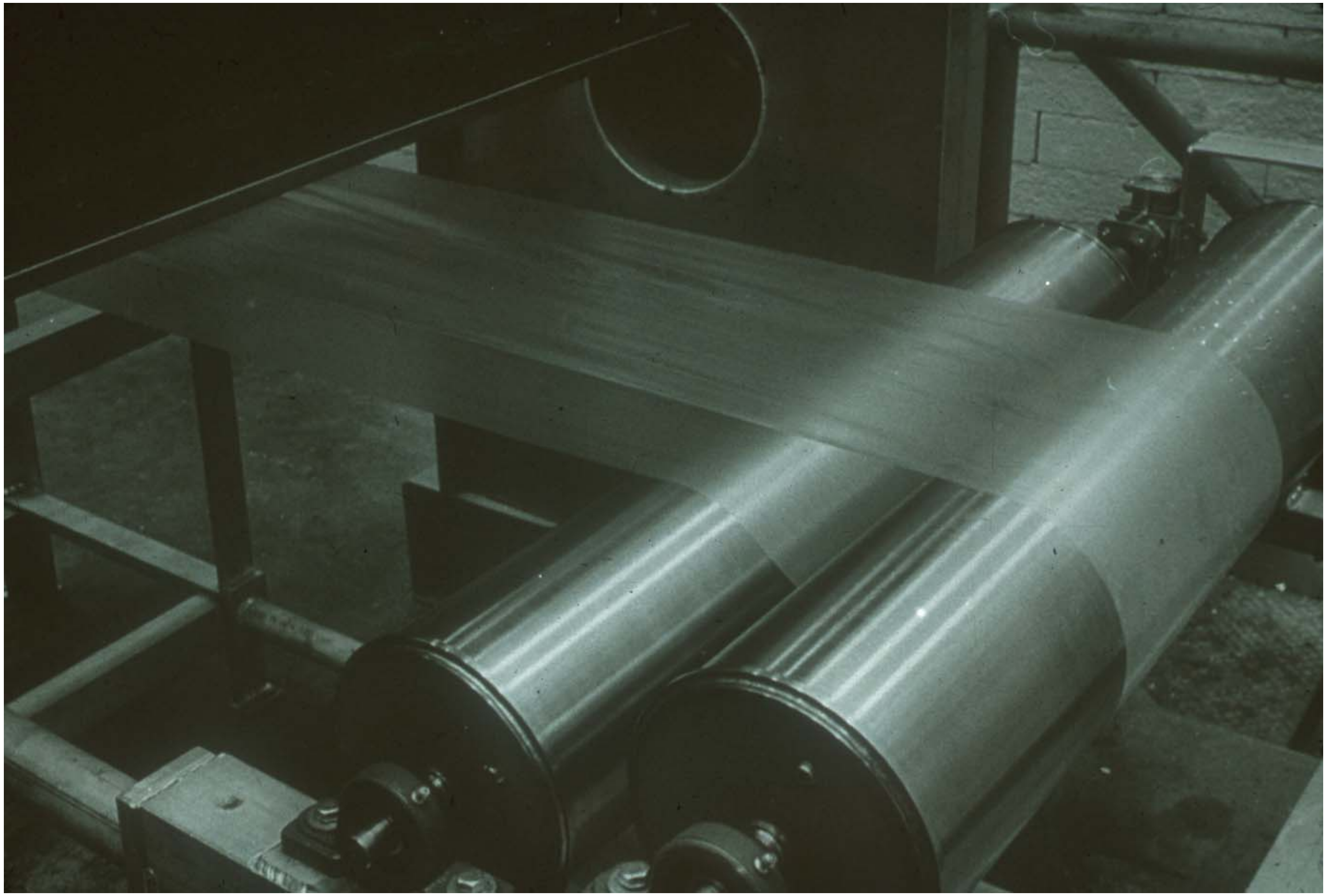
Products Improved by Crosslinking

- Plastic Products in Finished Form
- Heat Shrinkable Tubing and Film
- Electrical Wire and Cable Jackets
- Tires for Automobiles and Trucks
- Plastic Foam Padding for Automobiles
- Bulk Plastic Materials
- Hydrogel Materials

Crosslinking Formed Plastic Products

Crosslinking Heat-Shrinkable Tubing
Plastic Memory Effect

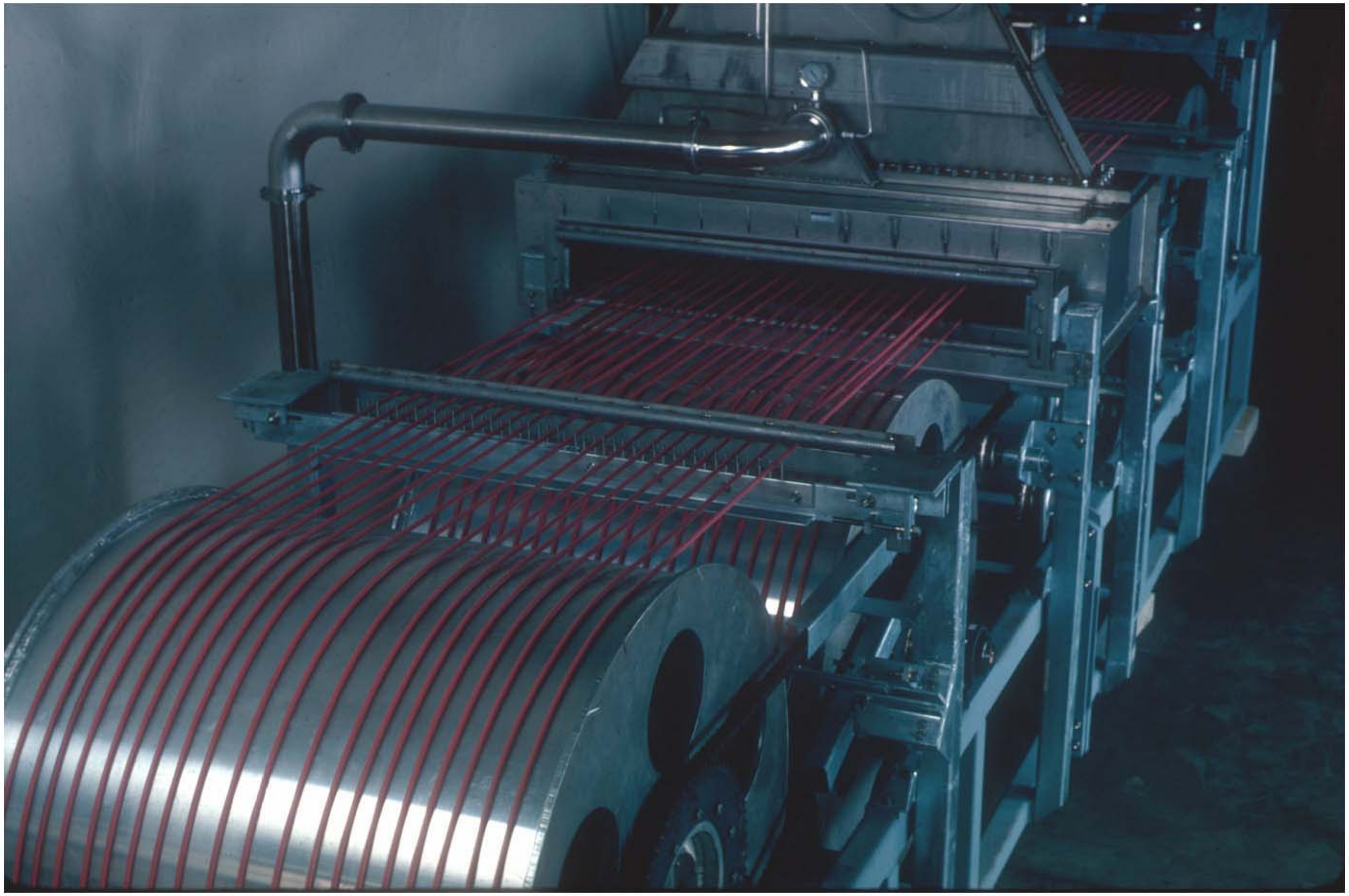
Irradiating Heat-Shrinkable Plastic Film



Crosslinking Electrical Wire Insulation Improved Flame Retardancy

Crosslinking Jackets on Multi-conductor Cables

Wire and Tubing Irradiation Method



Precuring Automobile Tire Components
Improved Dimensional Stability

Irradiating Plastic Foam Cushions for Cars

Applications of Radiation Processing

Degrading polymeric materials

- Polytetrafluoroethylene – for powders
- Polypropylene – to improve formability
- Cellulose – to produce viscose for rayon

Degrading Scrap Polytetrafluoroethylene

Cellulose Degradation for Viscose and Rayon

Applications of Radiation Processing

Biological Applications

- Sterilizing Medical Products
- Disinfecting Consumer Products
- Pasteurizing and Preserving Foods

Sterilizing Disposable Medical Products

Disinfecting Cosmetic Products

Disinfesting Fresh Fruits and Vegetables

Pasteurizing Uncooked Meats

Pasteurizing Natural Spices

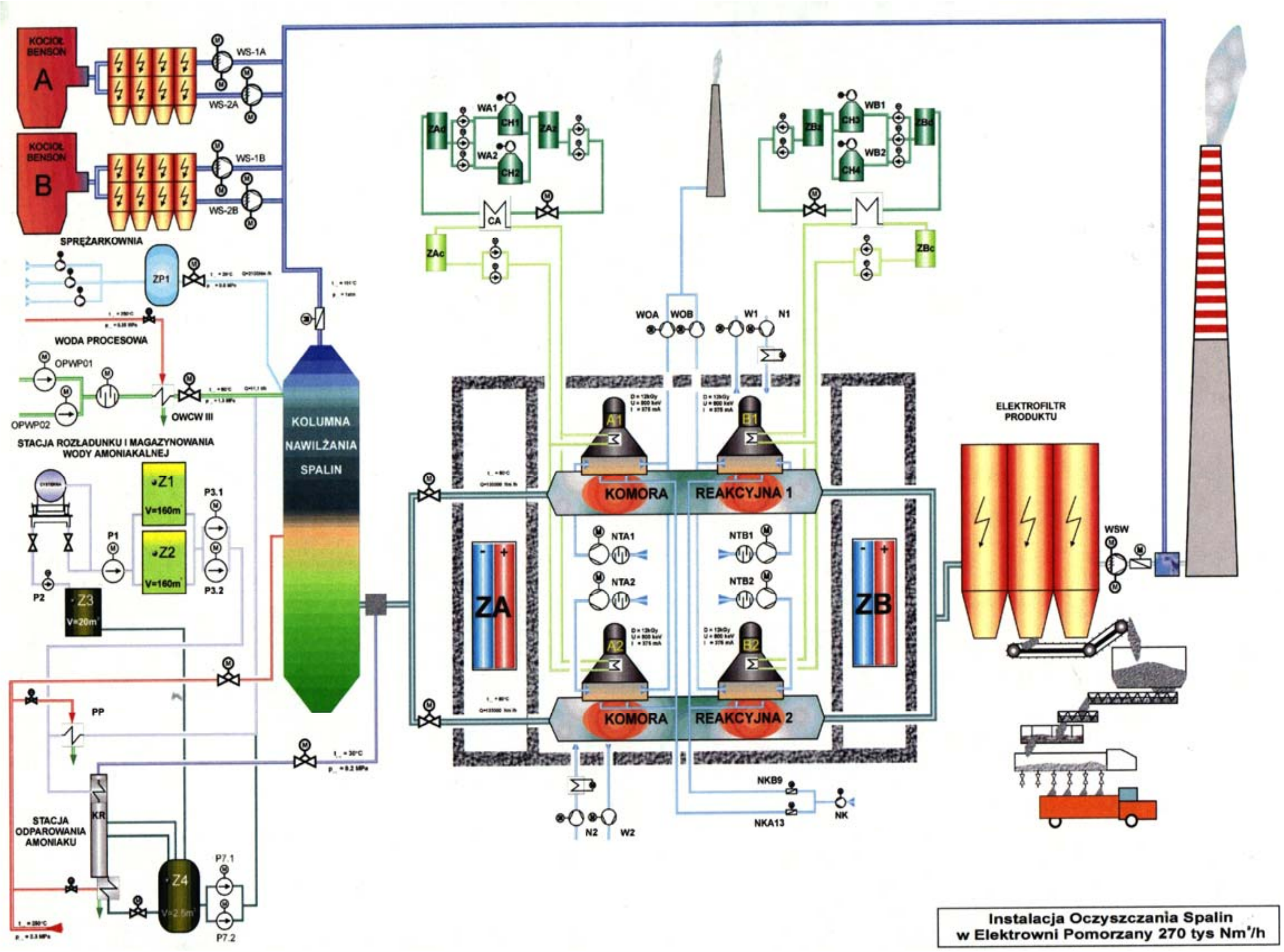
Applications of Radiation Processing

Environmental Applications

Reducing Acid Rain – by extracting
sulfur and nitrogen oxides from smoke

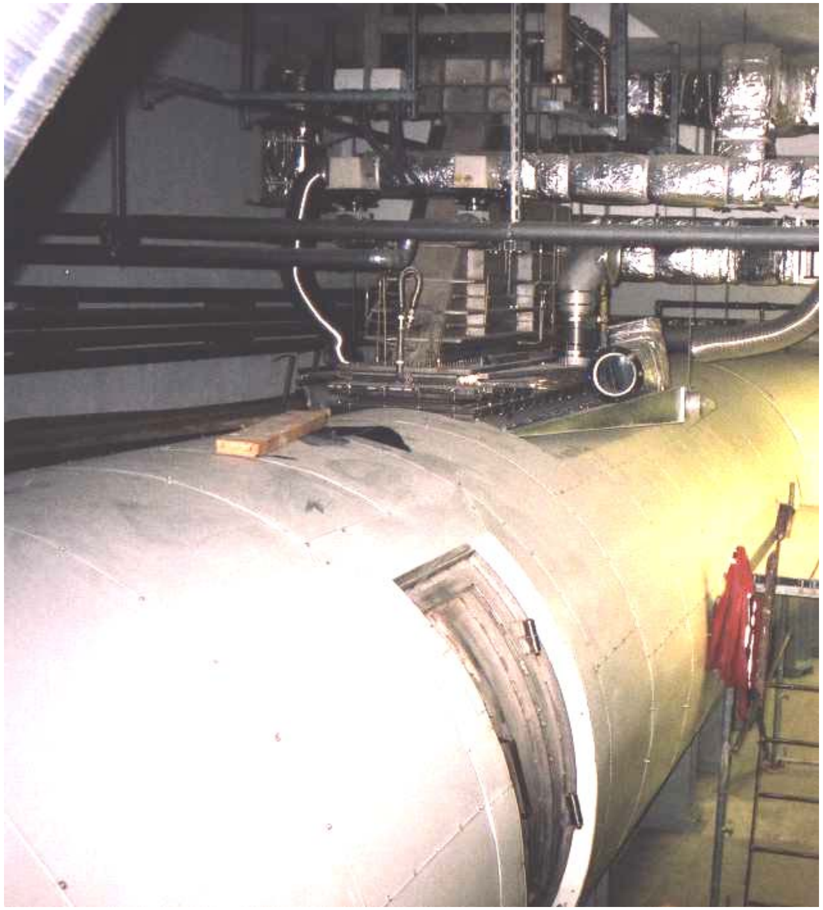
Treating Waste Materials – by decomposing
toxic substances from wastewater

Pomorzany Flue Gas EB Process Flow Diagram



Instalacja Oczyszczania Spalin w Elektrowni Pomorzany 270 tys Nm³/h

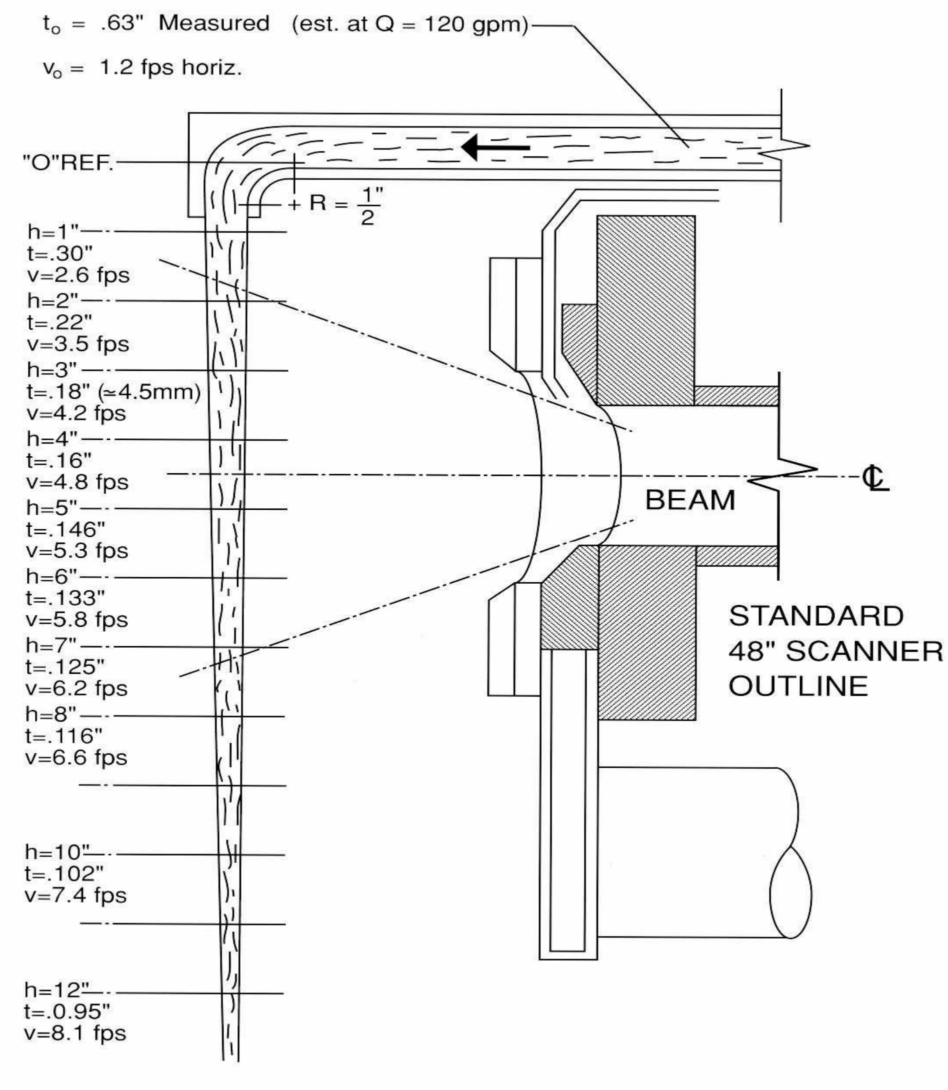
Pomorzany Flue Gas EB Irradiation Vessel



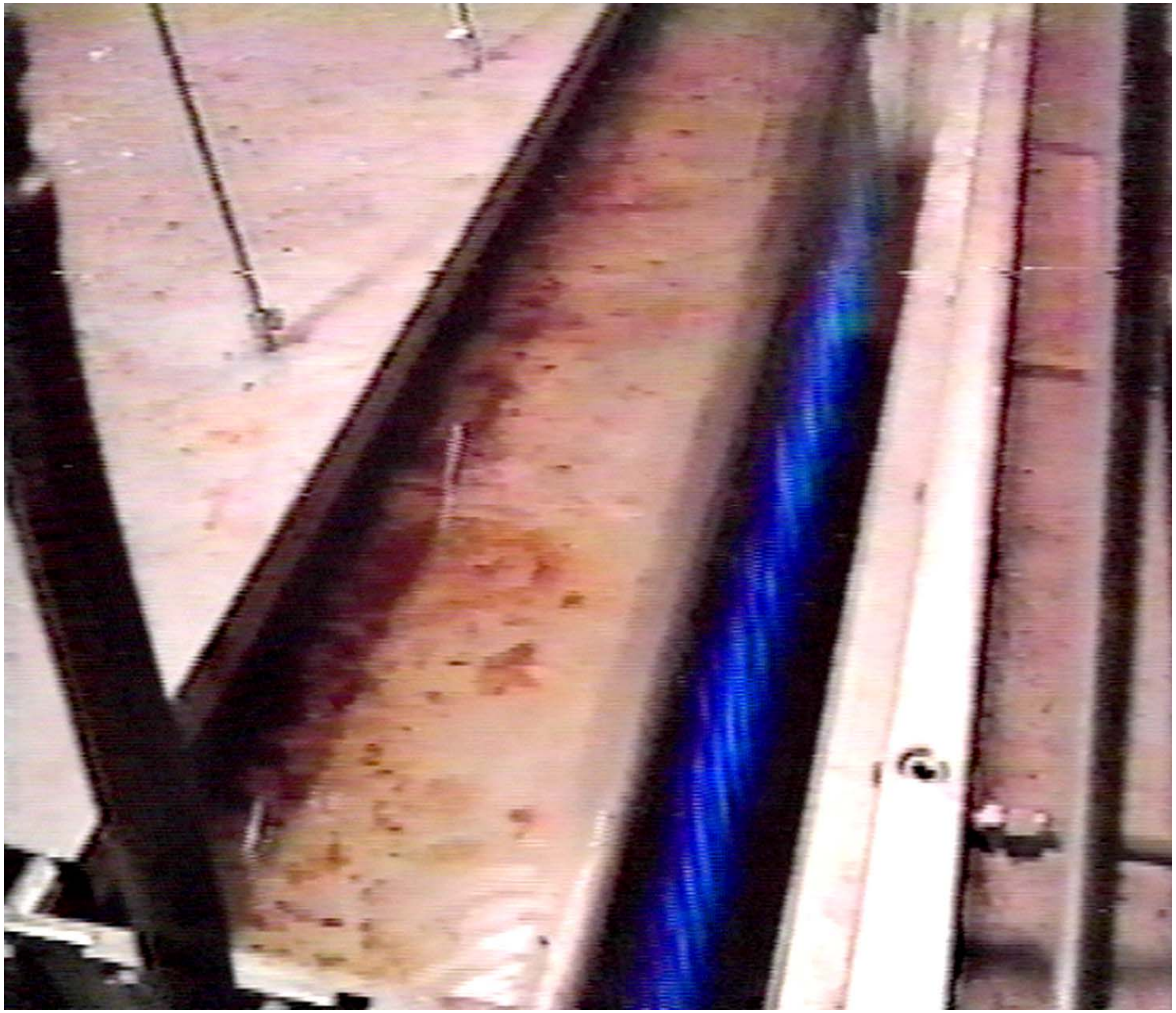
NHV DC Electron Accelerator 700 keV – 260 kW

Wastewater Treatment Plant

Miami Dade County EB Wastewater Treatment



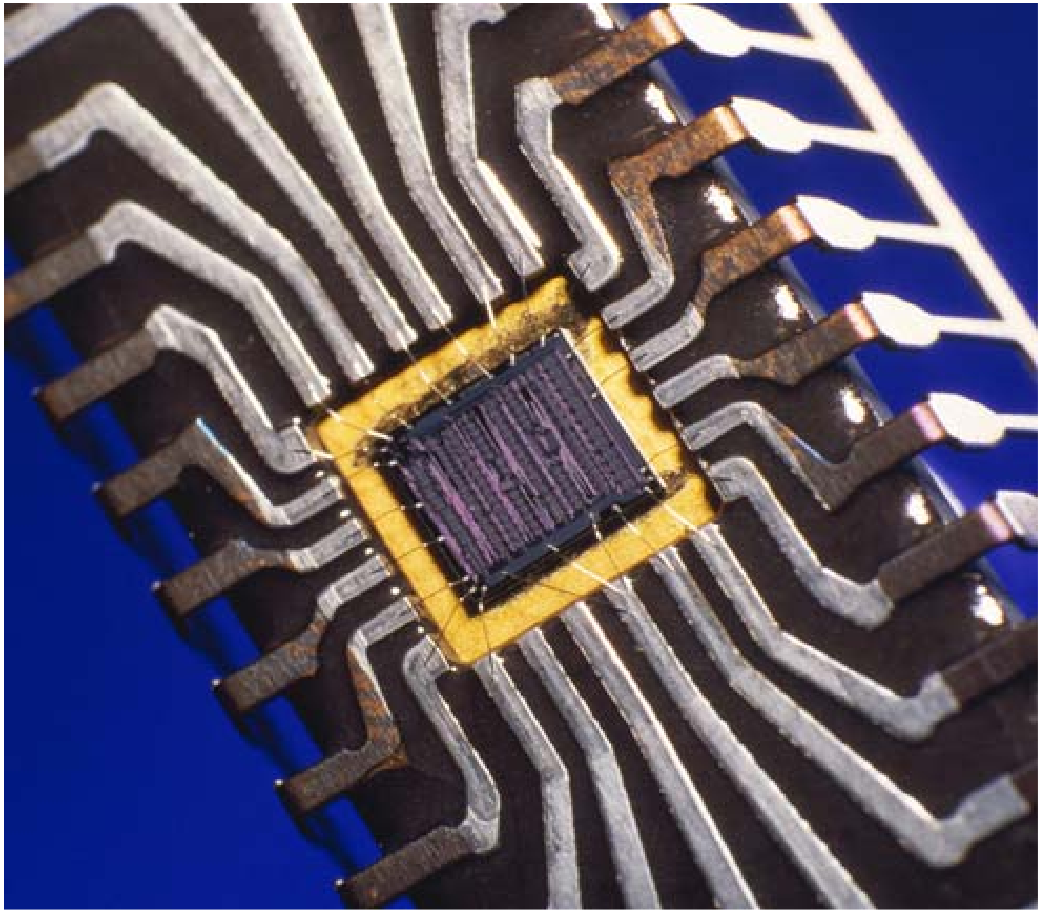
Miami Dade County EB Wastewater Treatment



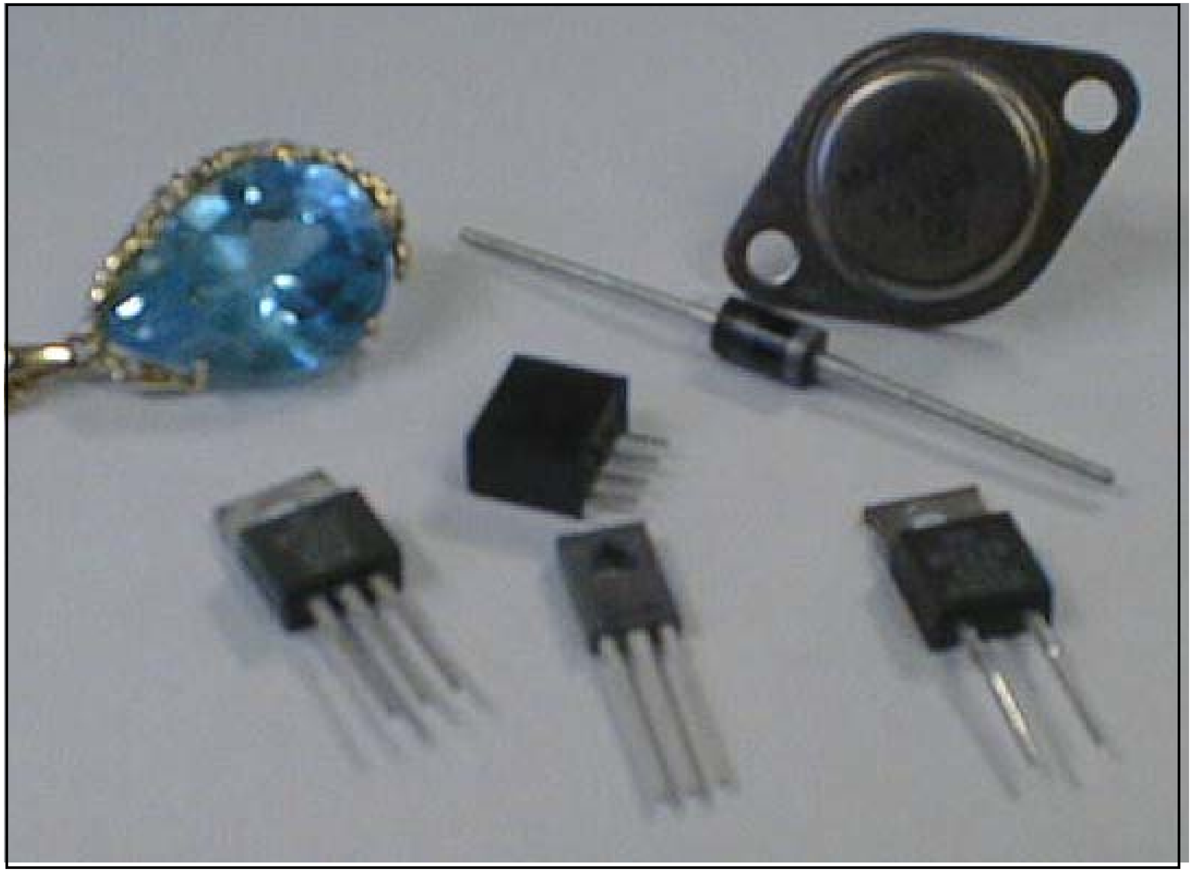
Applications of Radiation Processing

- Solid State Applications
  - Modifying Semiconductors
  - Coloring Gemstones

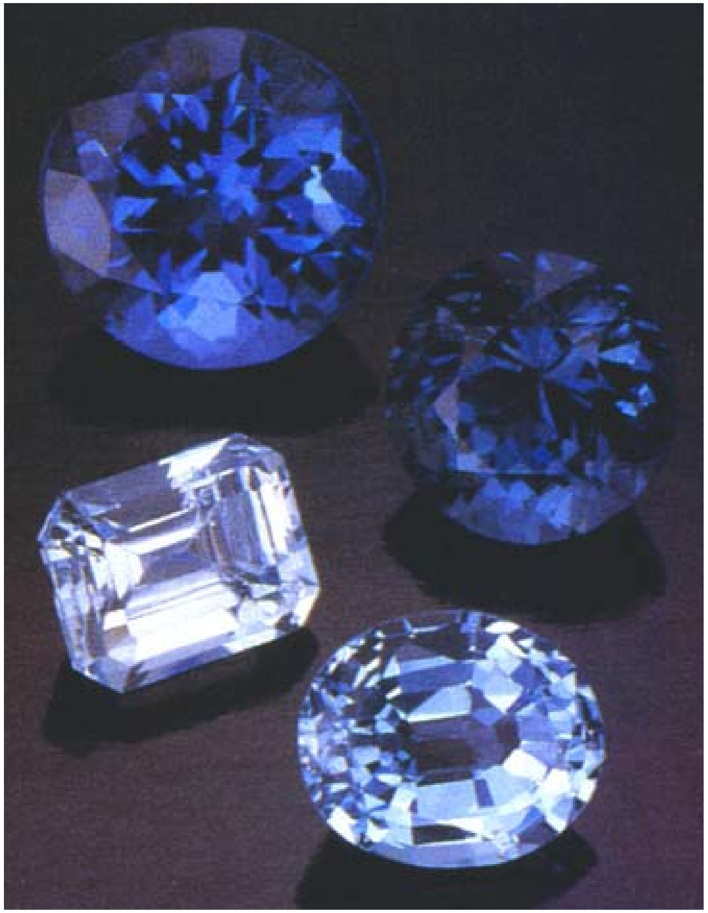
Modifying Semiconductors



Modifying Semiconductors



Coloring Gemstones



Physical Aspects of Radiation Processing

Material Penetration vs Electron Energy

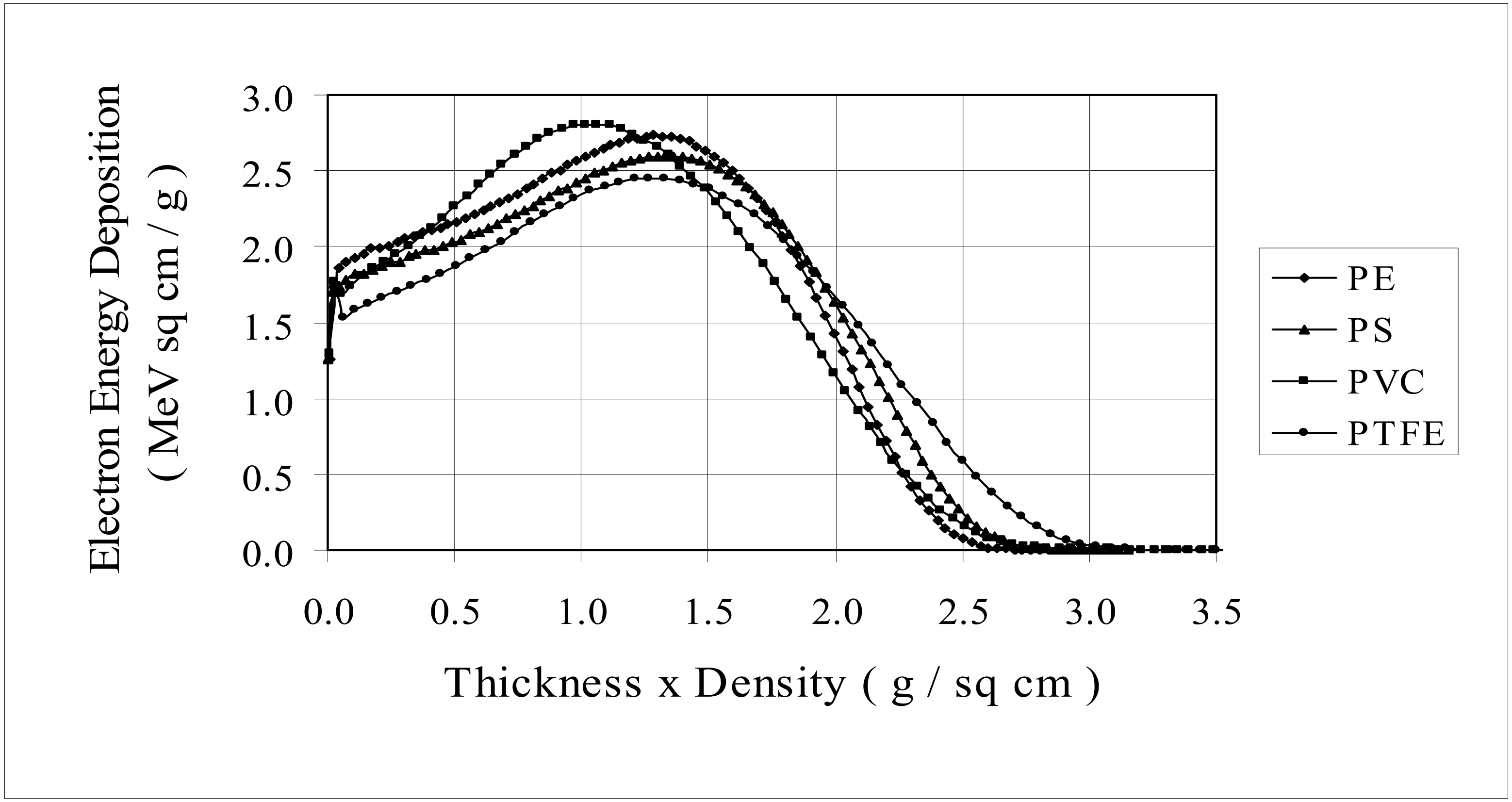
Mass Throughput Rate vs Electron Beam Power

Area Throughput Rate vs Electron Beam Current

X-Ray Processing Characteristics

Physical Aspects of Radiation Processing

Penetration vs Electron Energy
Polymer Comparisons – 5 MeV



Physical Aspects of Radiation Processing

Penetration vs Electron Energy
Polymer Comparisons

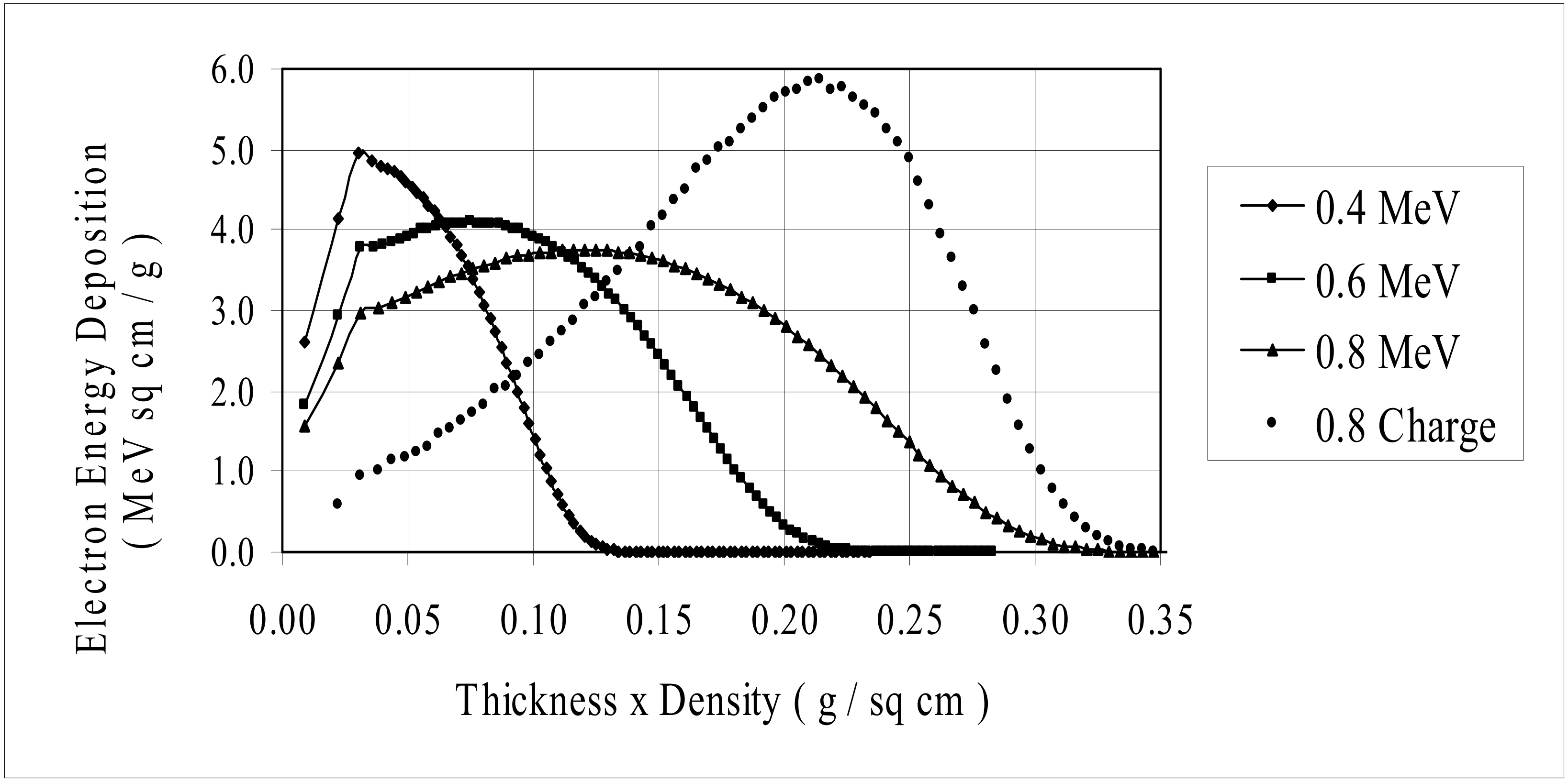
Hydrogen has more atomic electrons per unit mass than any other element.

Polymers with more hydrogen have higher energy depositions per incident electron.

Polymers with more hydrogen have lower electron ranges for the same incident electron energy.

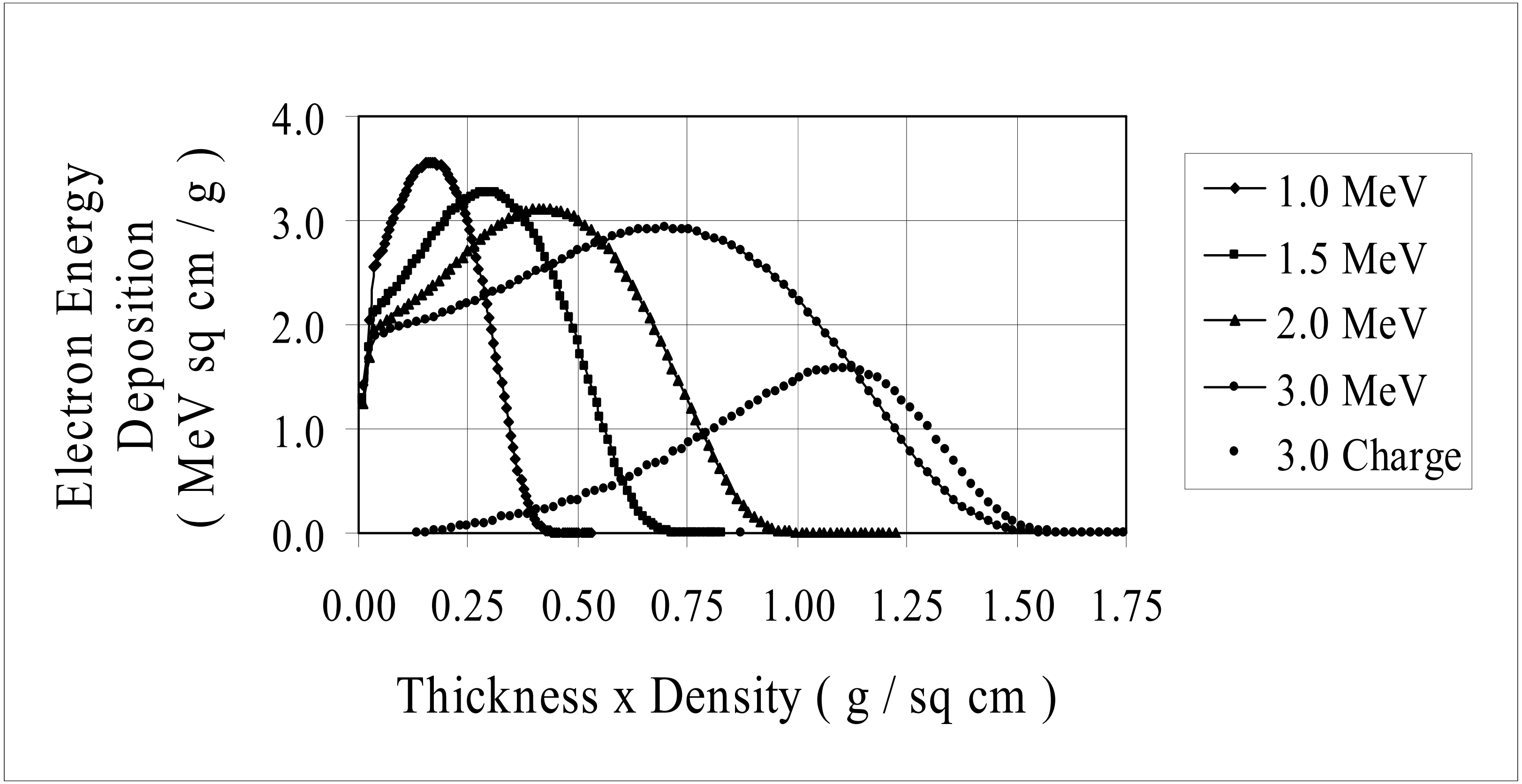
Physical Aspects of Radiation Processing

Penetration vs Electron Energy
Polyethylene



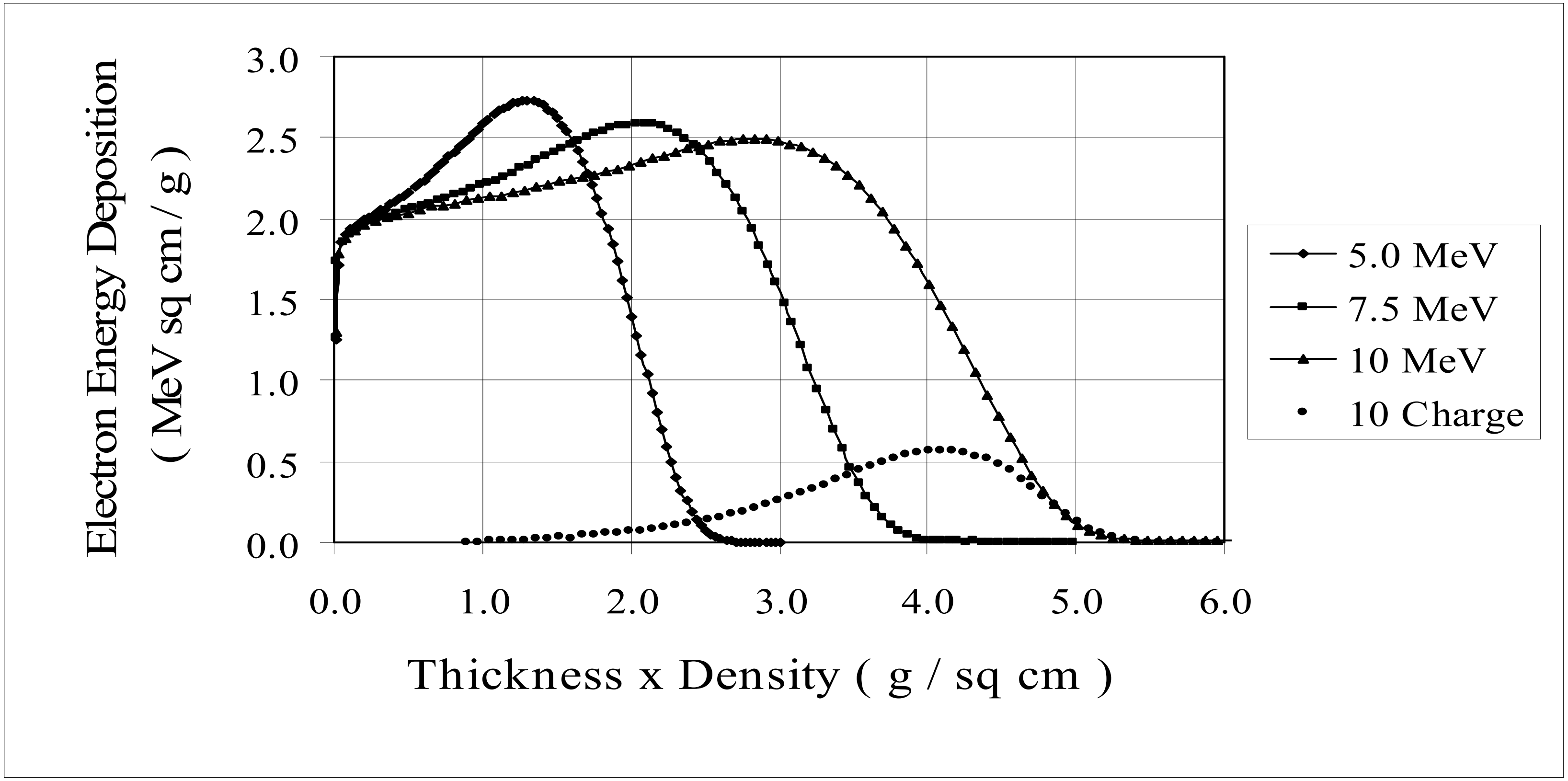
Physical Aspects of Radiation Processing

Penetration vs Electron Energy
Polyethylene



Physical Aspects of Radiation Processing

Penetration vs Electron Energy
Polyethylene



Physical Aspects of Radiation Processing

Penetration vs Electron Energy
Electrostatic Charge Deposition

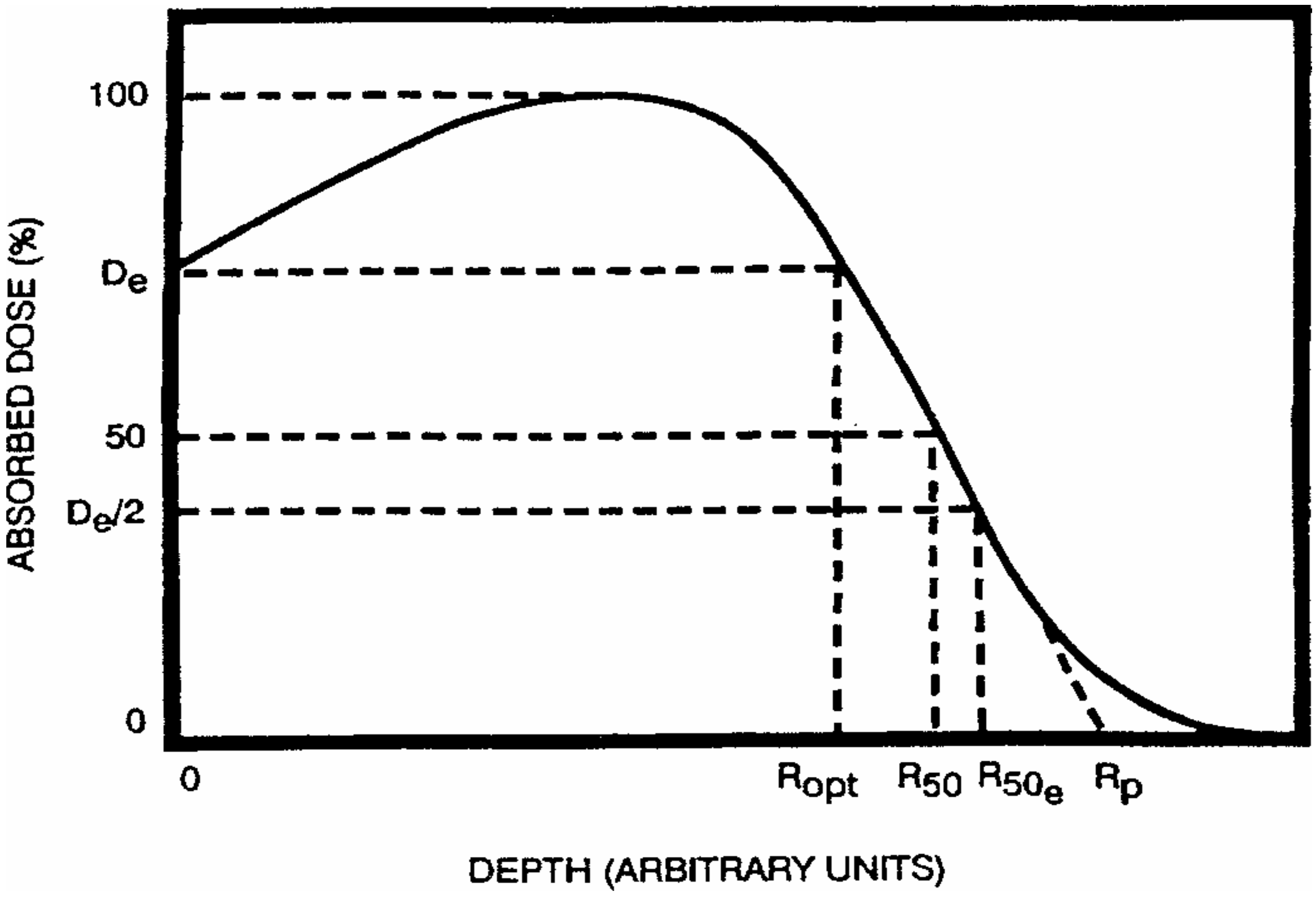
Electrostatic charges are deposited by incident electrons which come to rest in thick materials.

The charge depositions are concentrated near the Ends of the electron ranges.

The charge density decreases and the total energy deposition increases as the incident electron energy increases.

Physical Aspects of Radiation Processing

Electron Range Definitions



Physical Aspects of Radiation Processing

Electron Range Definitions

R(opt) ─ Exit Dose Equals Entrance Dose

R(50) ─ Exit Dose Equals Half Maximum Dose

R(50e) ─ Exit Dose Equals Half Entrance Dose

R(p) ─ Tangent Line Extends to Zero Dose

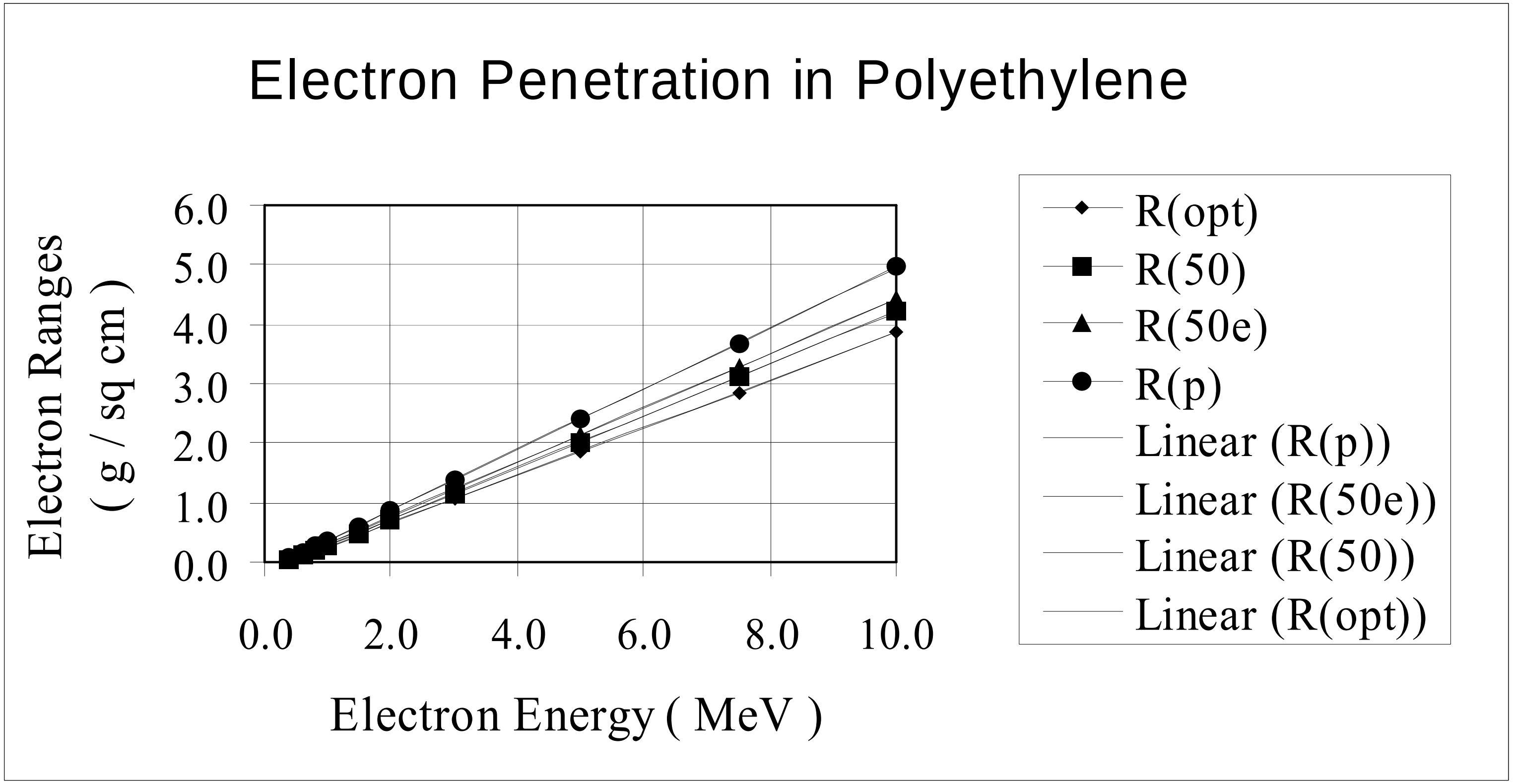
Physical Aspects of Radiation Processing

Electron Range Values

MeV	R(opt)	R(50)	R(50e)	R(p)
0.4	0.000	0.054	0.054	0.083
0.6	0.075	0.126	0.129	0.169
0.8	0.161	0.202	0.214	0.262
1.0	0.243	0.282	0.302	0.358
1.5	0.449	0.486	0.529	0.610
2.0	0.652	0.699	0.754	0.861
3.0	1.054	1.128	1.209	1.373
5.0	1.859	2.000	2.131	2.405
7.5	2.854	3.134	3.284	3.682
10.0	3.884	4.204	4.429	4.955

Physical Aspects of Radiation Processing

Electron Range Graphs



Physical Aspects of Radiation Processing

Linear Range vs Energy Equations

R(opt) = 0.404 E – 0.161

R(50) = 0.435 E – 0.152

R(50e) = 0.458 E – 0.152

R(p) = 0.510 E – 0.145

Physical Aspects of Radiation Processing

Ranges in Other Materials

Electron ranges in other materials can be estimated by multiplying the polyethylene range with the ratio of their CSDA ranges.

R(material) = R(polyethylene) x CSDA(m) / CSDA(pe)

CSDA ranges for many materials with a wide range of electron energies can be obtained from ICRU Report 37.

Physical Aspects of Radiation Processing

Absorbed Dose vs Electron Beam Power

1 kGy = 1 kJ/kg

D(ave) = F(p) P T / M

D(ave) = F(p) P / (M / T)

D(ave) = average dose in kGy
P = emitted power in kW
T = treatment time in s
M = mass in kg

Physical Aspects of Radiation Processing

Mass Throughput Rate vs Electron Beam Power

$$M / T = F(p)\ P / D(ave)$$

$$F(p) = F(e)\ F(i)$$

$F(p)$ = fraction of emitted power absorbed
$F(e)$ = fraction of incident power absorbed
$F(i)$ = fraction of emitted current intercepted

Physical Aspects of Radiation Processing

Mass Throughput Rate vs Electron Beam Power

$$M / T = f(p)\,P / D(o)$$

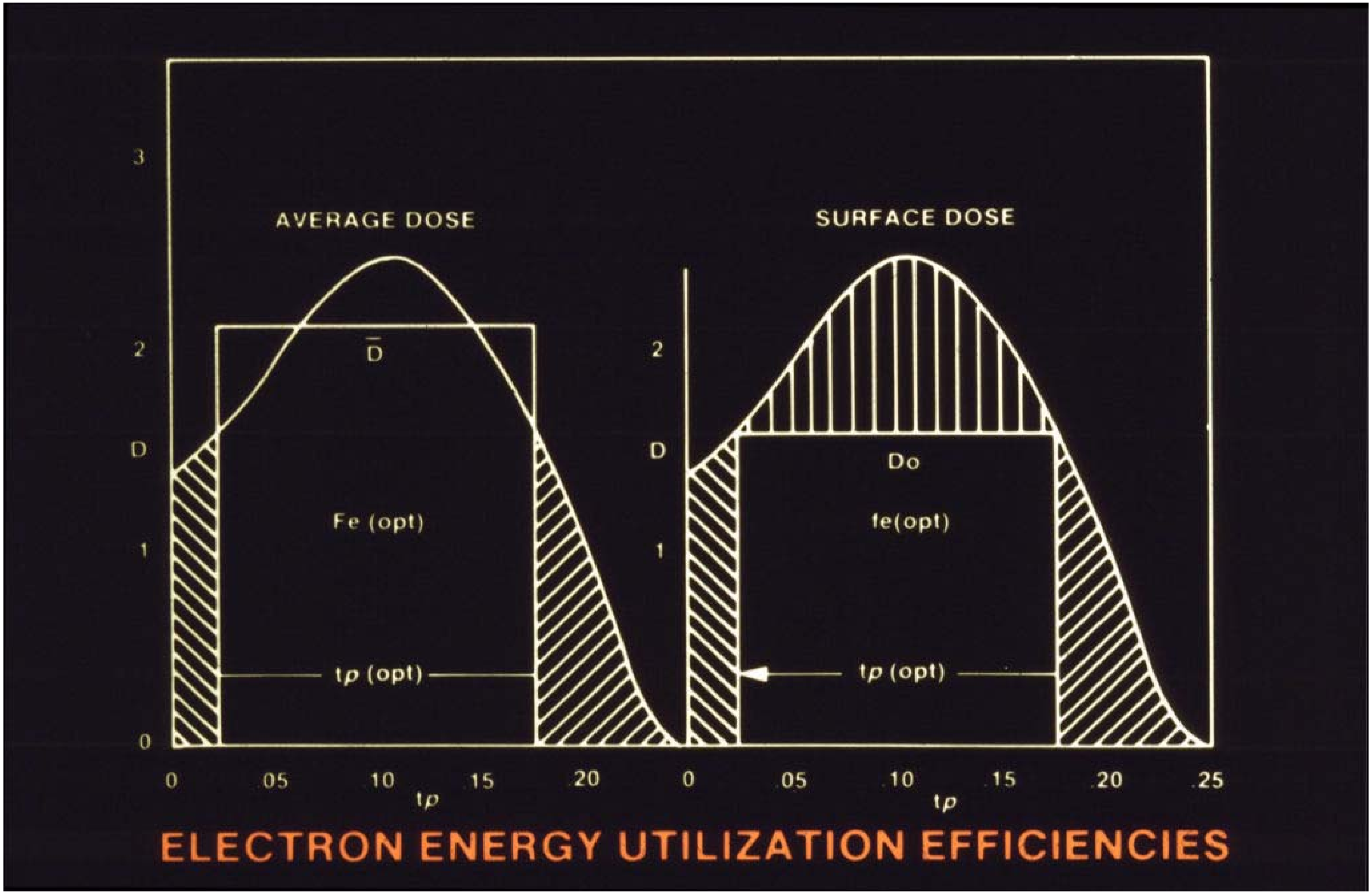
$$f(p) = f(e)\,F(i)$$

$D(o)$ = surface dose in kGy

$f(p)$ = surface dose value of $F(p)$

$f(e)$ = surface dose value of $F(e)$

Physical Aspects of Radiation Processing



Physical Aspects of Radiation Processing

Processing Parameters vs Incident Energy

MeV	D(e)	K(o)	f(e)	F(e)
0.4	4.963	0.496	0.000	0.000
0.6	3.795	0.380	0.474	0.496
0.8	2.982	0.298	0.599	0.695
1.0	2.550	0.255	0.619	0.777
1.5	2.118	0.212	0.634	0.850
2.0	1.966	0.197	0.641	0.862
3.0	1.887	0.189	0.663	0.867
5.0	1.860	0.186	0.692	0.875
7.5	1.860	0.186	0.708	0.873
10.0	1.878	0.188	0.730	0.867

Physical Aspects of Radiation Processing

Example – Mass Throughput Rate

E = 1.0 MeV
P = 100 kW
F(i) = 0.80
f(e) = 0.619
D(o) = 100 kGy

M / T = 0.619 x 0.80 x 100 / 100

M / T = 0.495 kg/s or 1783 kg/h

Physical Aspects of Radiation Processing

Absorbed Dose vs Electron Beam Current

$$D\ (\mathrm{kGy}) = P\ (\mathrm{kW})\ T\ (\mathrm{s})\ /\ M\ (\mathrm{kg})$$

$$P\ (\mathrm{kW}) = E\ (\mathrm{MeV})\ I\ (\mathrm{mA})$$

$$E\ (\mathrm{MeV}) = D(e)\ (\mathrm{MeV\ cm^2/g})\ Z\ (\mathrm{g/cm^2})$$

$D(e)$ = energy deposition per electron

Z = thickness x density ($\mathrm{g/cm^2}$)

Z = mass / area ($\mathrm{g/cm^2}$)

Physical Aspects of Radiation Processing

Absorbed Dose vs Electron Beam Current

$$D\ (\mathrm{kGy}) = E\ (\mathrm{MeV})\ I\ (\mathrm{mA})\ T\ (\mathrm{s})\ /\ M\ (\mathrm{kg})$$

$$D\ (\mathrm{kGy}) = D(e)\ Z\ I\ (\mathrm{mA})\ T\ (\mathrm{s})\ /\ M\ (\mathrm{kg})$$

$$D\ (\mathrm{kGy}) = D(e)\ Z\ I\ (\mathrm{mA})\ T\ (\mathrm{s})\ /\ Z\ A\ (\mathrm{cm}^2)\ 10^{-3}$$

$$D\ (\mathrm{kGy}) = D(e)\ I\ (\mathrm{mA})\ T\ (\mathrm{s})\ /\ 10\ A\ (\mathrm{m}^2)$$

Physical Aspects of Radiation Processing

Absorbed Dose vs Electron Beam Current

$$D(z) = K(z)\, F(i)\, I\, T / A$$

$D(z)$ = dose at the depth z in kGy

$K(z) = D(e, z) / 10$ in kGy m^2/mA s

$K(z)$ = Area Processing Coefficient ─ evaluated at the depth where the dose is specified

$F(i)$ = fraction of emitted beam current intercepted

I = emitted beam current in mA

T = treatment time in s

A = product area in m^2

Physical Aspects of Radiation Processing

Area Throughput Rate vs Electron Beam Current

$$A / T = K(z)\ F(i)\ I / D(z)$$

A / T = area throughput rate in m^2/s

$K = D(e) / 10$ in $kGy\ m^2/mA\ s$

K = Area Processing Coefficient

$F(i)$ = fraction of beam current intercepted

$F(i)$ = product area / irradiated area

I = emitted beam current in mA

$D(z)$ = dose in kGy where $K(z)$ is evaluated

Physical Aspects of Radiation Processing

Processing Parameters vs Incident Energy

MeV	D(e)	K(o)	f(e)	F(e)
0.4	4.963	0.496	0.000	0.000
0.6	3.795	0.380	0.474	0.496
0.8	2.982	0.298	0.599	0.695
1.0	2.550	0.255	0.619	0.777
1.5	2.118	0.212	0.634	0.850
2.0	1.966	0.197	0.641	0.862
3.0	1.887	0.189	0.663	0.867
5.0	1.860	0.186	0.692	0.875
7.5	1.860	0.186	0.708	0.873
10.0	1.878	0.188	0.730	0.867

Physical Aspects of Radiation Processing

Example – Area Throughput Rate

$E = 1.0$ MeV

$I = 100$ mA

$F(i) = 0.80$

$K(o) = 0.255$

$D(o) = 100$ kGy

$A / T = 0.255 \times 0.80 \times 100 / 100$

$A / T = 0.204\ m^2/s$ or $734\ m^2/h$

Physical Aspects of Radiation Processing

Example – Mass Throughput from Area Throughput

$E = 1.0$ MeV

$I = 100$ mA

$F(i) = 0.80$

$R(opt) = 0.243\ g/cm^2$ or $2.43\ kg/m^2$

$A / T = 734\ m^2/h$

$M / T = (A / T) \times R(opt)$

$M / T = 734 \times 2.43 = 1785$ kg/h

Physical Aspects of Radiation Processing

X-Ray Processing Characteristics

X-Ray Energy and Angular Distributions

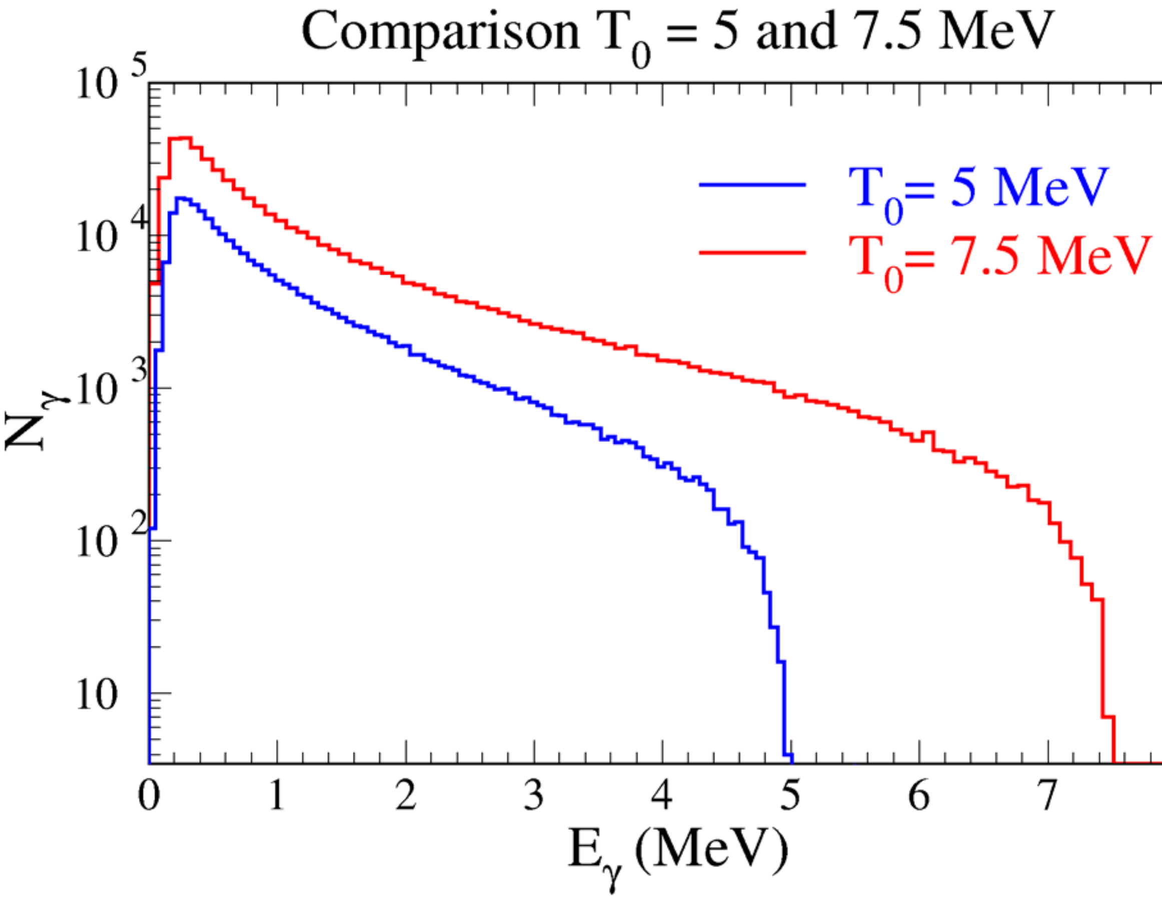
X-Ray Broad Beam Penetration in Water

X-Ray Utilization vs Product Thickness

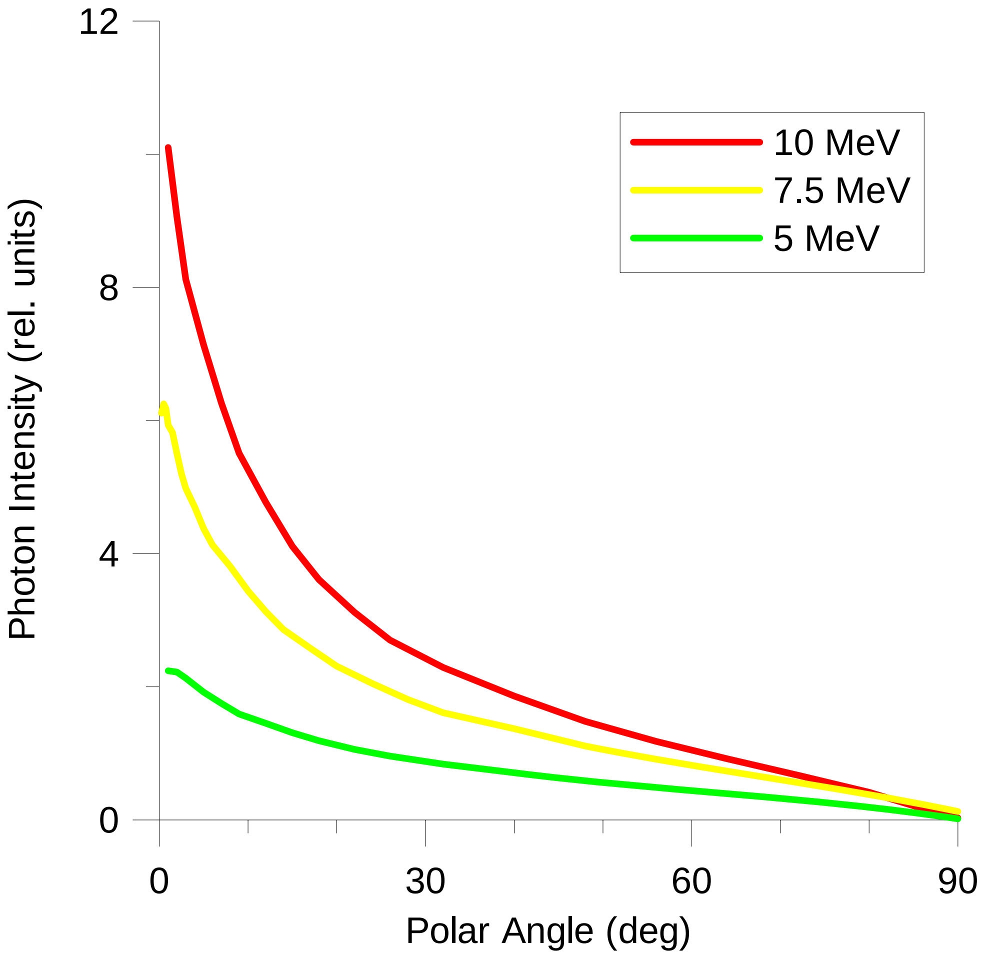
X-Ray Emission Efficiency vs Electron Energy

Palletron^{TM} Rotational X-Ray Processing

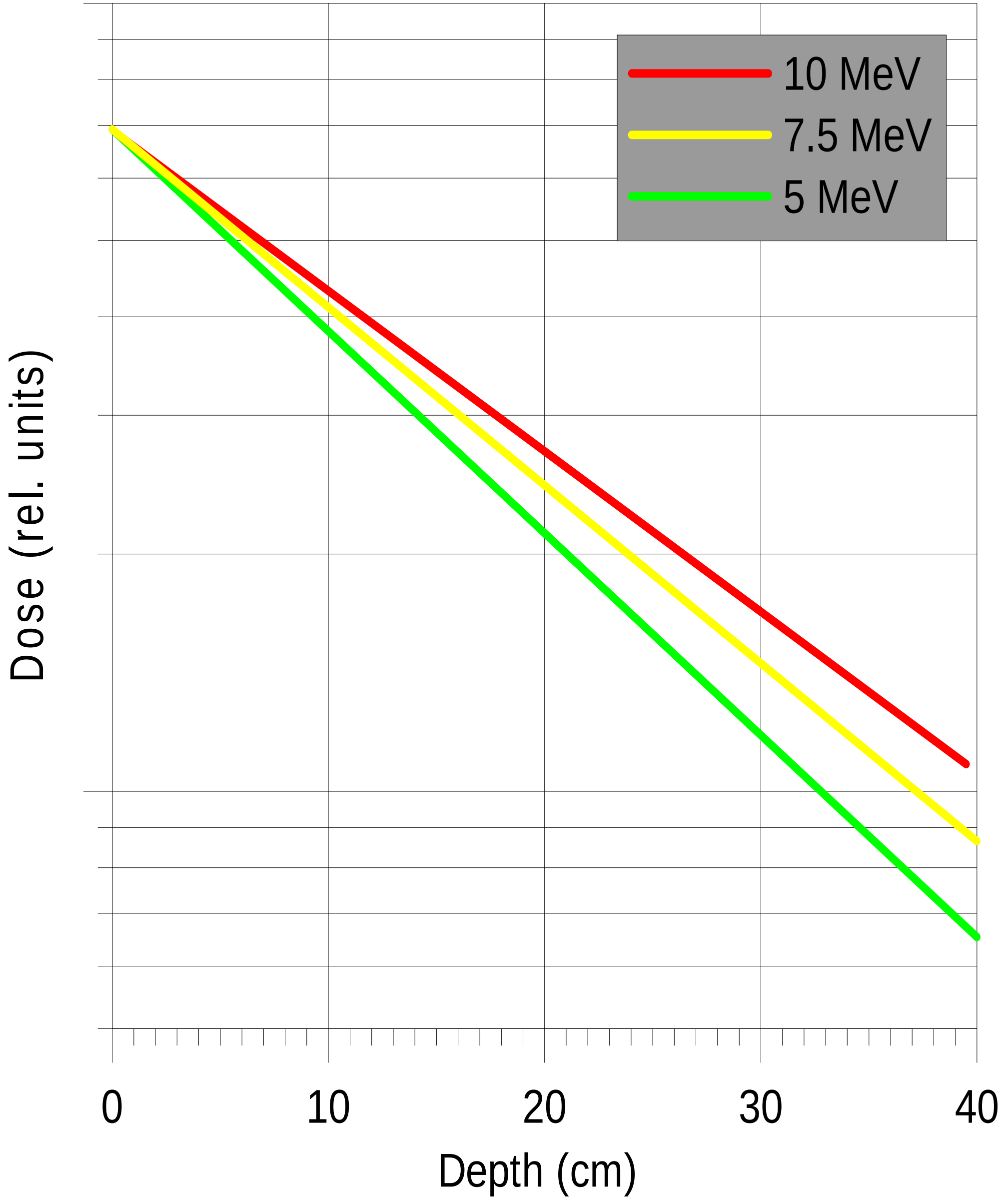
X-Ray Photon Energy Spectrum



X-Ray Photon Angular Distribution

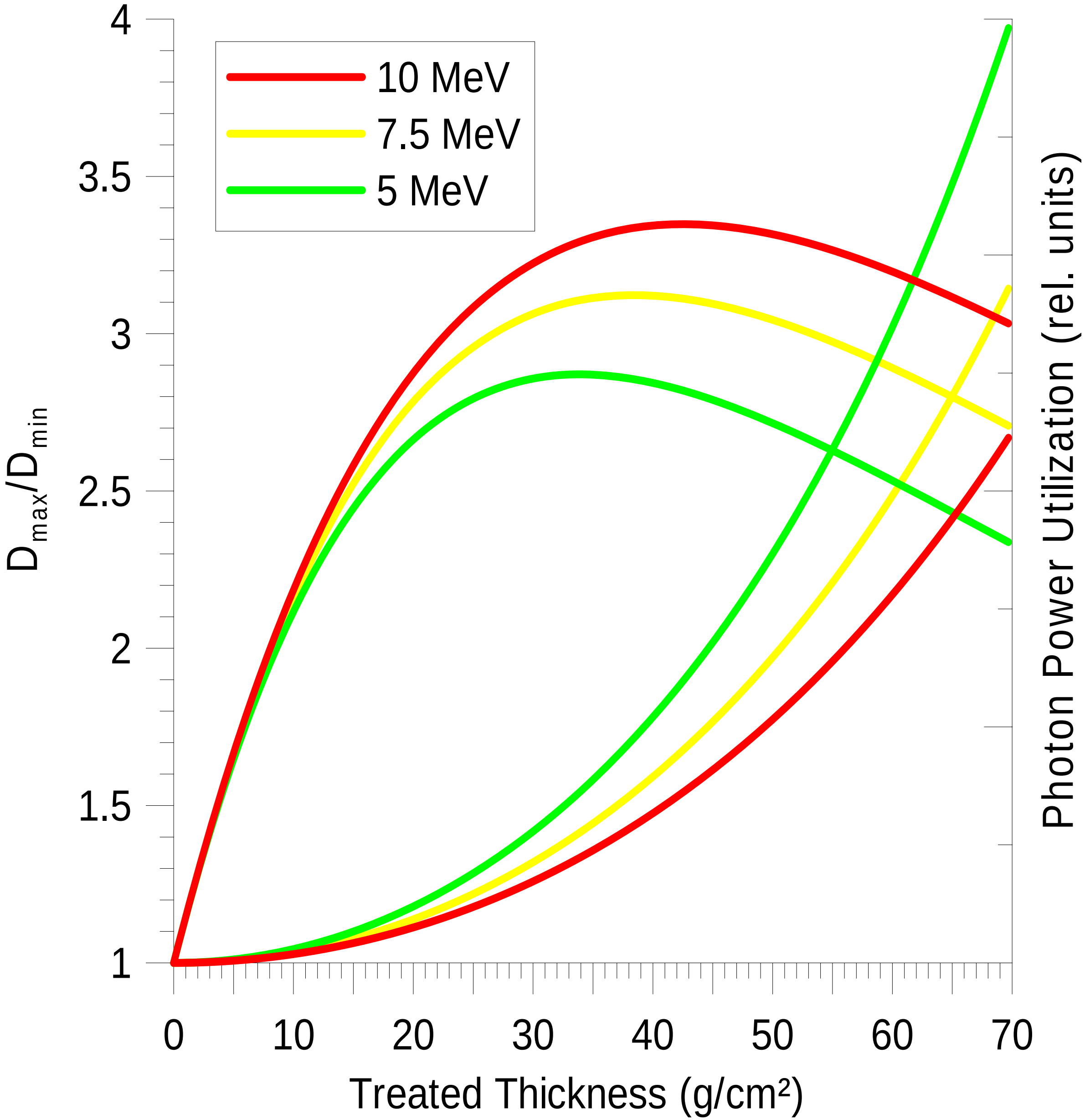


Broad Beam X-Ray Penetration in Water



Energy (MeV)	Tenth Value Layer (cm) Present Work Calc.	Exp.	prev. Calc.
10	49.0	47.9	49.0
7.5	44.3	N/A	N/A
5	39.0	39.5	38.0

Two-Sided X-Ray Process in Water



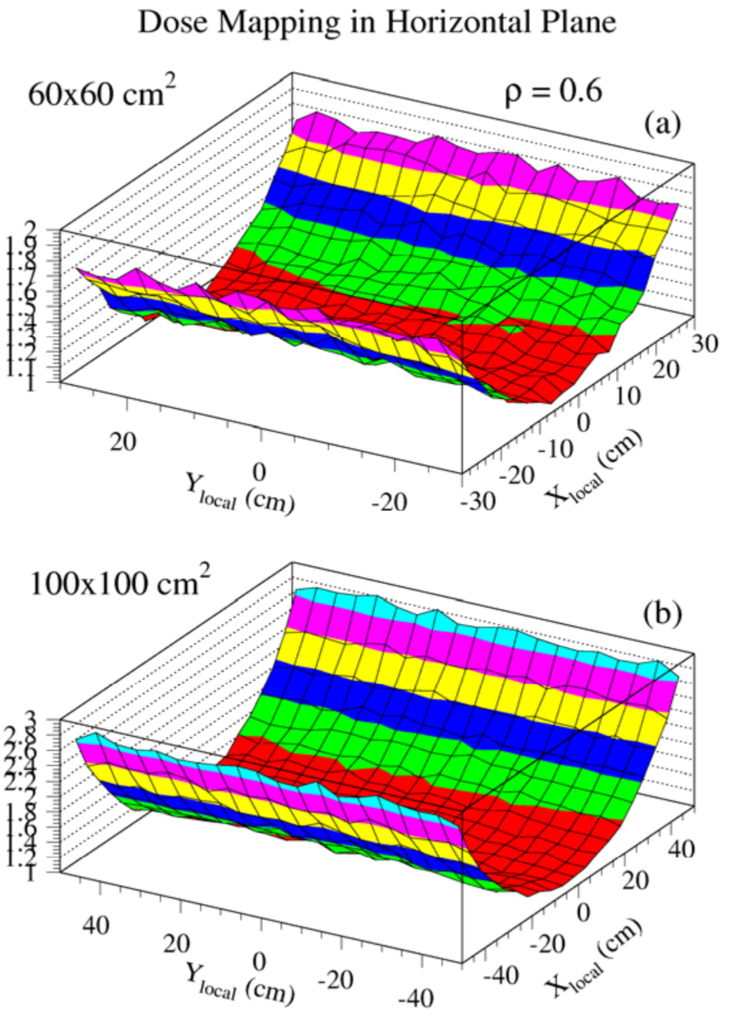
Optimum Thickness

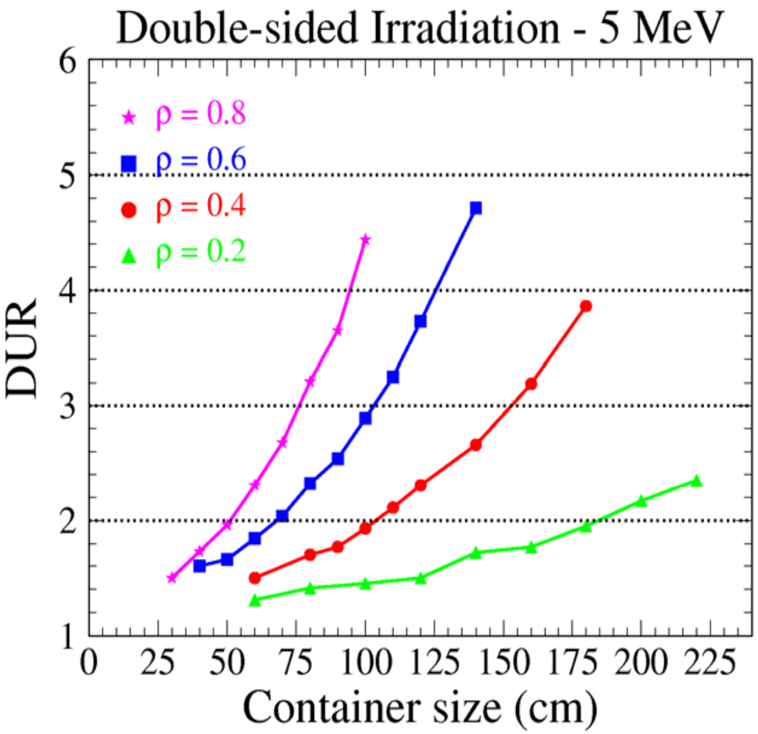
Energy (MeV)	$2/\lambda$ (cm)
10	42.5
7.5	38.5
5	33.9

Two-Sided X-Rays vs Gamma Rays

Electron Energy (MeV)	X-Ray Efficiency (%)	Tenth Value Layer Calculation (cm water)	Optimum Thickness Double Sided (cm)	Max/Min
10.0	16.2	49.0	43	1.54
7.5	13.3	44.3	38	1.54
5.0	8.2	39.0	34	1.54
Co-60		31.0	28	1.75

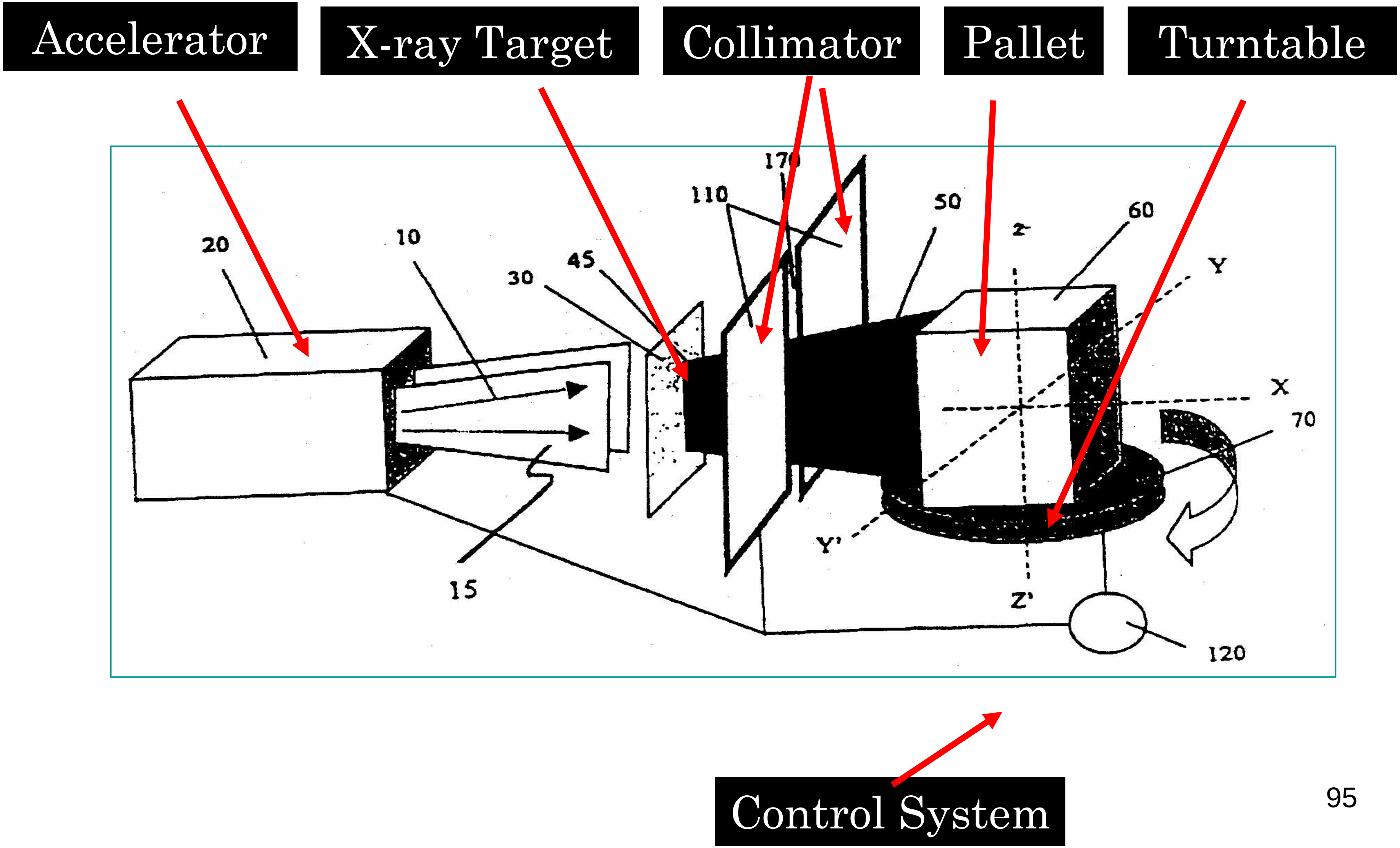
Two-Sided X-Ray Irradiation


Dose Mapping in Horizontal Plane


Double-sided Irradiation - 5 MeV

Sterigenics Dual-Beam X-ray Facility

IBA Palletron^{TM} Rotational Method



Accelerator

X-ray Target

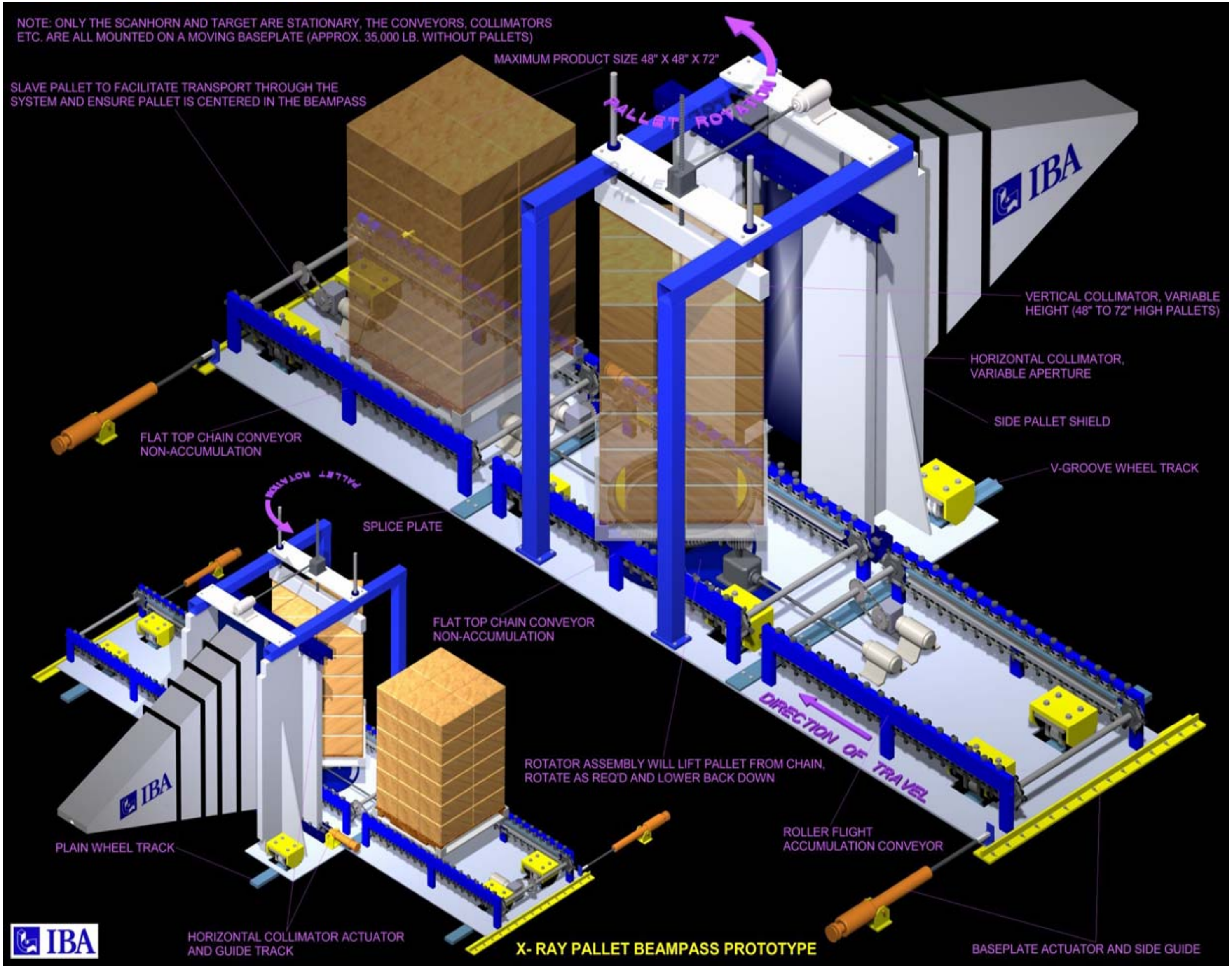
Collimator

Pallet

Turntable

Control System

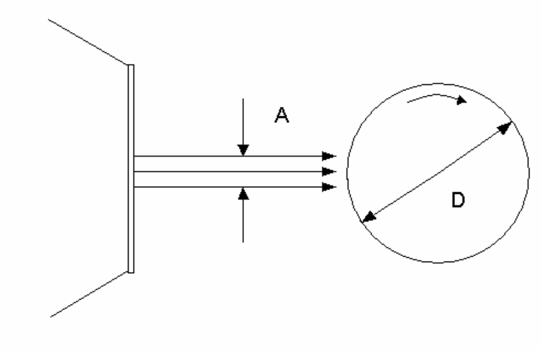
IBA Palletron^{TM} Rotational Method



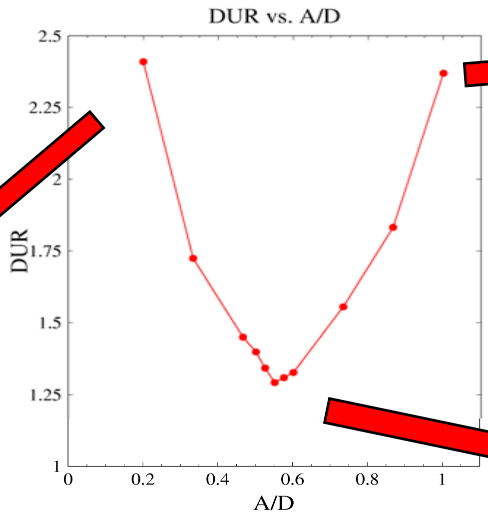
IBA Palletron® Dose Distribution Measurement Verification of Monte Carlo Simulation

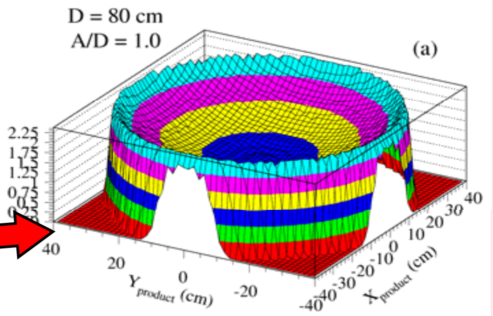
IBA Palletron^{TM} Rotational Method

Cylinder Irradiation with X-Rays

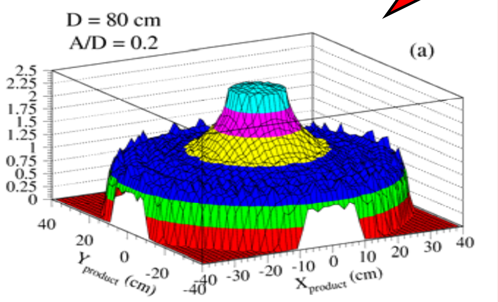


D= 80 cm / ρ= 0.8

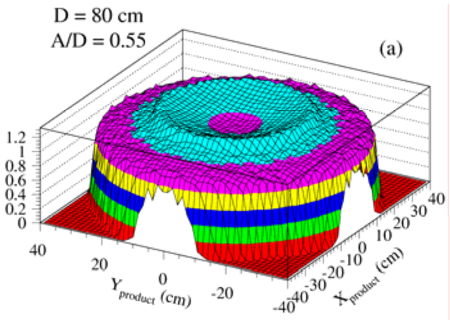




A/D = 1



DUR versus A/D



A/D << 1

⇒ Optimal A/D = 0.55

IBA Palletron^{TM} Performance Figures

r £ 0.4:

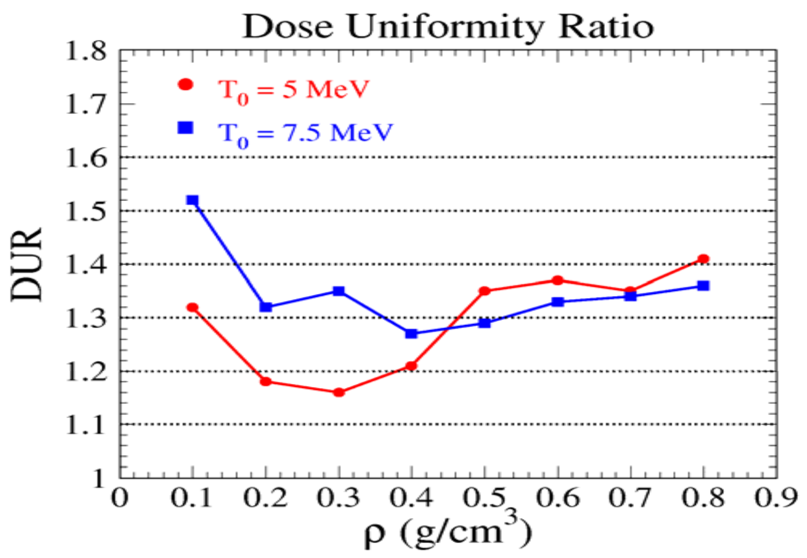
- constant rotation speed
- collimators widely open

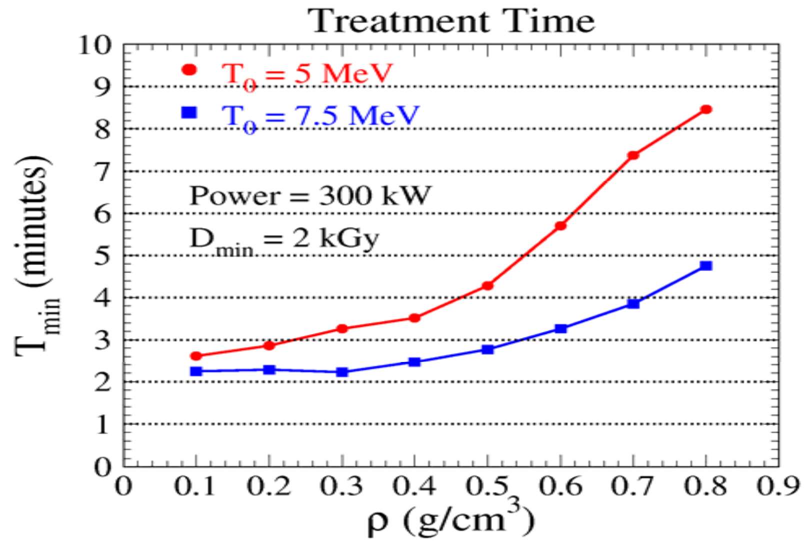
r > 0.4:

- variable rotation speed
- aperture tuned to product density

Significant gain at 7.5 MeV:

- Better conversion efficiency
- More energetic X-Rays
- X-rays peaked forward





IBA Palletron^{TM} Processing Capacities

Throughputs calculated with the following assumptions:

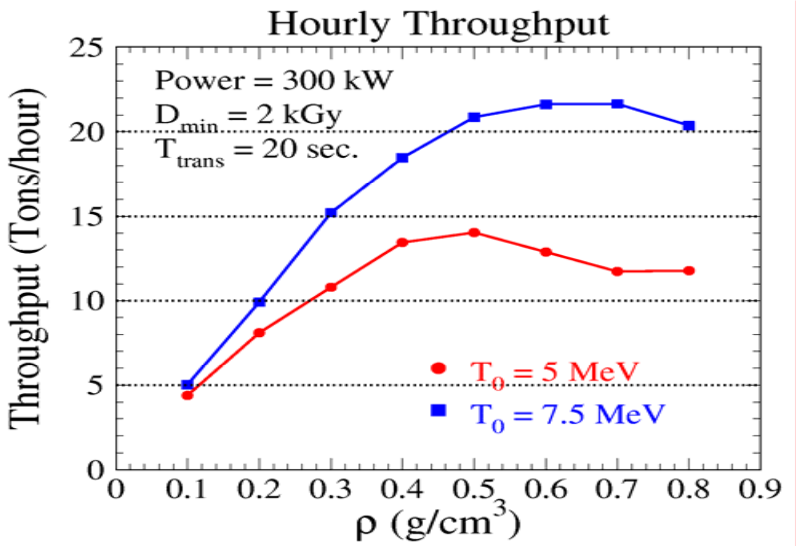
Beam = 5 MeV/300 kW or 7.5 MeV/300 kW

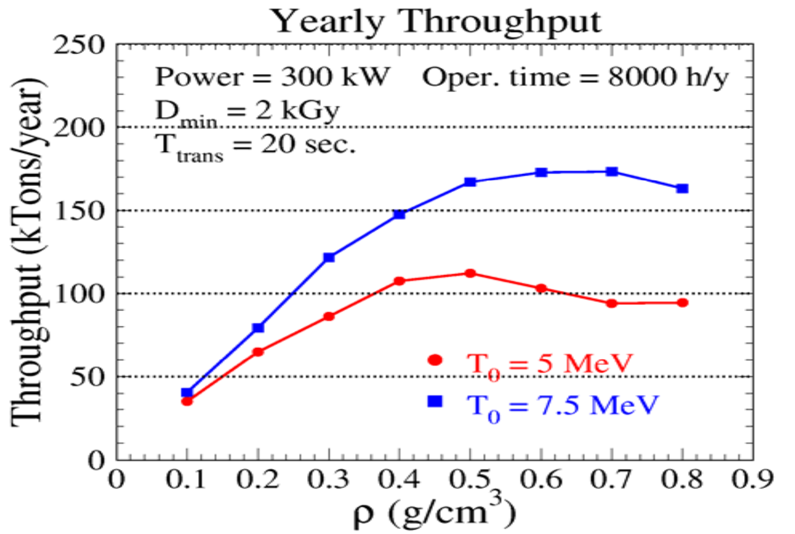
Minimal dose = 2 kGy

Transfer time between pallets = 20 seconds

Operating time = 8000 hours/year

110 kTons/year at 5 MeV for product density of 0.5 g/cm^3





Industrial Electron Accelerators

Direct Current Accelerators
  Single Gap – Extended Beam
  Multiple Gap – Scanned Beam

Microwave Linear Accelerators
  S-Band Systems
  L-Band Systems

Radio Frequency Accelerators
  Single Cavity – Single Pass
  Single Cavity – Multiple Pass

Industrial Electron Accelerators

Direct Current Accelerators

Single Gap – Extended Beam

Electron Energy – 80 keV to 300 keV
Electron Beam Power – up to 300 kW
Electron Beam Width – up to 3 m

RPC BroadBeam® Electron Beam Processor

AEB Modular EB Emitter 120 keV - 40 mA

AEB Modular Two-Emitter Assembly

Industrial Electron Accelerators

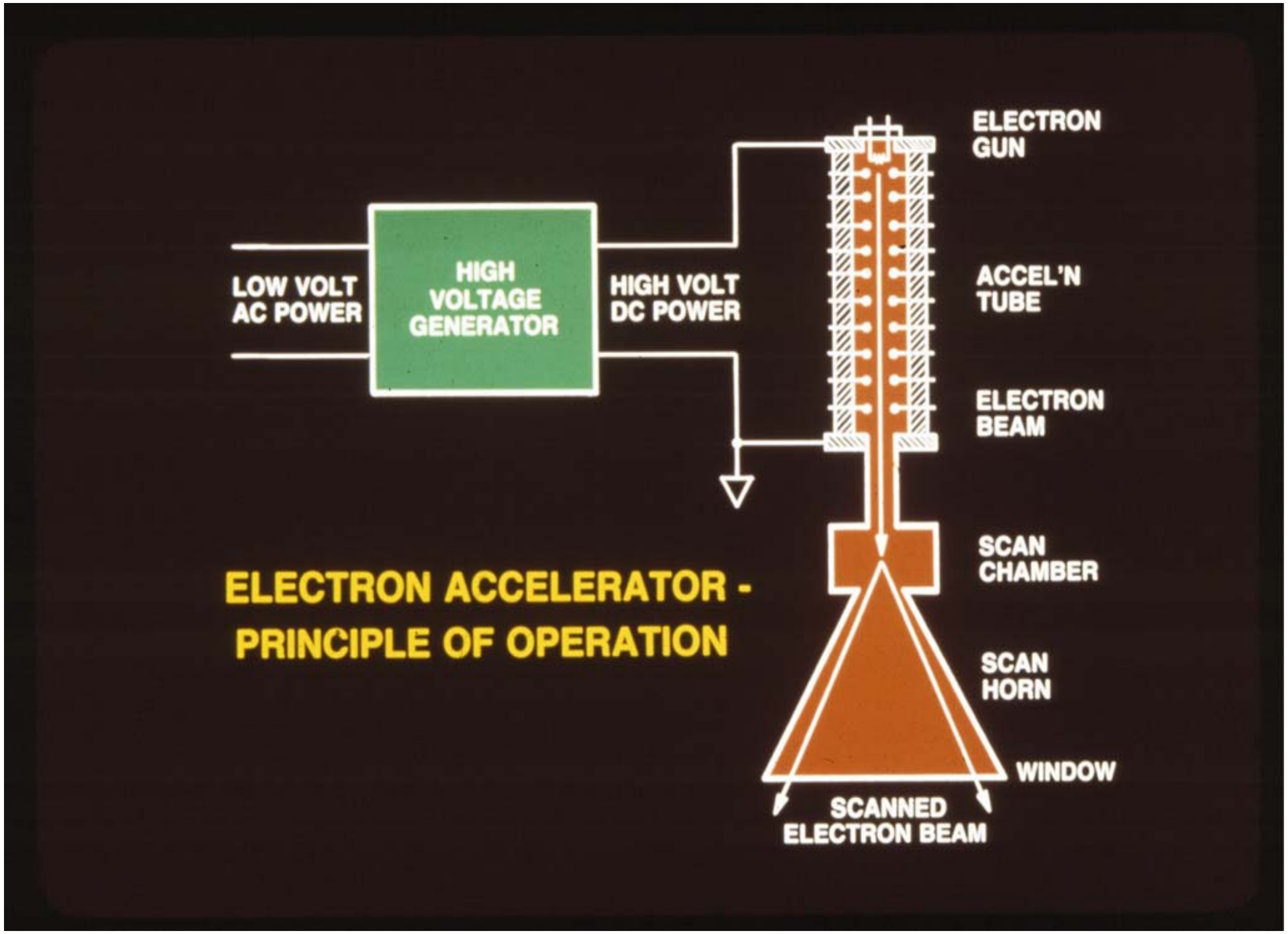
Direct Current Accelerators

Multiple Gap – Scanned Beam

Electron Energy – 300 keV to 5 MeV
Electron Beam Power – up to 300 kW
Electron Beam Width – up to 3 m

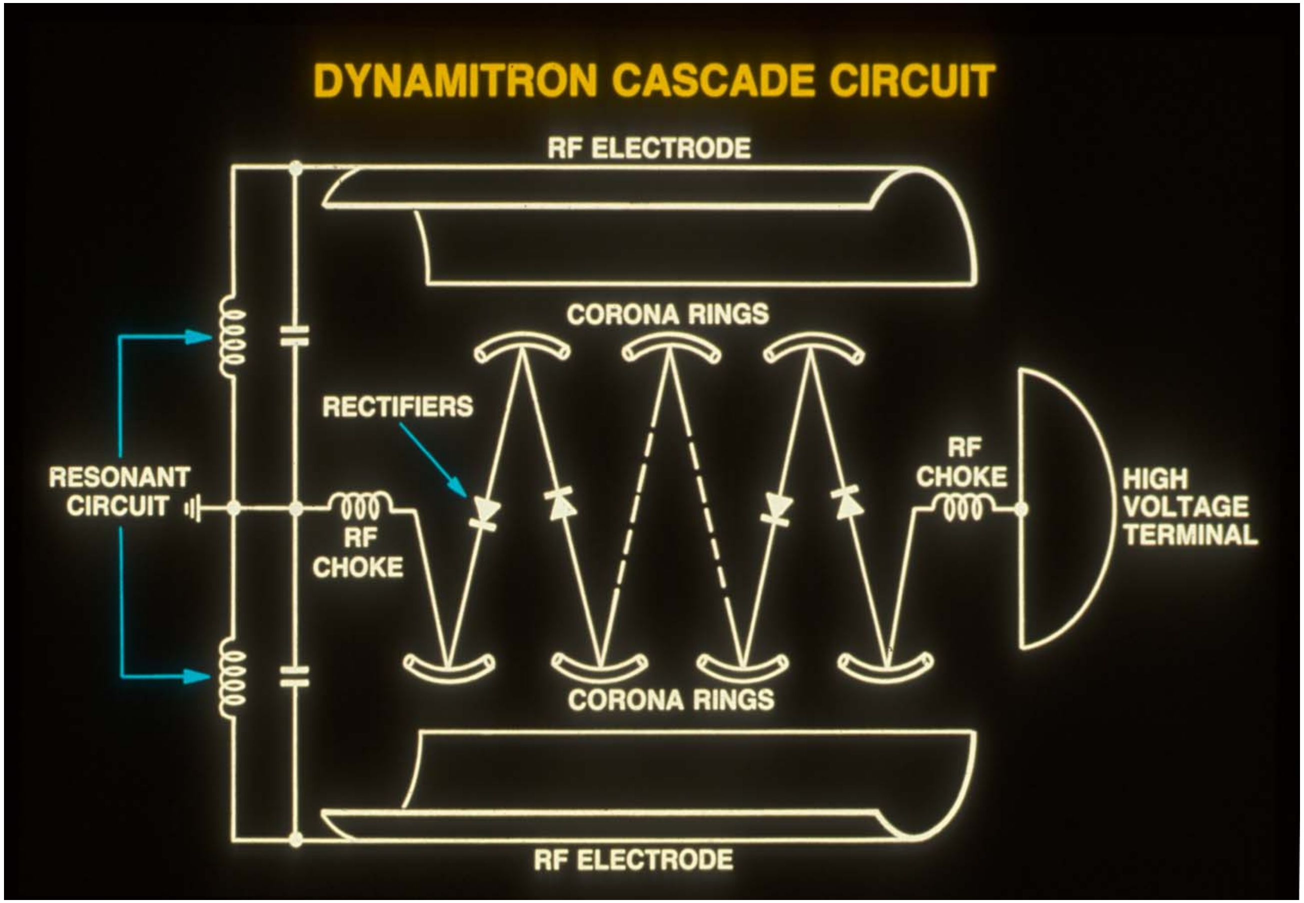
Industrial Electron Accelerators

Multiple Gap – Scanned Beam DC Accelerator



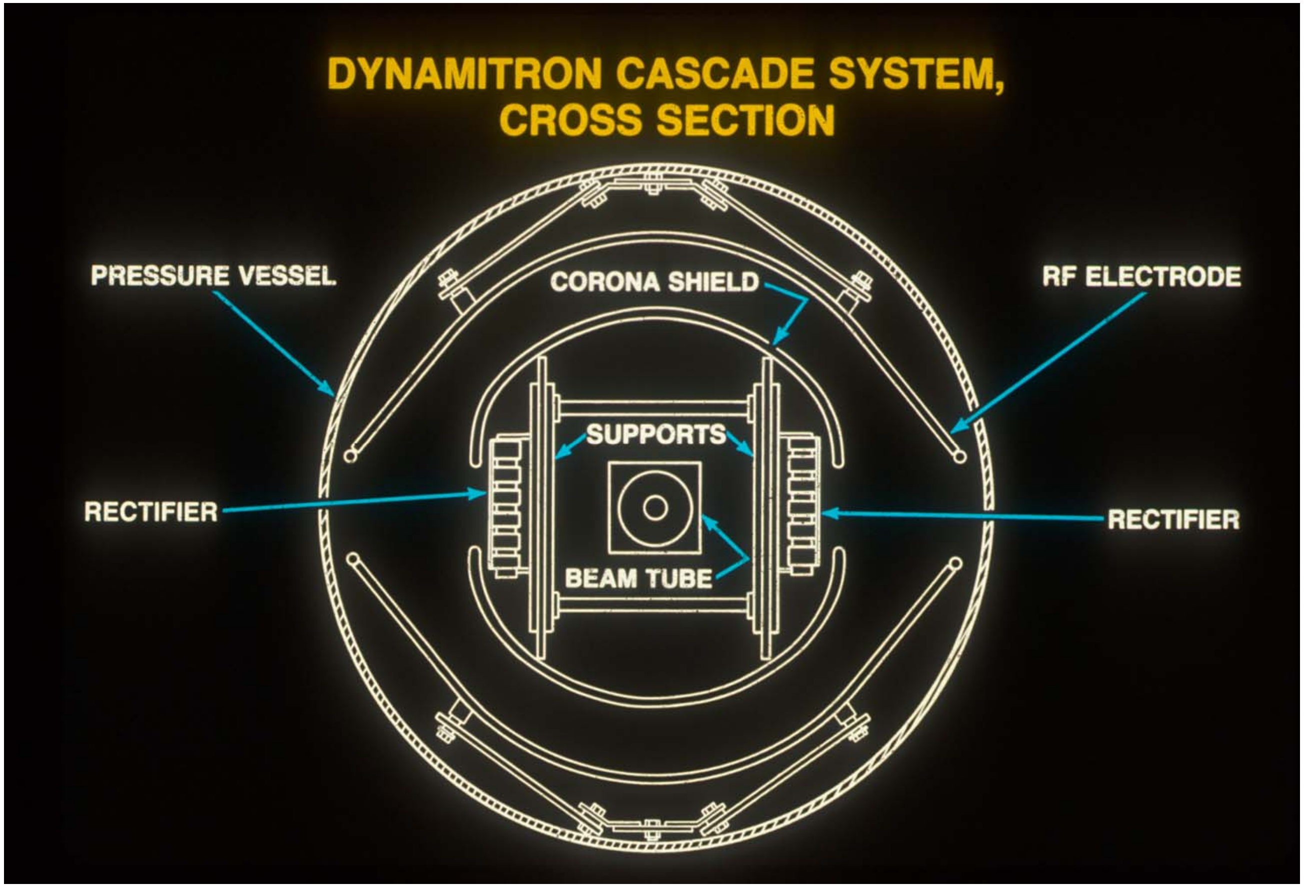
Industrial Electron Accelerators

Parallel-Coupled Capacitive Cascade Circuit

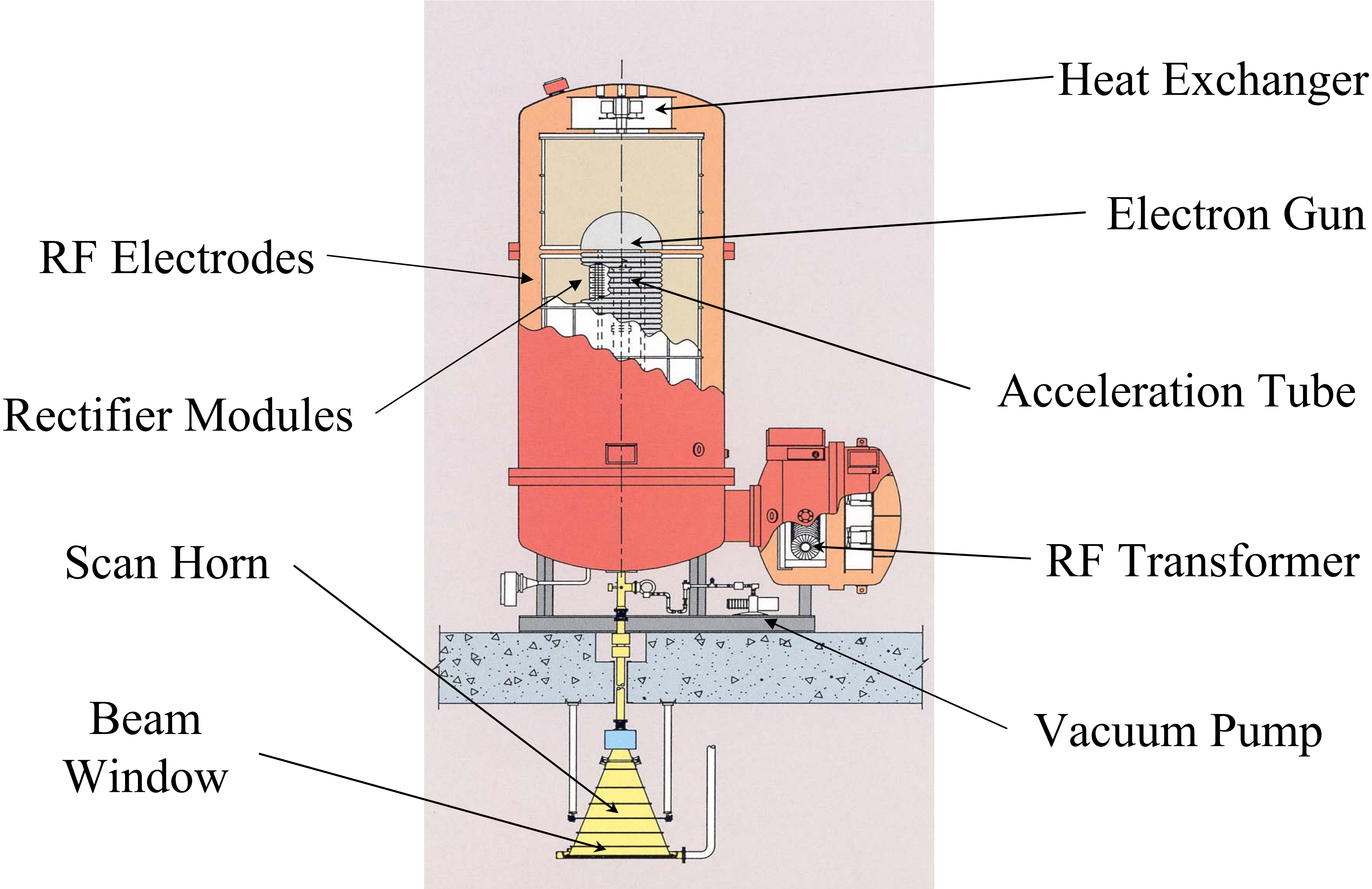


Industrial Electron Accelerators

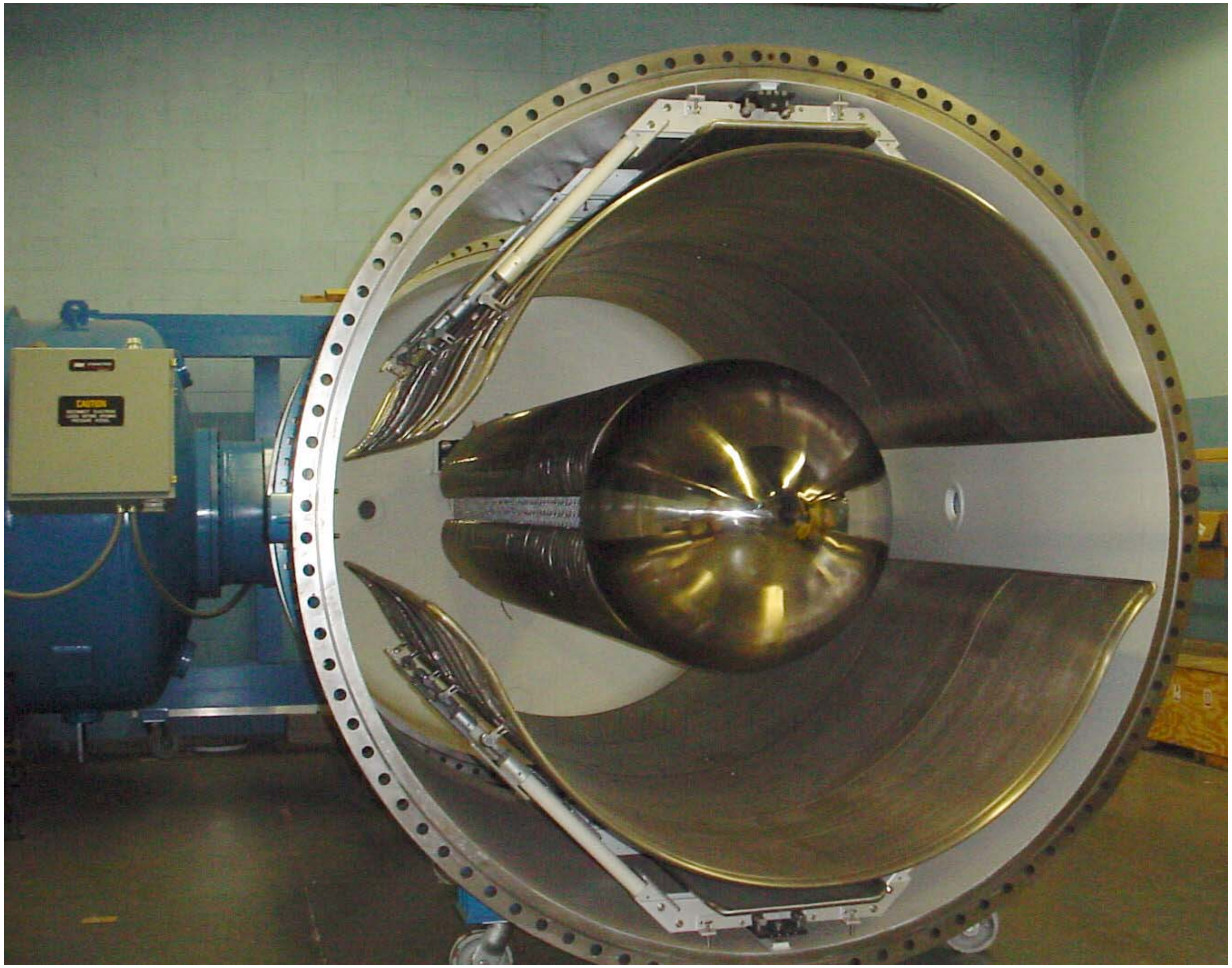
Parallel-Coupled Capacitive Cascade Circuit



RDI Dynamitron® Assembly Drawing

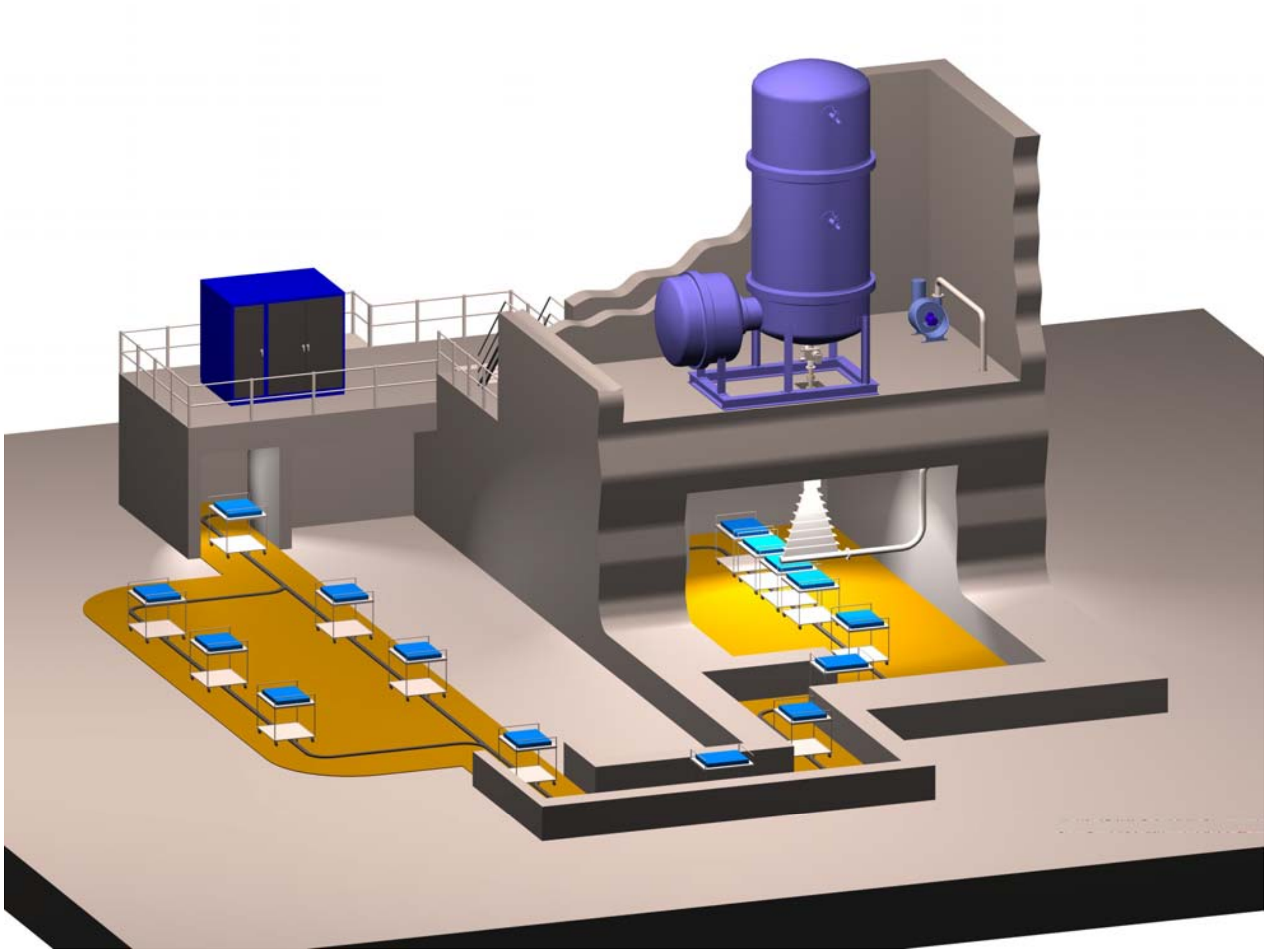


RDI Dynamitron® Assembly 5 MeV – 300 kW



RDI Dynamitron® Rectifier Column 5 MeV

RDI Dynamitron® EB Processing Facility



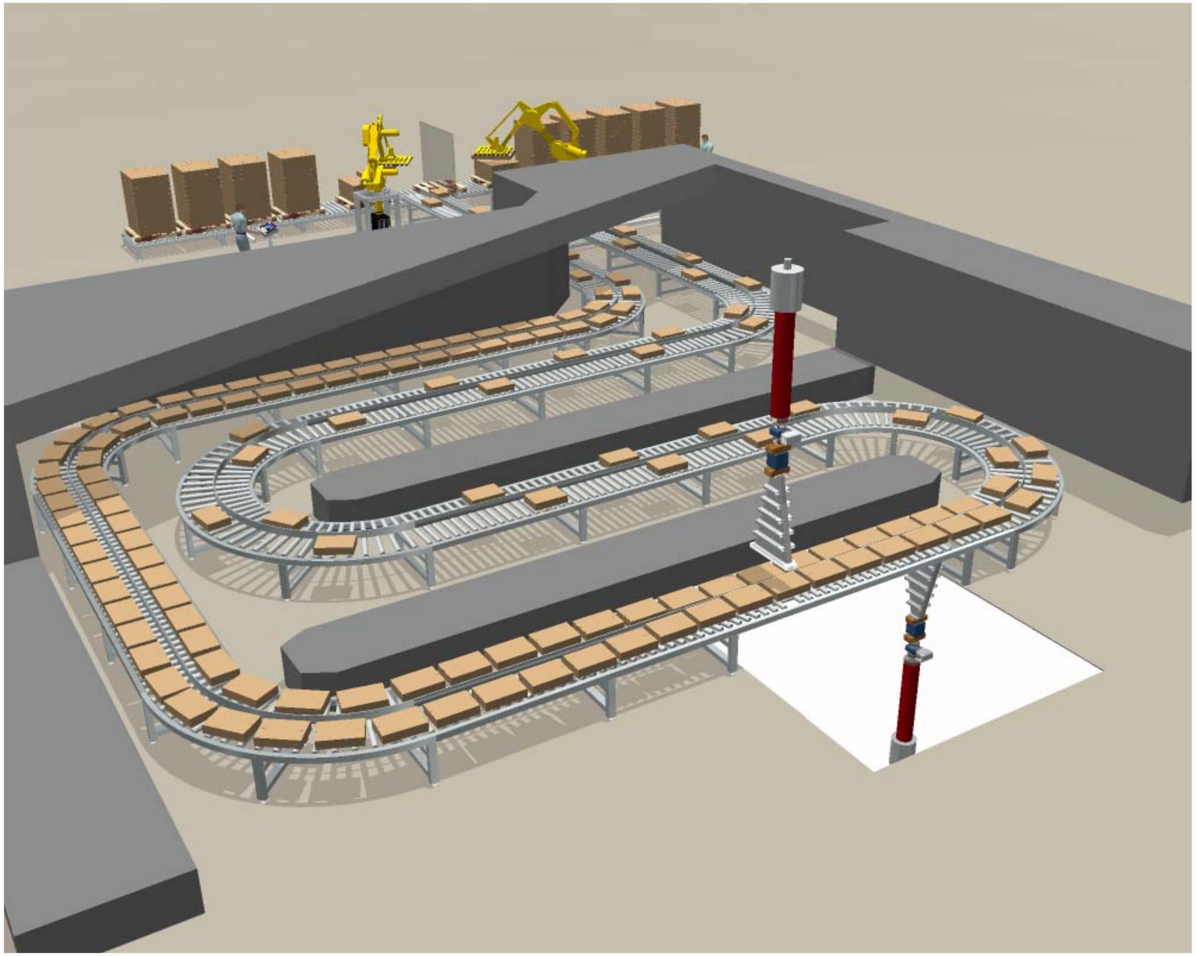
Industrial Electron Accelerators

Microwave Linear Accelerators

S-Band Systems

Microwave Frequency – 3 GHz
Electron Energy – 2 MeV to 20 MeV
Electron Beam Power – up to 20 kW
Electron Beam Width – up to 1 m

SureBeam Dual S-Band Linac EB Facility



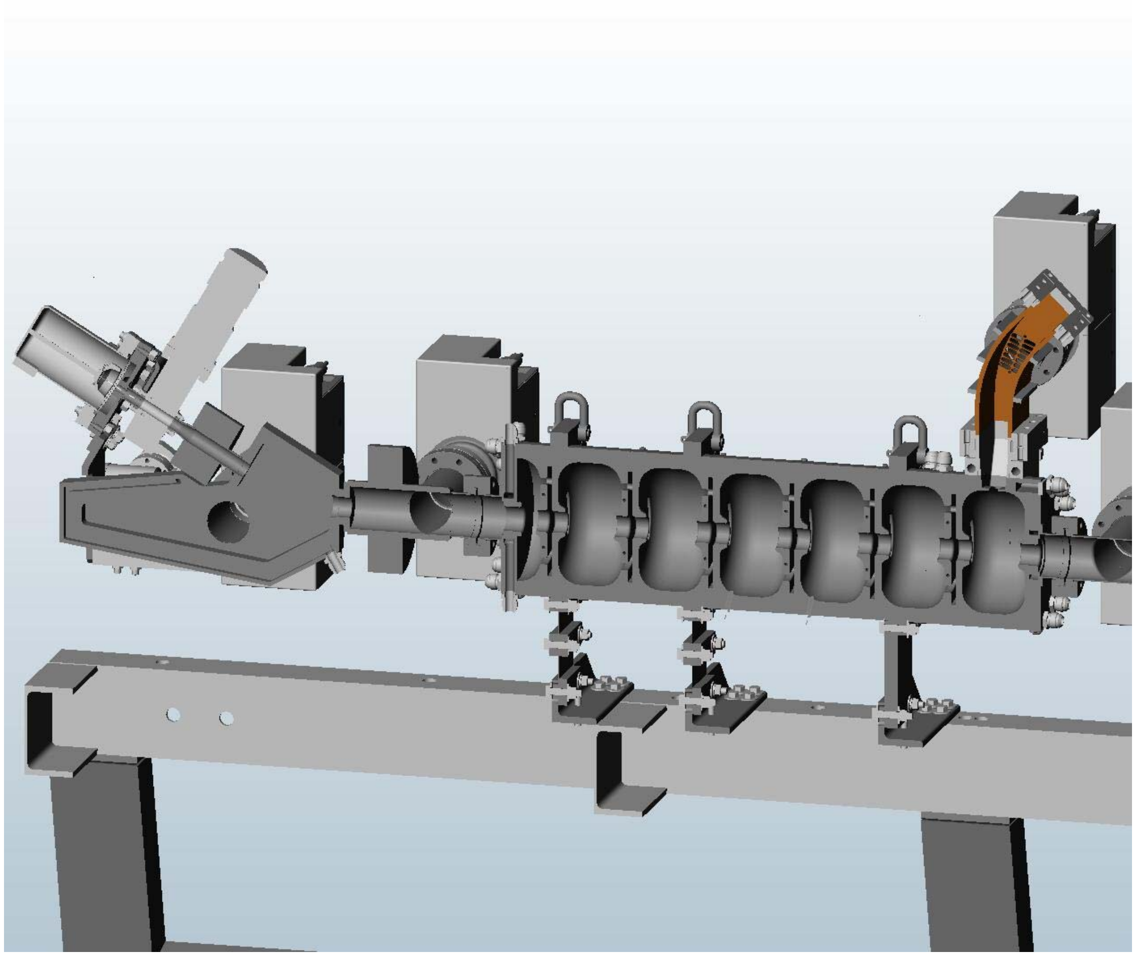
Industrial Electron Accelerators

Microwave Linear Accelerators

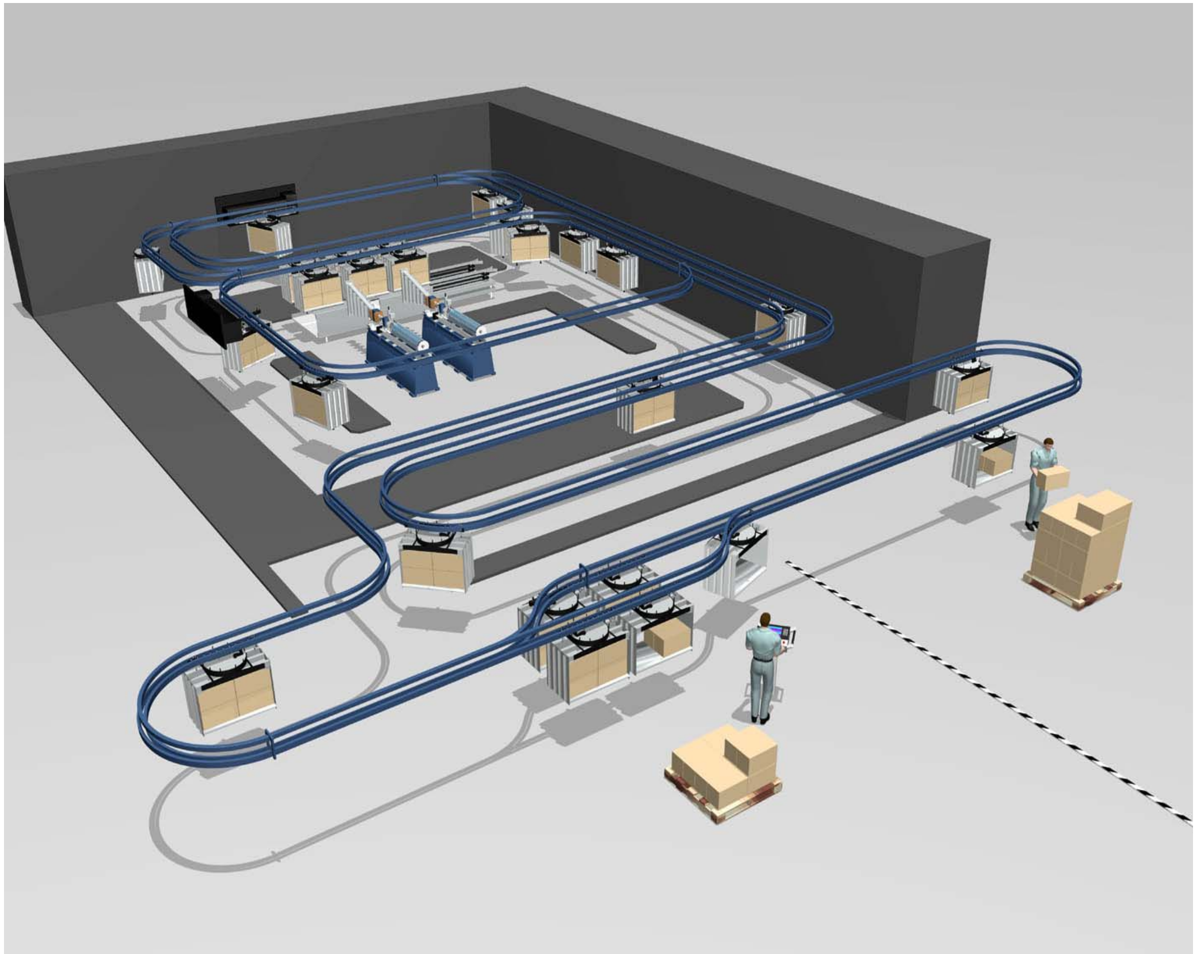
L-Band Systems

Microwave Frequency – 1.3 GHz
Electron Energy – 5 MeV to 10 MeV
Electron Beam Power – up to 80 kW
Electron Beam Width – up to 1.5 m

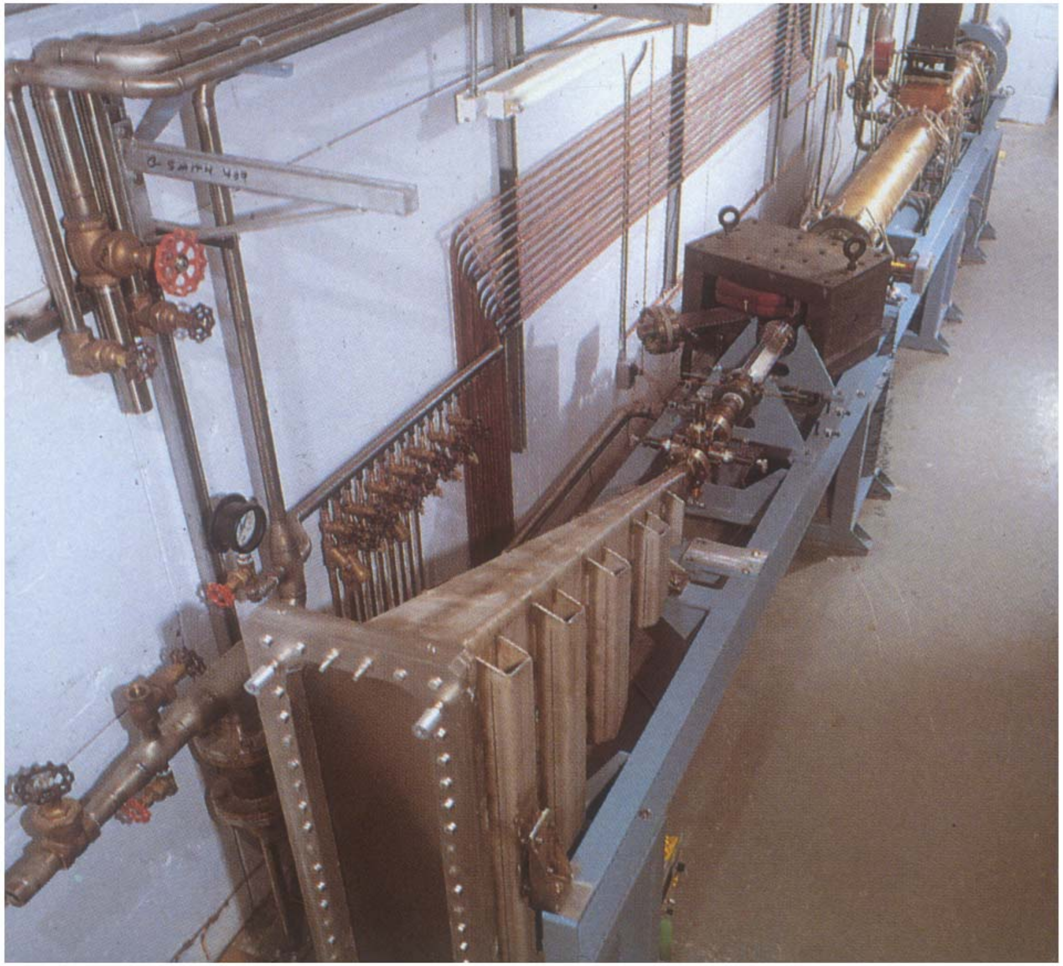
SureBeam L-Band Linac 5 MeV – 80 kW



SureBeam Dual L-Band Linac X-Ray Facility



AECL Impela® L-Band Linac 10 MeV – 60 kW



Iotron Impela® L-Band Linac EB Facility

Industrial Electron Accelerators

Radio Frequency Accelerators

Single Cavity – Single Pass Systems

Radio Frequency – 100 to 200 MHz
Electron Energy – 0.5 MeV to 4 MeV
Electron Beam Power – up to 50 kW
Electron Beam Width – up to 1 m

Industrial Electron Accelerators

Radio Frequency Accelerators

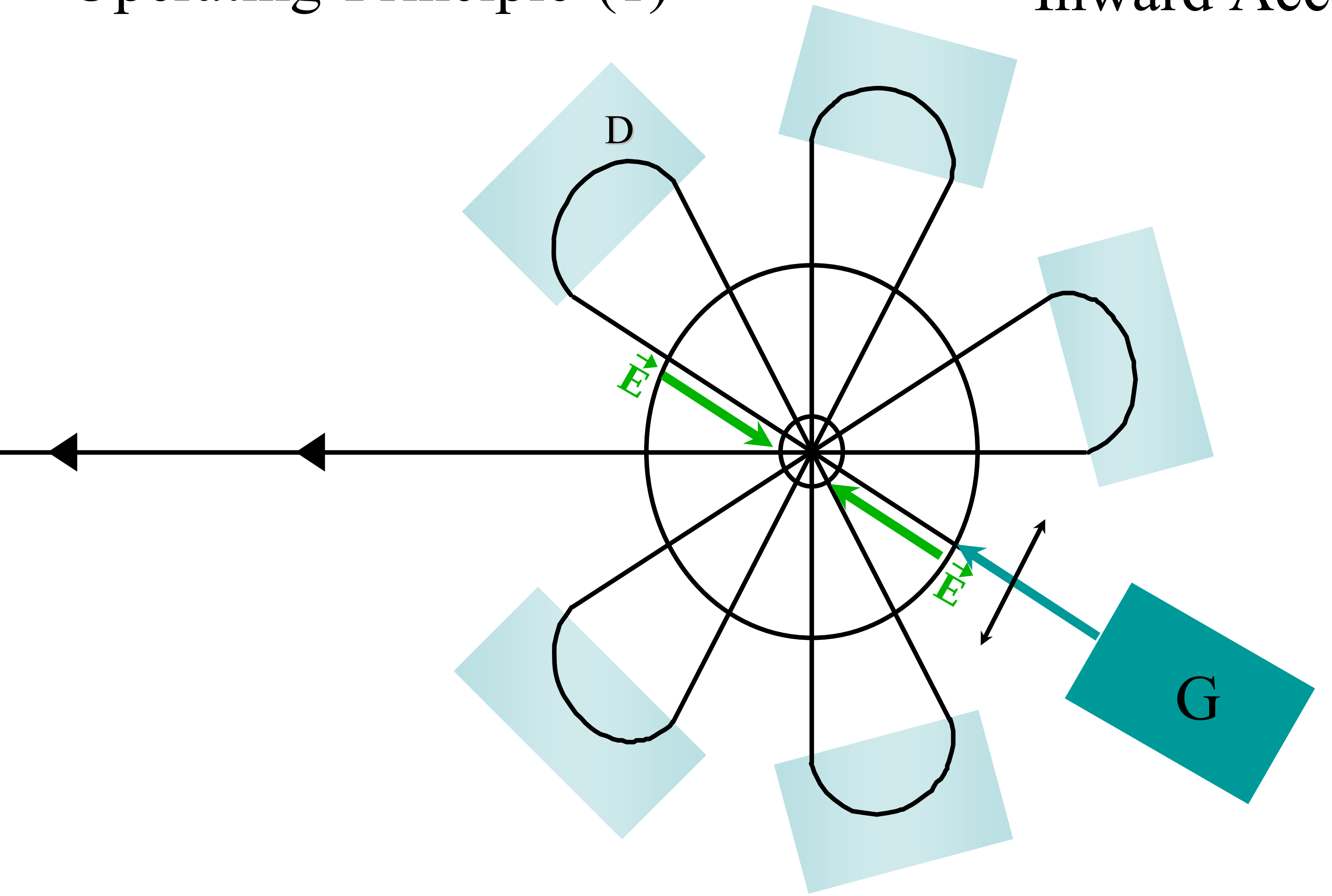
Single Cavity – Multiple Pass Systems

Radio Frequency – 107 to 215 MHz
Electron Energy – 5 MeV to 10 MeV
Electron Beam Power – up to 700 kW
Electron Beam Width – up to 2 m

IBA Rhodotron® RF Electron Accelerator

Operating Principle (1)

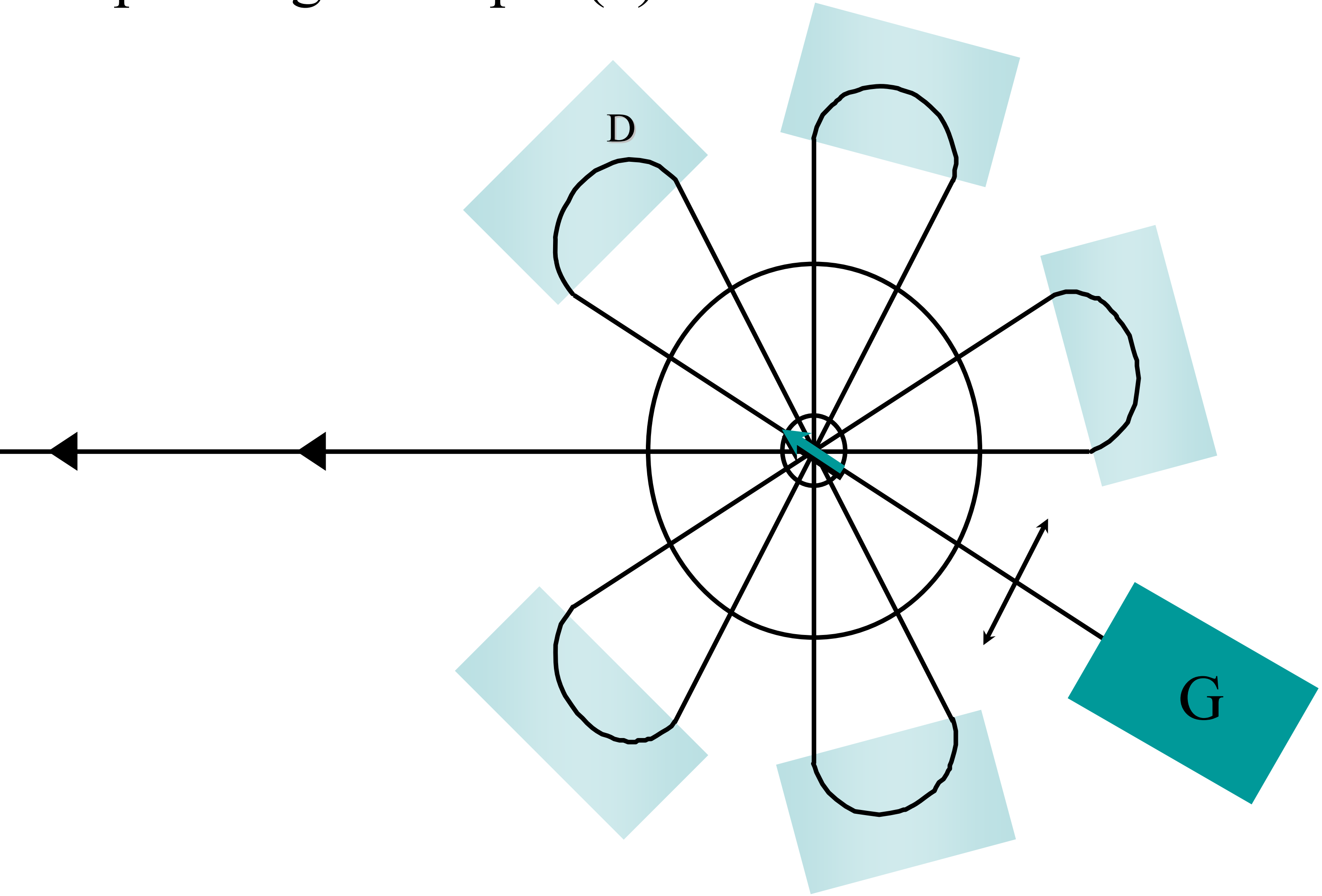
Inward Acceleration



IBA Rhodotron® RF Electron Accelerator

Operating Principle (2)

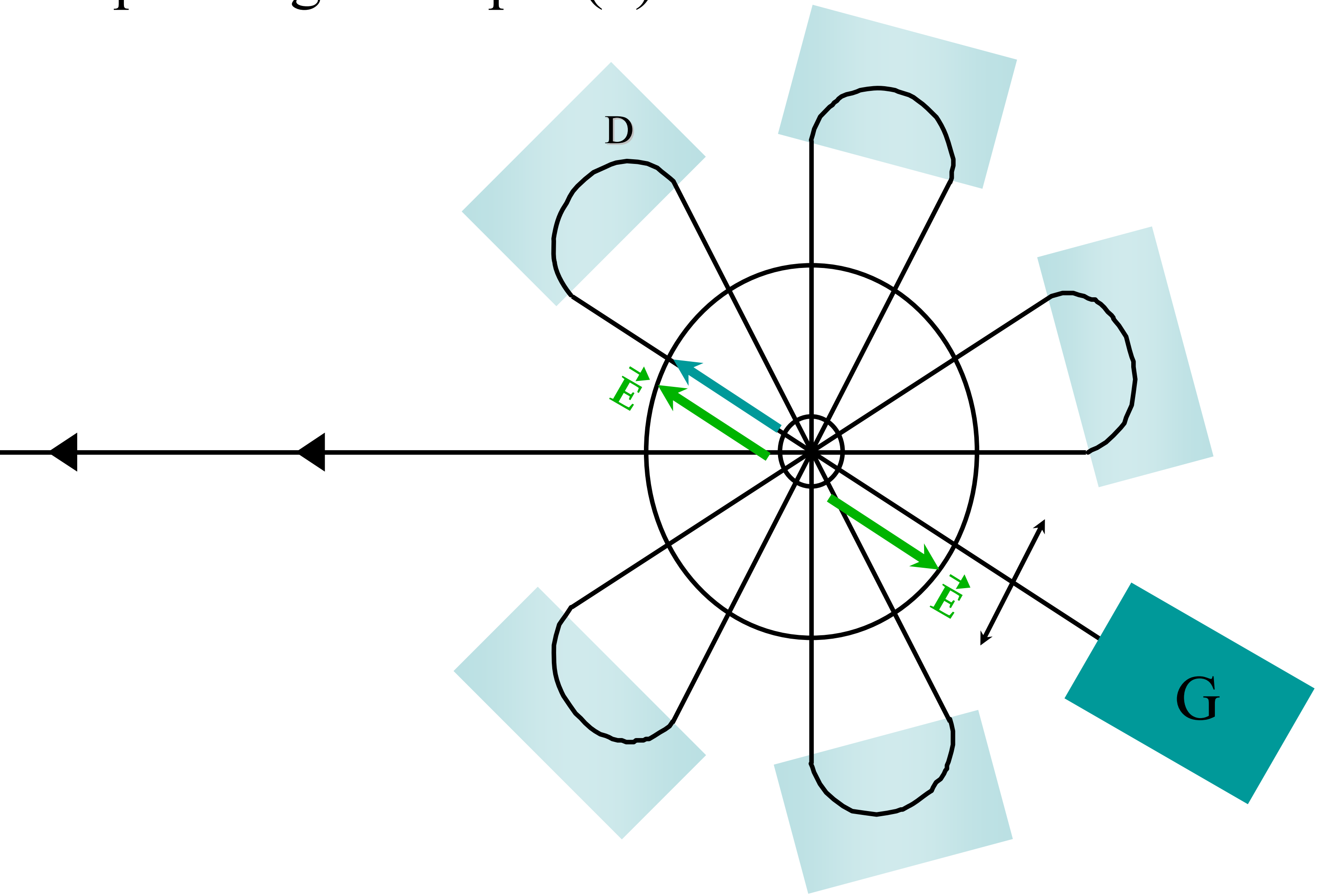
RF Field Reversal



IBA Rhodotron® RF Electron Accelerator

Operating Principle (3)

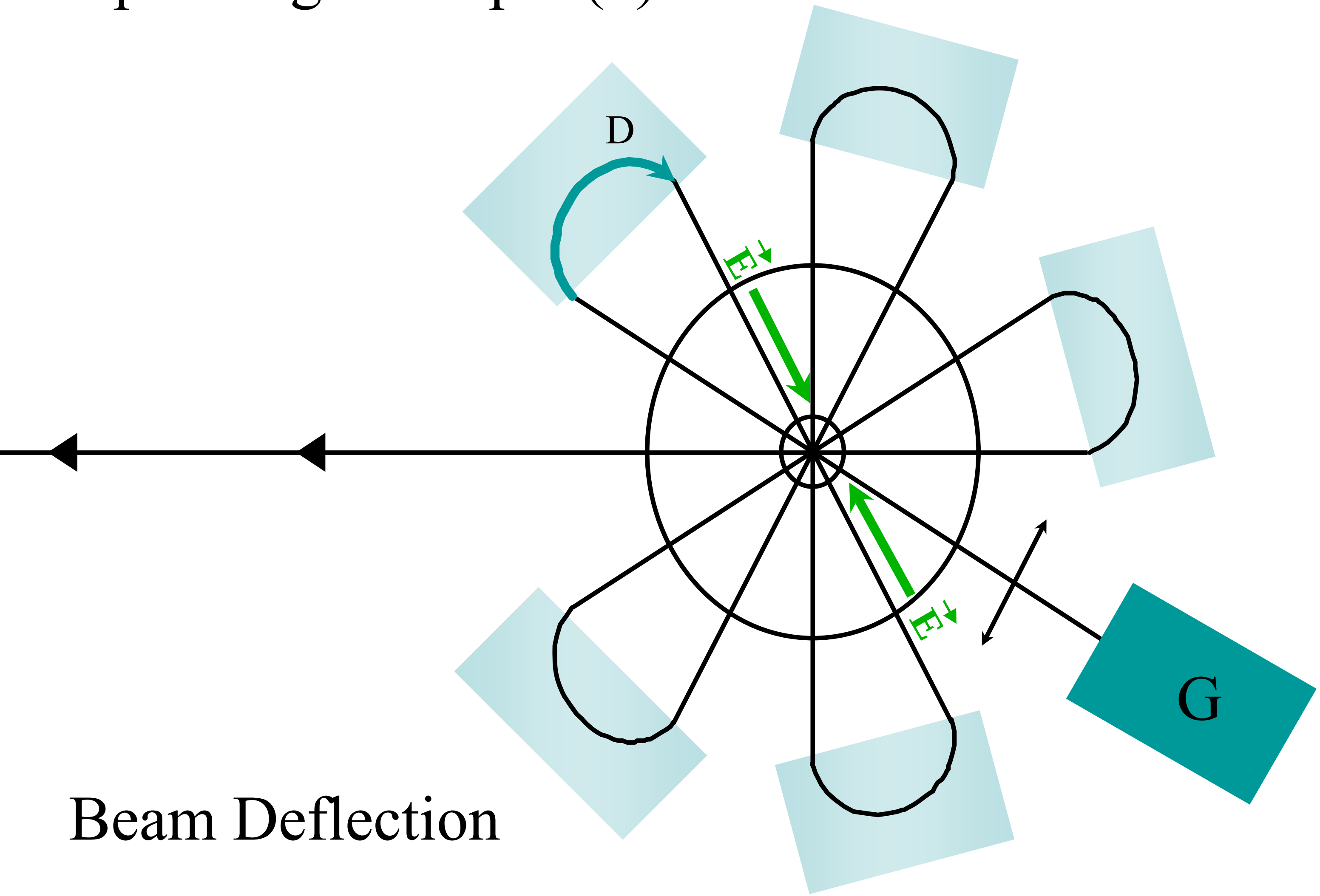
Outward Acceleration



IBA Rhodotron® RF Electron Accelerator

Operating Principle (4)

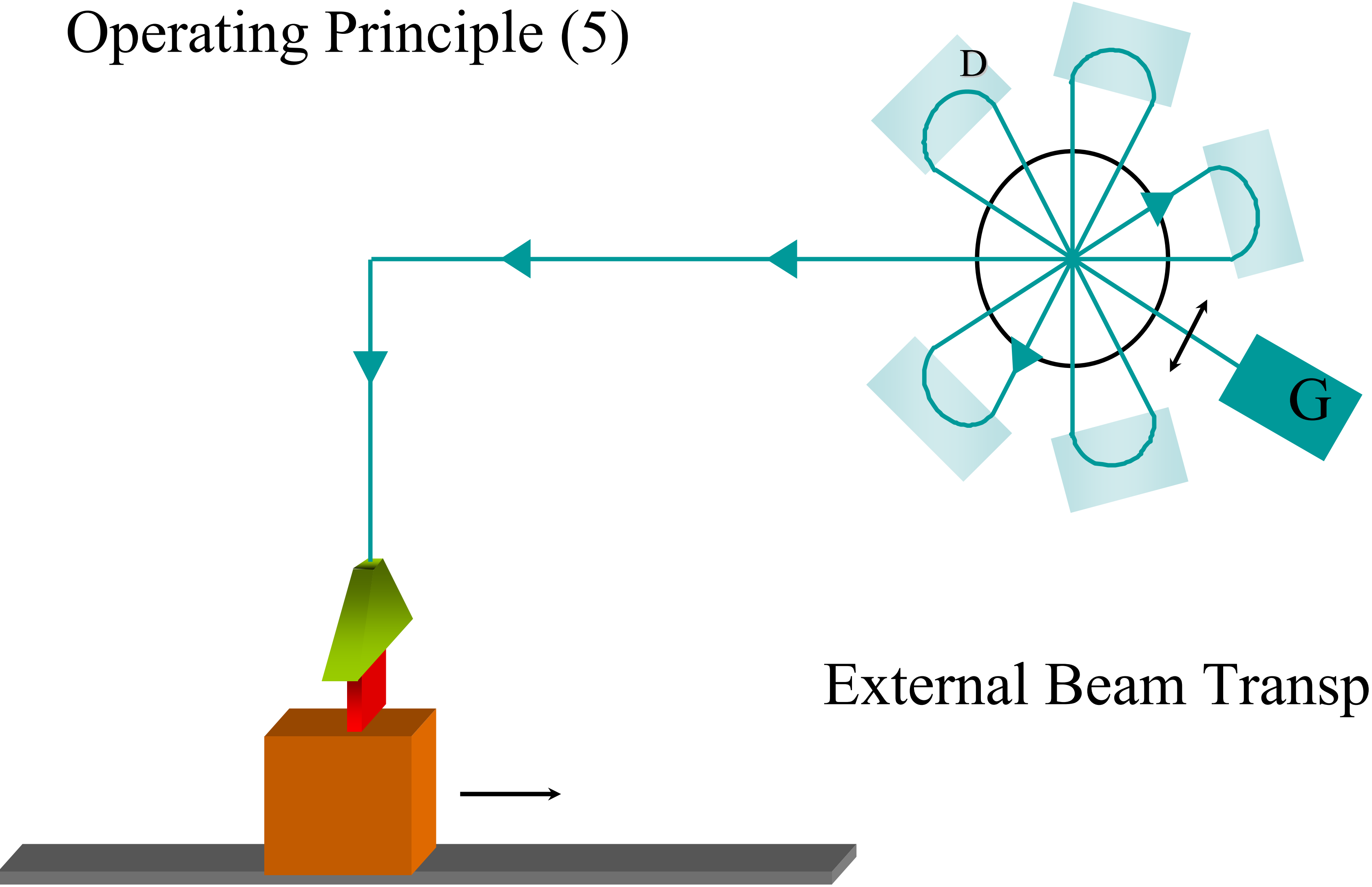
RF Field Reversal



Beam Deflection

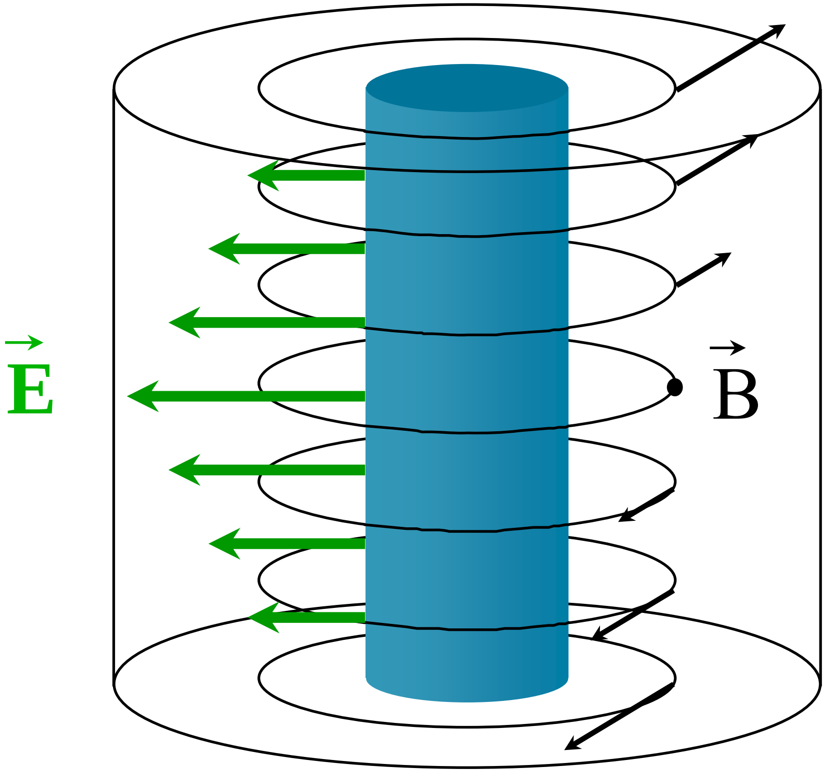
IBA Rhodotron® RF Electron Accelerator

Operating Principle (5)



External Beam Transport

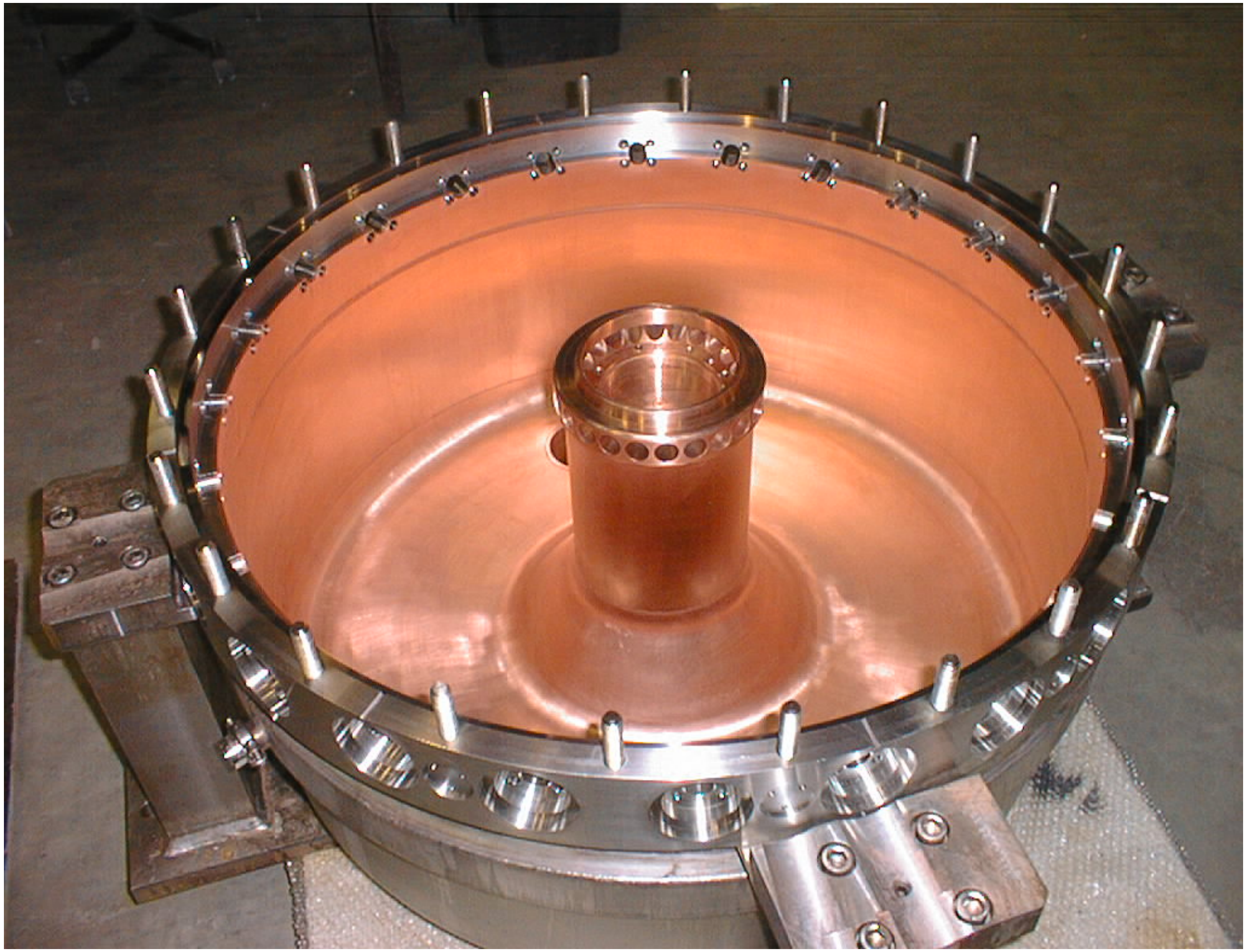
IBA Rhodotron® RF Electron Accelerator



Electric ($\vec{E}$) and magnetic ($\vec{B}$) fields in a Rhodotron coaxial cavity

IBA Rhodotron® RF Electron Accelerator

Copper Plated Steel Cavity

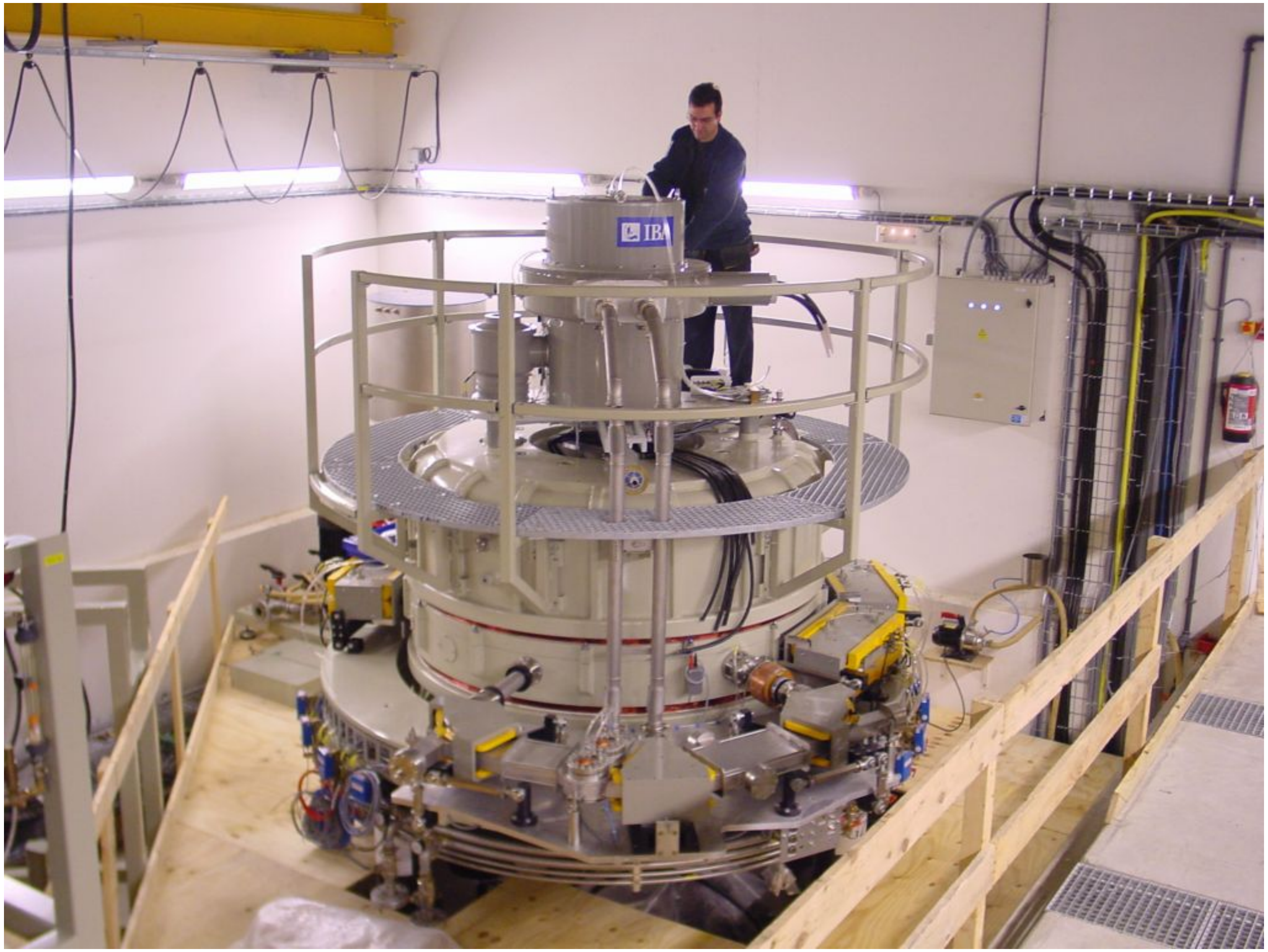


IBA Rhodotron® RF Electron Accelerator

Assembly of Beam Reversing Magnets

IBA Rhodotron® RF Electron Accelerator

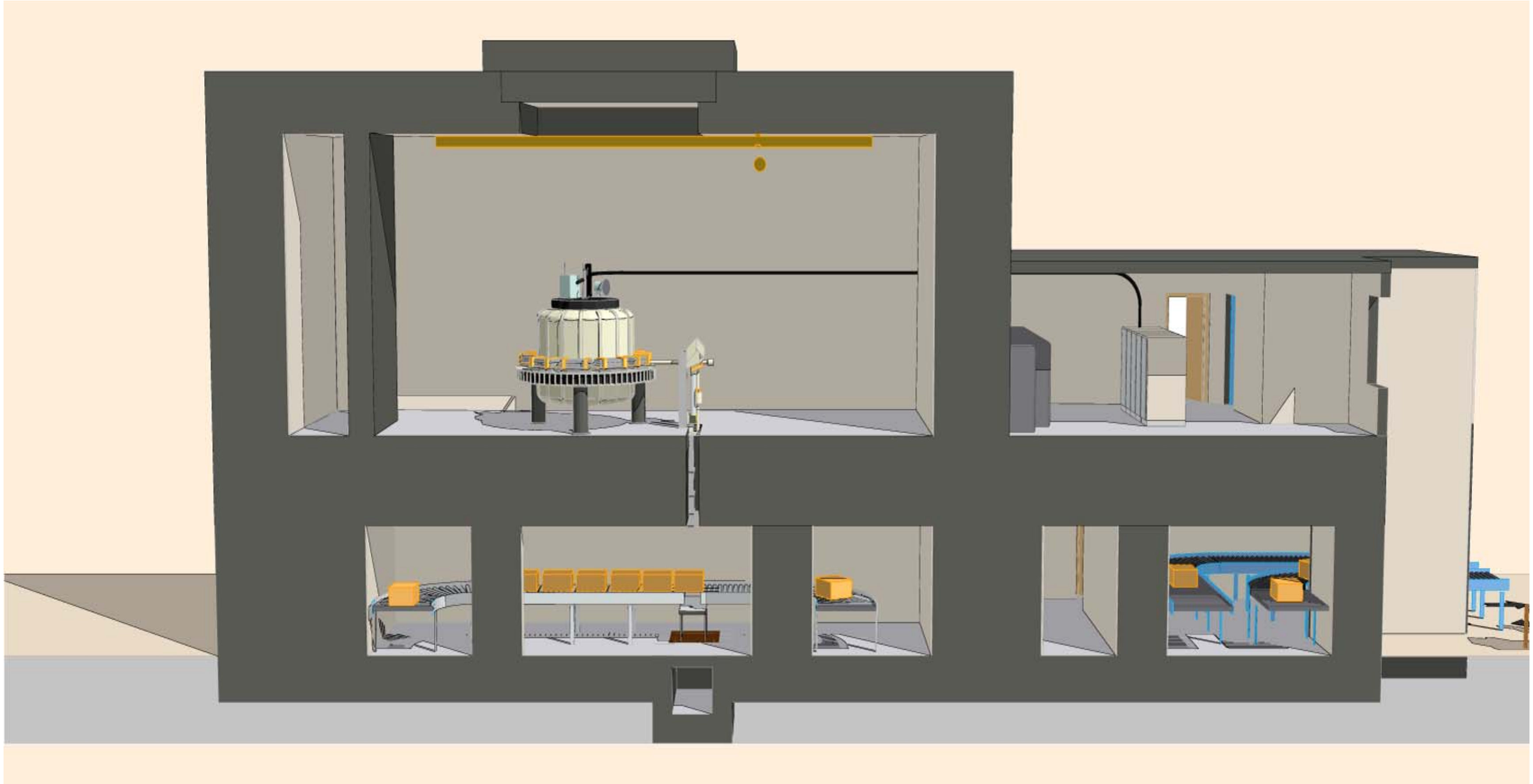
Model TT1000 7 MeV – 100 mA – 700 kW



IBA Rhodotron® Specifications

	TT100	**TT200**	**TT300**	**TT1000**
Energy (MeV)	3-10	3-1	3-10	5 – 7.5
Power range at 10 MeV (kW)	1-3	1-8	1-150	NA
at 5 MeV (kW)	1-18	1-80	1-135	1 - 500
at 7 MeV (kW)	1-25	1-80	1-150	1 - 700
Design Value (kW)	45	100	> 200	> 800
Full (cavity) diameter (m)	1.60 (1.05)	3.00 (2.00)	3.00 (2.00)	3.00 (2.00)
Full (cavity) height (m)	1.75 (0.75)	2.40 (1.80)	2.40 (1.80)	3.40 (1.80)
Weight (T)	2.5	11	11	11
MeV/pass	0.83	1.0	1.0	0.83 – 1.5
Number of passes	12	10	10	6
Stand-by kW used	< 15	< 15	< 15	<25
Full beam kW used	< 21	< 260	< 370	<1000 @500 kW <1400 @750 kW

IBA Rhodotron EB Processing Facility



Industrial Applications of Electron Accelerators

Conclusion

Ideas about how to accelerate atomic particles to high energies originated about 75 years ago. The motivation then was to investigate the structure of atomic nuclei.

Those early concepts have evolved into very complex accelerator technologies, which have many practical applications outside the field of nuclear physics.

Industrial Applications of Electron Accelerators

Conclusion

Radiation processing of materials and commercial products is one of those offshoots. It is a diverse field that has justified constructing over 1000 industrial electron beam irradiation facilities.

Some of the emerging applications, such as food irradiation and reduction of environmental pollution, offer the prospects of significant benefits to human health and wellfare.