Prospects and Challenges for the Industrial Use of Electron Beam Accelerators

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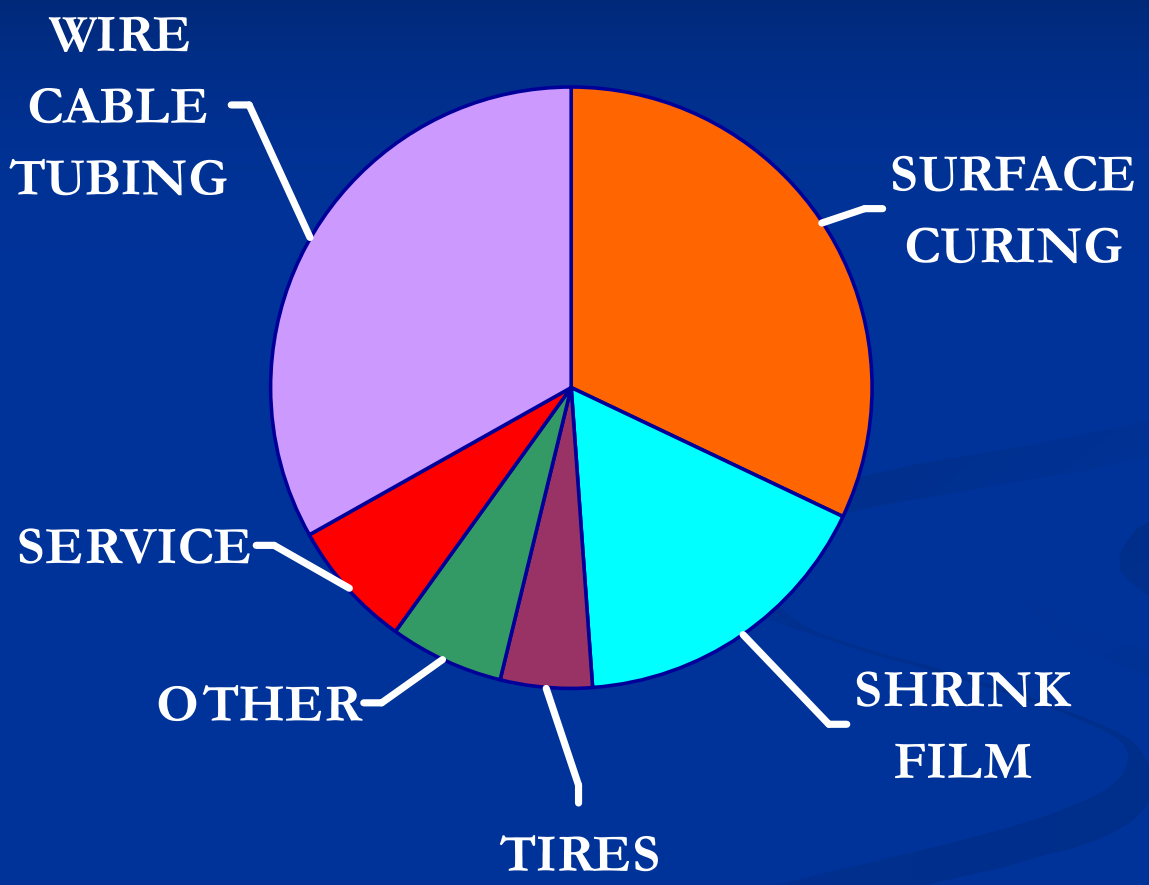
Industrial Electron Beam Markets



>1400 high current EB manufacturing installations

EB Market Segments Require Different Energies

Market Segment	Electron Energy	Typical Penetration
Surface Curing	80 – 300 keV	0.4 mm
Shrink Film	300 – 800 keV	2 mm
Wire & Cable	0.4 – 3 MeV	5 mm
Sterilization	3 –10 MeV	38 mm

Industrial EB Processing Demands Beam Current

$$\text{Dose} = \frac{k \times \text{current}}{\text{line speed}}$$

k = proportionality factor

Product through-put dependent upon beam current

EB Equipment Development

Coolidge (GE) – 1920s

Westendorp (GE) – 1940s

Van de Graaff and

Emanuelson (HVE) – 1960s

Cleland (RDI/IBA) – 1960s

Jongen and Abs (IBA) – 1990s

Low-energy EB Equipment Development

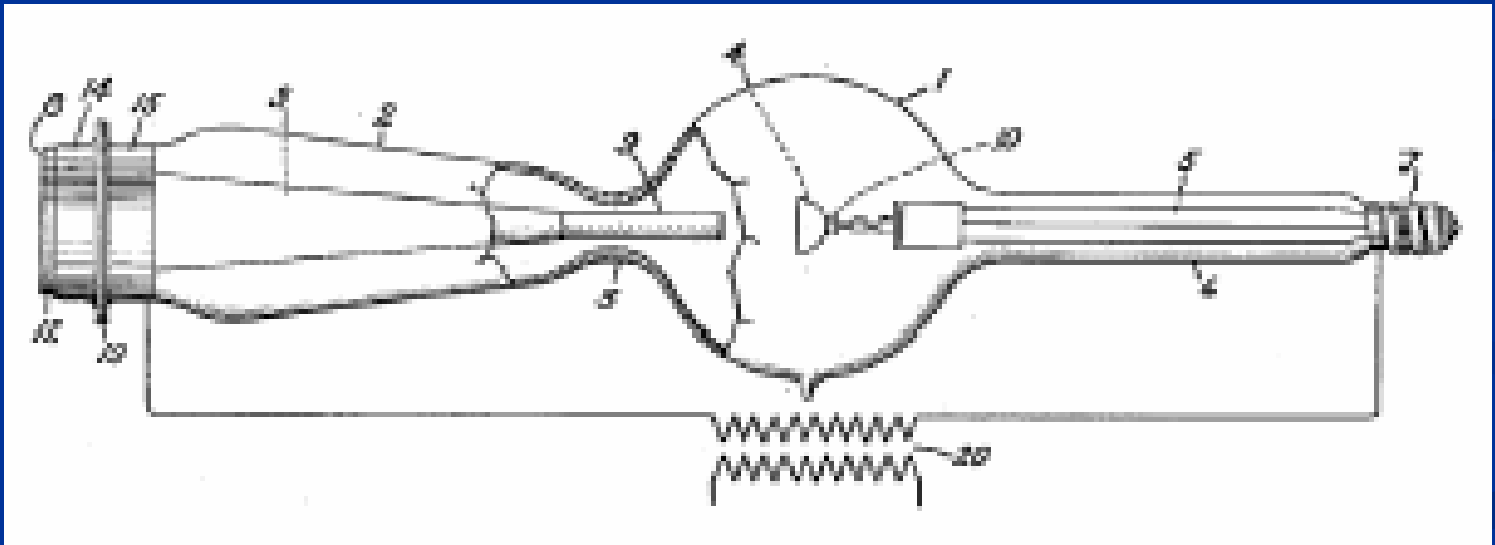
Quintal and Nablo (ESI) – 1970s

Farrell (RPC/PCT) – 1970s

Avnery (AEB) – 1990s

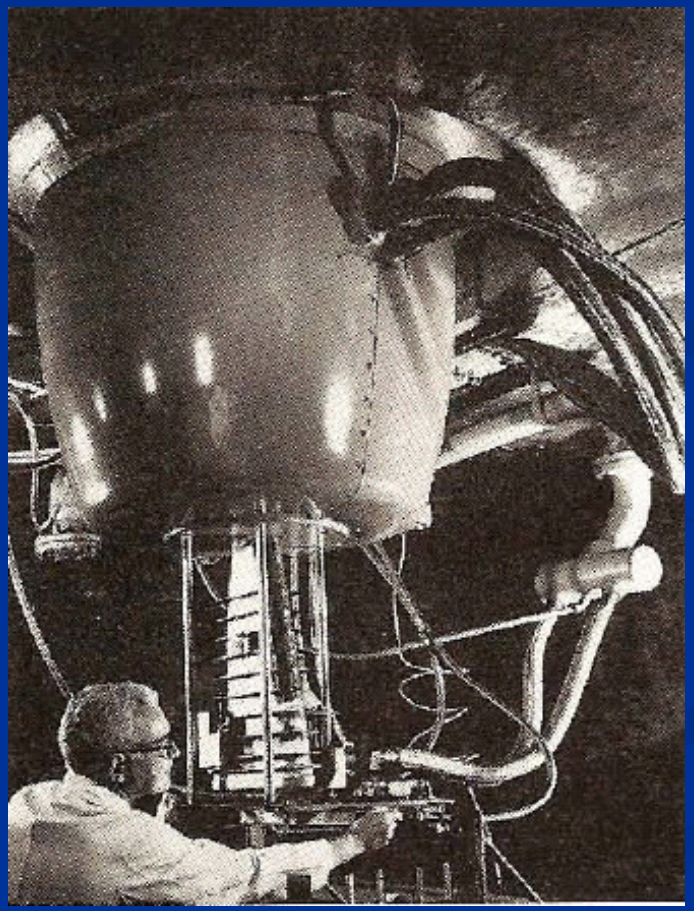
EB Equipment Development

Coolidge's Electron Tube with Foil Window
First External Beam Electron Accelerator



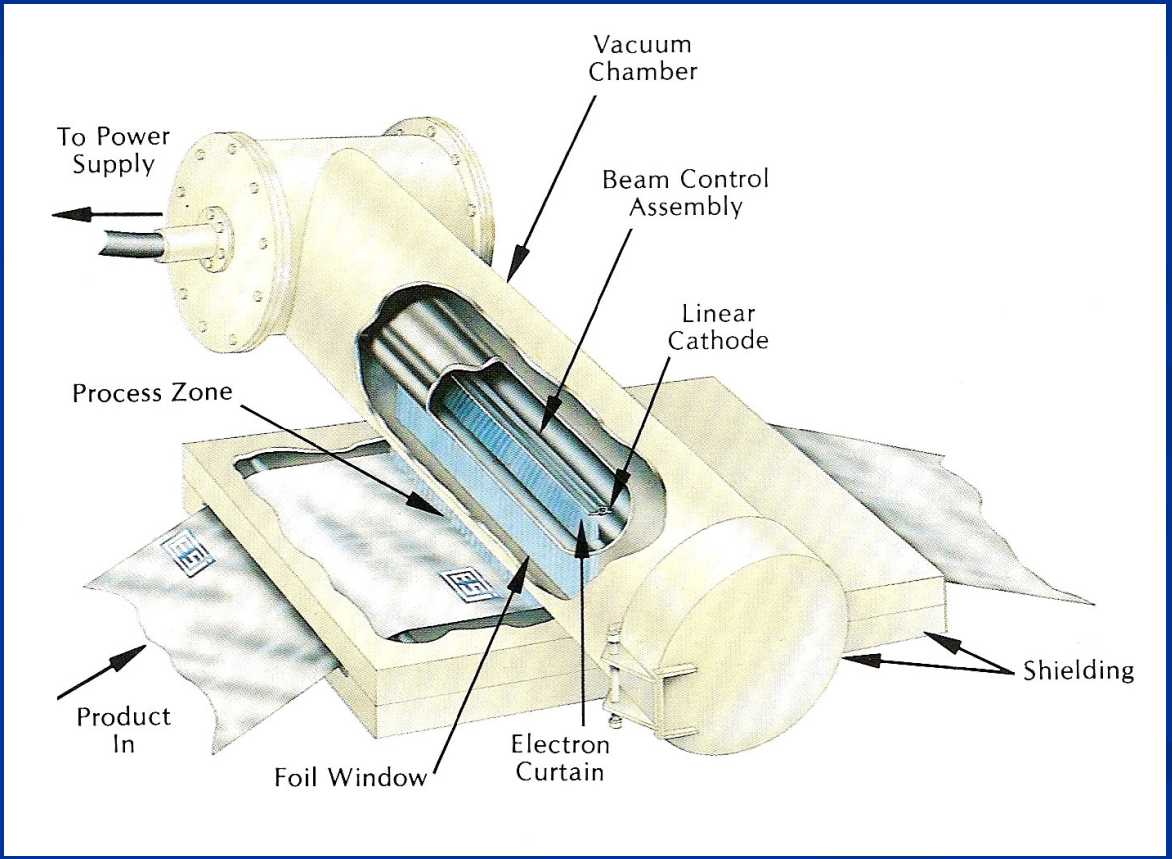
EB Equipment Development

Raychem 1957 Use of GE Resonant Transformer



EB Equipment Development

Low-energy ESI Unit



EB Processing in Industry

Arthur Charlesby

EB Processing in Industry

Paul Cook establishes Raytherm (1957) and then the Raychem Corporation (1960) now Tyco Electronics = greatest kW EB capacity, used for wire and heat shrinkable products.

Bill Baird visits Cook and then develops the Cryovac process for manufacture of heat shrinkable food packaging films (1958) = greatest number of EB units in production.

EB Processing in Industry

Paul Cook – July 2007

Heat Shinkable Tubing

Used to cover/protect wire and cable splices

EB Processing in Industry

Cryovac 500 keV Self-shielded Unit

Heat Shrinkable Food Packaging

10 EB units in one factory used to crosslink heat shrinkable film

EB Processing in Industry

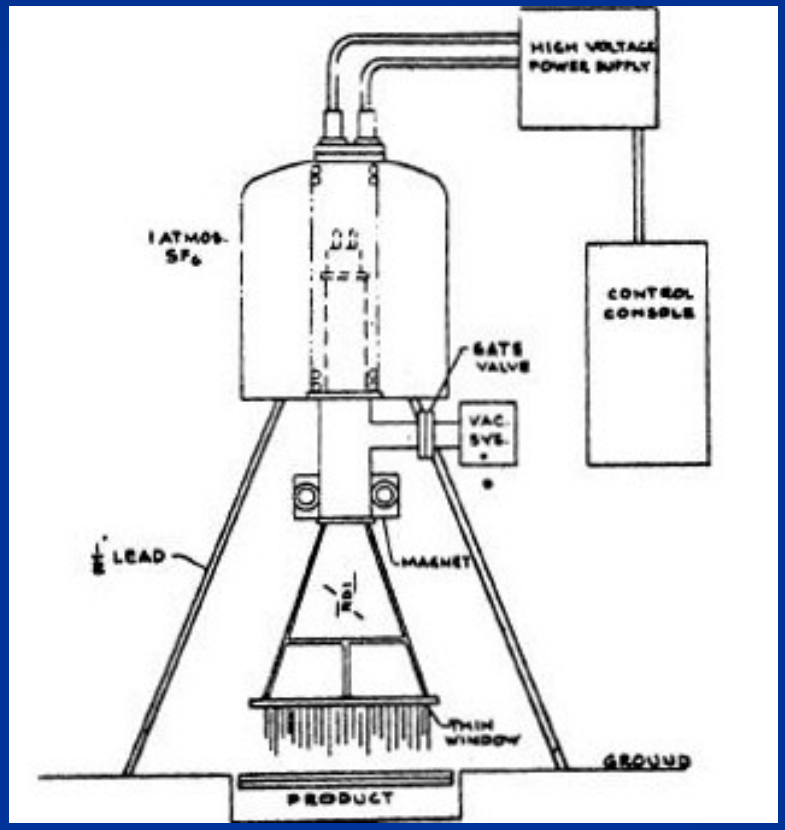
Low-energy Applications

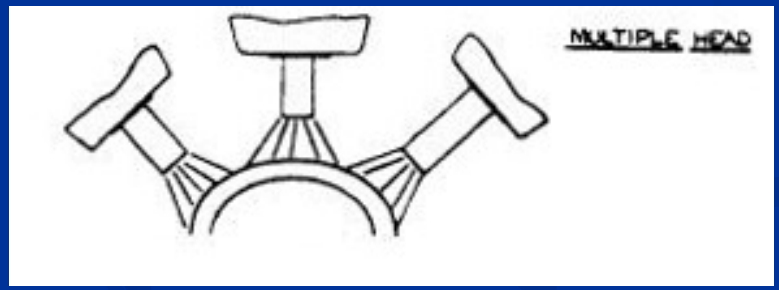
Bill Burlant at Ford uses low-energy EB to cure automotive coatings (1960s). Ford EB curing decorative coatings on plastic parts at ~10^7 pieces/year in early 1970s.

Dan Carlick at Sun Chemical pioneers UV/EB curable inks (1970s).

EB Processing in Industry

RDI Low-energy Cable Connected Dynacote™ EB





Multiple Scanned Beams

EB Economic and Environmental Impact

+ Many diverse, profitable end-use applications
+ Efficient manufacturing adds product value
+ EB is a very efficient means of energy transfer
+ Elimination of volatile organic compounds (VOCs) enhances air quality and reduces greenhouse gas emissions

EB Pollution Prevention

Low-energy Applications

System:	Solvent	EB Curable
Coating solids:	60%	100%
Dried coating, g/m^2:	20 g	20 g
VOCs/m^2, grams: (0.9 density solvent)	12 g	0 g
CO_2 from solvent/fuel: (solvent incineration)	37 g/m^2	none

EB Energy Efficiency

Low-energy Applications

System:	Solvent	EB Curable
Coating solids:	60%	100%
Energy to dry, kJ/m^2: (solvent = 27.3 kJ/g; EB output = 70% input; dose = 30 kGy)	328 kJ	0.86 kJ
Energy, watt-hours per square meter:	91 w-h	0.24 w-h

Equipment Trends

+ Down-sizing of low-energy EB accelerators

+ Development of high-power EB accelerators making X-ray conversion practical

Low-energy EB Downsizing

Advanced Electron Beams
Application Development Unit

Low-energy EB Downsizing

Advanced Electron Beams
Two-module Pilot Line Beams

Low-energy EB Downsizing

Energy Sciences Incorporated
EZ-Cure III™ Accelerator

Low-energy EB Downsizing

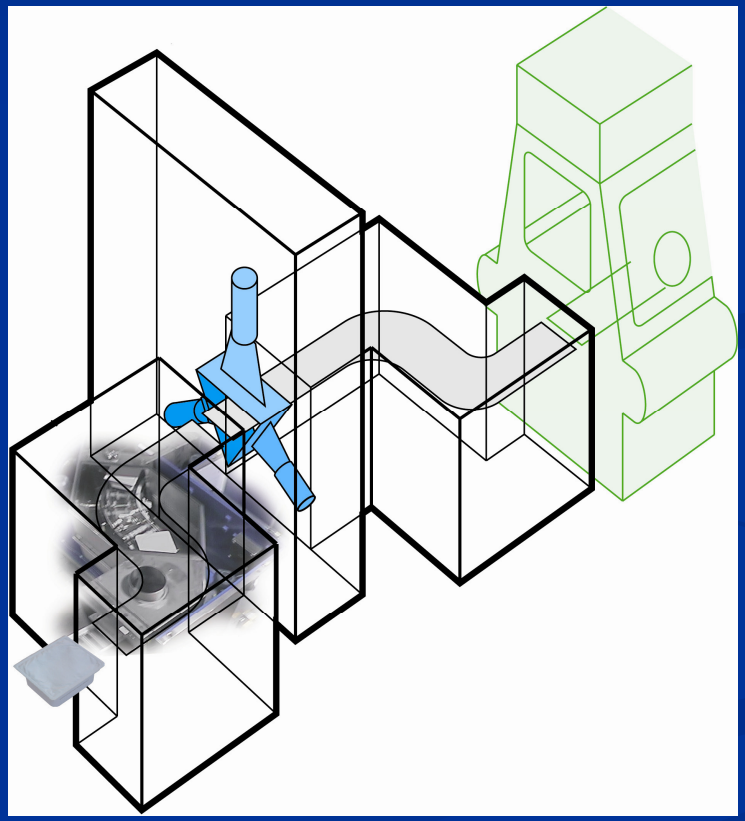
PCT Engineered Systems
Broadbeam™ LE Series

Low-energy EB Downsizing

Getinge Linac STERSTAR™ System

Low-energy EB Downsizing

Getinge Linac STERSTAR System Schematic



Low-energy EB Downsizing

Major New End-use Application

+ Surface decontamination of substrate materials before entering aseptic packaging

Concerns:

- Determination of bioburden
- Low-energy dosimetry

Mid-energy EB Downsizing

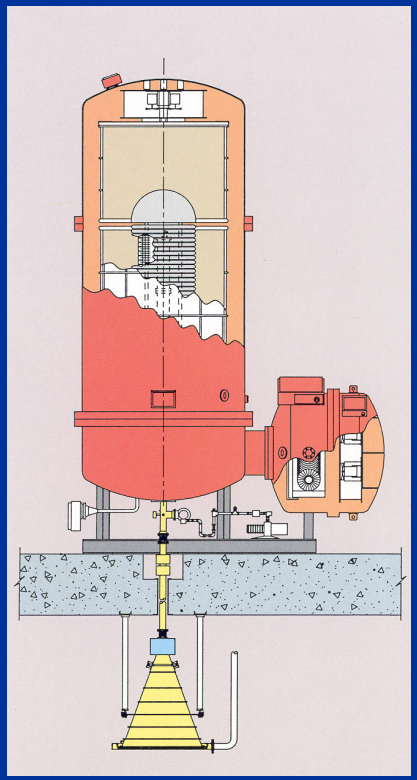
IBA Industrial Incorporated Easy-e-Beam™

800 keV, 100 ma

Development of High-power EB

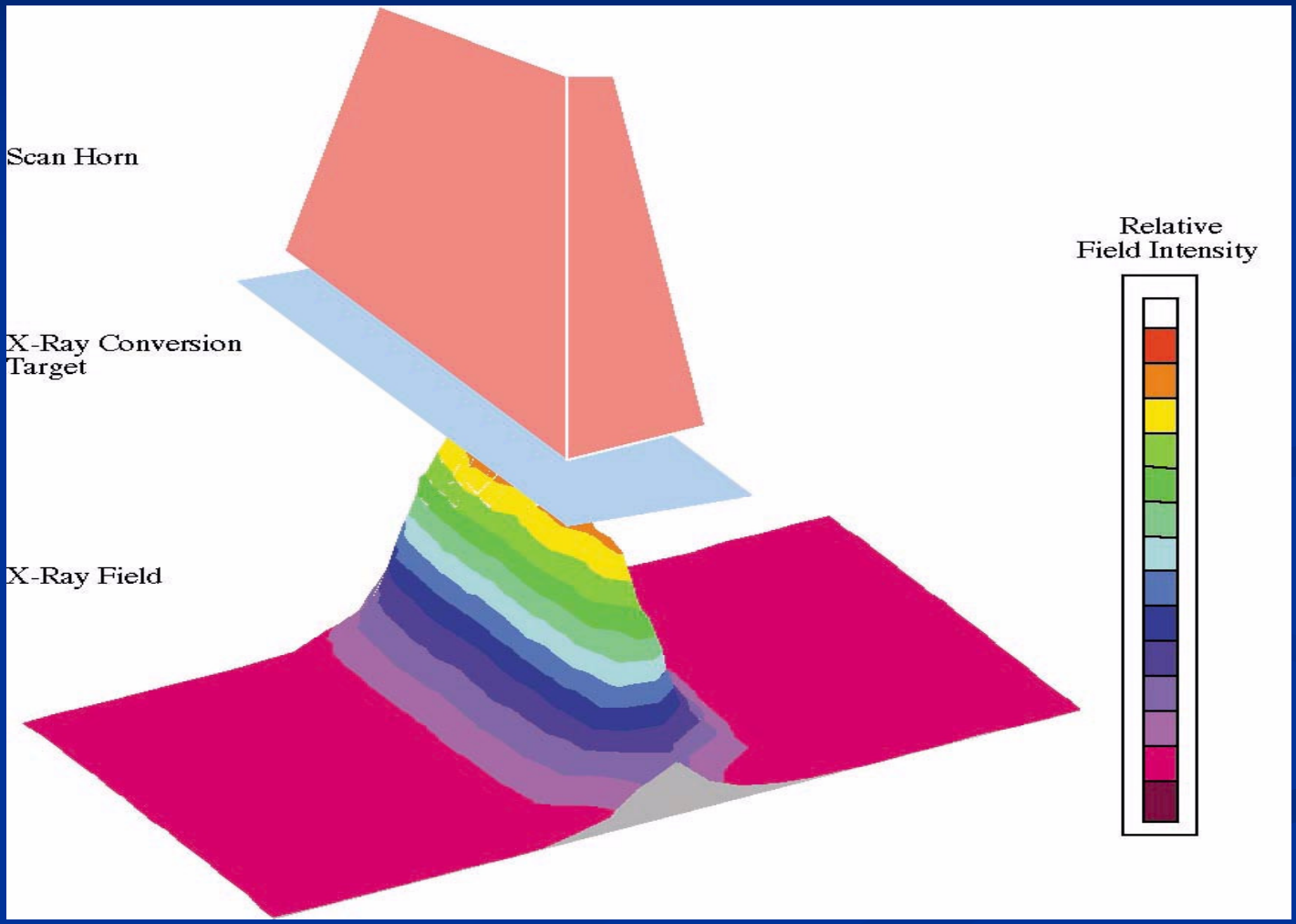
IBA Industrial Incorporated

5 MeV, 300 kW
Dynamitron®



7 MeV, 700 kW
Rhodotron®

High-power EB X-ray Conversion

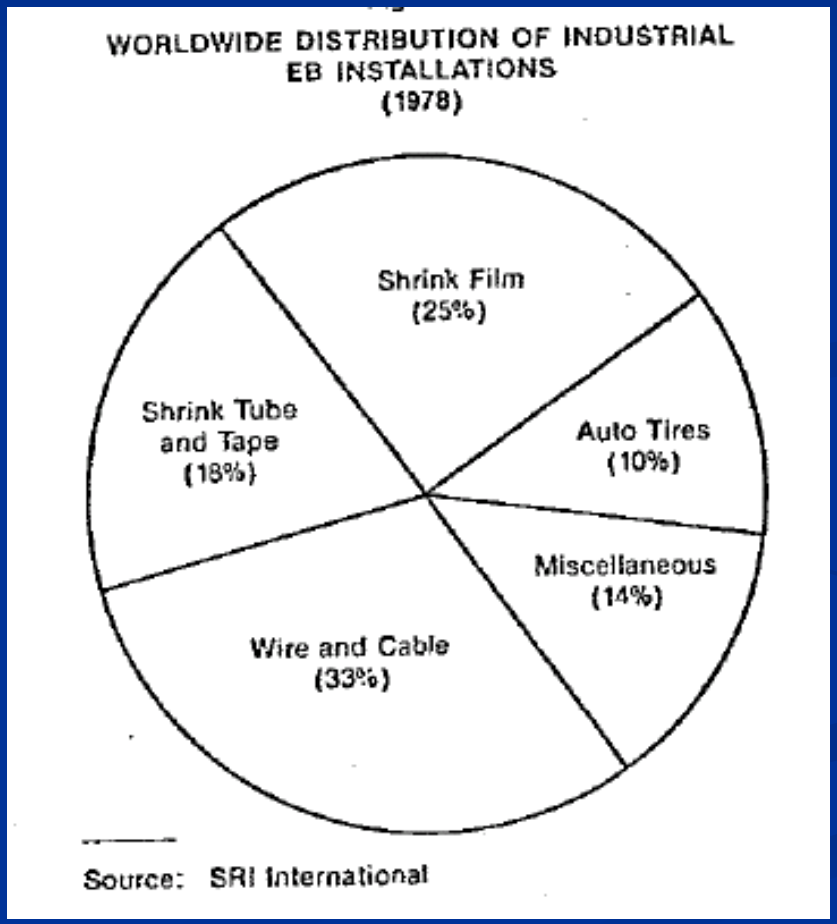


High-power EB X-ray Conversion

5 and 7 MeV Rhodotron EB Sourced X-ray Targets – Operational since 2002

Market Prospects – 1979 View

SRI International Study



Market Prospects – 1987 View

IMRP 6 Panel

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moderator; Consultant, Huntington, New York, USA

Mr. Urs V. Läuppi
Energy Sciences, Inc., Geneva, Switzerland, now with betacon, sa, La Rippe, Switzerland

Mr. Chester C. Thompson
Radiation Dynamics, Inc., Melville, New York, USA

Mr. David Lyall
Viritech, Ltd., Swindon, Great Britain

Mr. Ken-Ichi Mizusawa
Nissin-High Voltage, Ltd., New York, USA

Dr. Marshall R. Cleland
consultant, Englewood, Colorado, USA, now with Radiation Dynamics, Inc., Melville, New York, USA

Market Prospects – 1987 View

IMRP 6 Panel Input

Application	1979 Forecast for 1988 Market	1987 Market Size and Shares	
Shrink Tubing and Wire and Cable	161–210	185	39%
Shrink Film	50–75	105	22%
Tire Components	32–49	30	6%
Surface Curing	40–60	100	21%
Service Centers	13–20	25	5%
Other Applications	24–36	35	7%
Total Accelerators	320–450	480	100%

Market Prospects – 1987 Summary

- Low voltage, self-shielded equipment has taken off in the converting and web processing industries, complemented by a significant growth in the available radiation curable coating materials.
- Medium voltage accelerators continue to be the mainstay of the industry with growth in repeat orders to established markets like wire, cable, heat shrinkables and tires, with the capability of opening up the potential market to remove flue gas contaminants.
- High voltage, high current accelerators have been extended in capability so that they are now being more extensively used in the sterilization of medical disposables.
- Finally, there has been a resurgence in development work on higher current, very high energy (10 MeV) linear accelerators.

Market Prospects – 22 Years Hence

Positive Developments

+ Low-energy EB continues to grow at a fast pace with the downsizing of equipment making EB more affordable.

+ Mid-energy EB remains the mainstay of the entire industry but in historic markets.

+ Very high-power EB accelerators have made X-ray processing practical.

Market Prospects – 22 Years Hence

Areas Hindered by Lack of Demand

- Large-scale environmental applications have yet not generated market demand.
- Conversion of sterilization from gamma to EB is gradually improving.
- Food irradiation has not developed.

Non-technical societal and market barriers curtail areas of technical accomplishment.

Market Challenges in 2009

1. The need to address the market in a coherent manner. The EB market is inherently diverse in equipment and in applications.

   The metrology used in EB processing, dosimetry, lacks coherence and a unified approach to measurement.

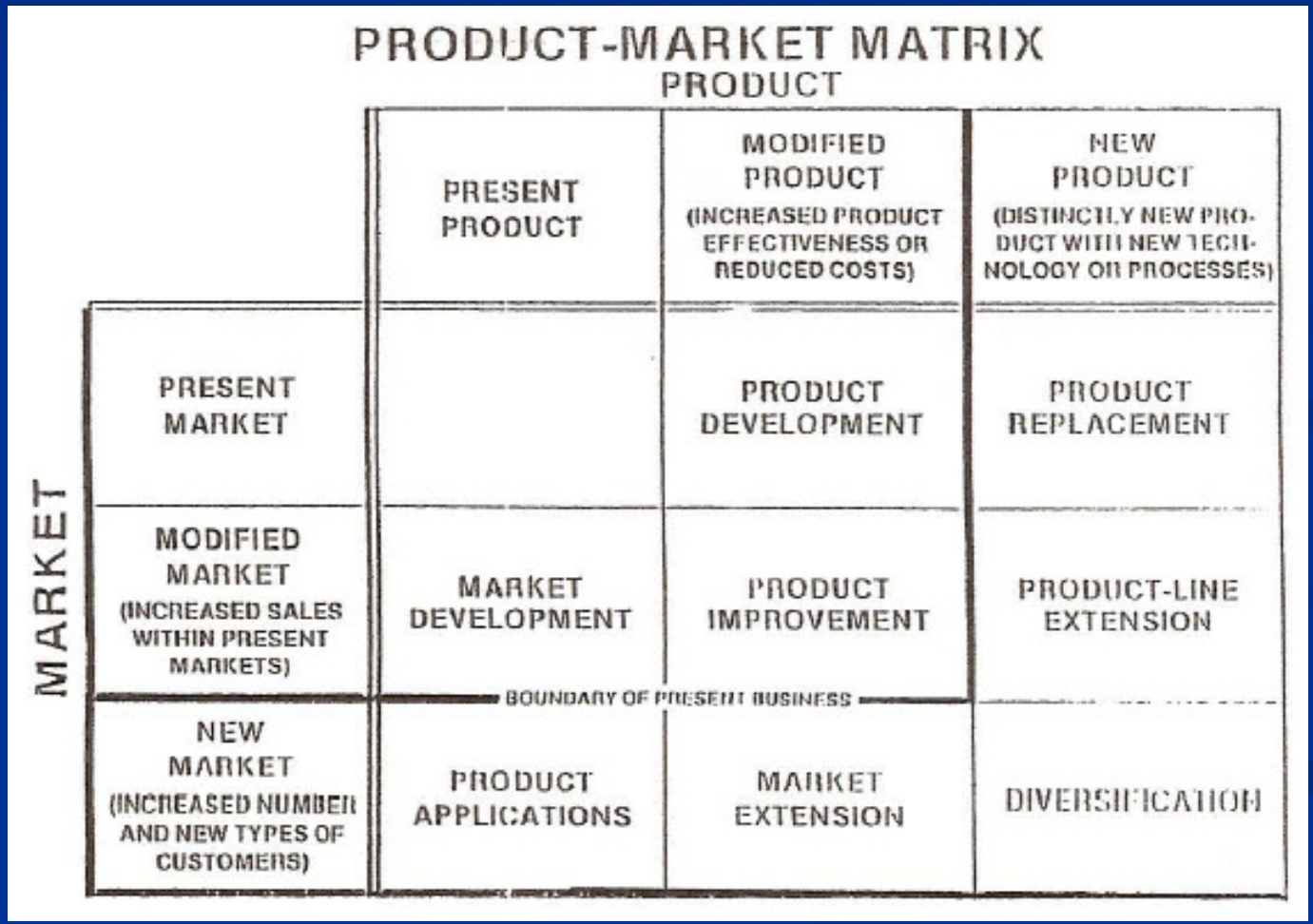
Market Challenges in 2009

2. <u>The need to be more selective in the choice of areas for applications development.</u>

   Considerable technical resources have been devoted to areas, which, while proven to be feasible and appealing in themselves, face non-technical societal barriers.

Market Challenges in 2009

Include Risk Assessment for Societal Benefits



Market Challenges in 2009

3. The need to emphasize energy efficiency.

Energy transfer efficiency is inherent in the practical use of ionizing radiation. When compared to EB, all thermal processes are very energy inefficient.

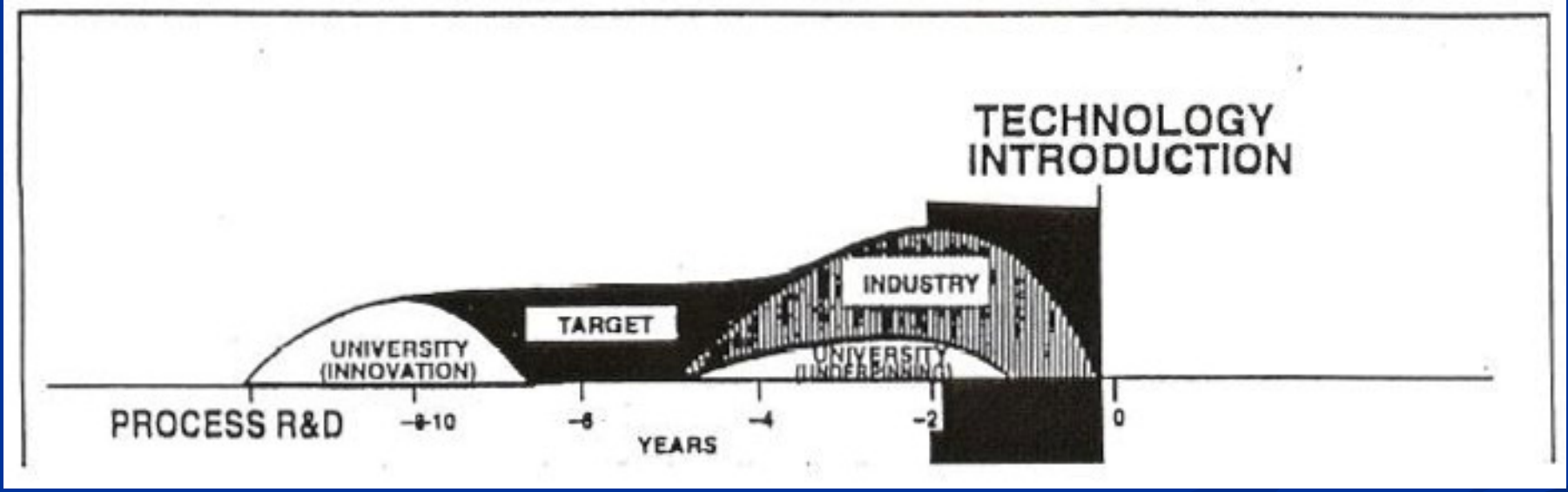
Market Challenges in 2009

4. The need to develop trained professionals.

Trained personnel are needed to explore new areas. This can be achieved by greater use of industry-academia partnerships, through fostering, but with industry guidance, of academic endeavors involving EB processing.

Market Challenges in 2009

Timeline for Technology Introduction



Market Challenges in 2009

5. The need for enhanced industry wide communication.

Out-reach complemented by closer communications within the industry is needed. Such out-reach should be extended to developing economies which have not yet invested in the more effective EB technologies.

Challenges in 2009

Challenges facing the EB processing industry:

- to address the market in a coherent manner
- to be more astute in the selection of areas for applications development
- to emphasize energy efficiency
- to develop trained professionals
- to enhance industry wide communication