

# Industrial Electron Beam Processing Overview of the Document

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# Industrial Electron Beam Processing

## Document sources:

- 1 – IAEA Industrial Irradiation of Polymers:  
Status and Prospects Report – August 2005
- 2 – Industrial Applications of Electron  
Accelerators: CERN Accelerator School –  
24 May to 2 June, 2005
- 3 – IAEA Consultants Meeting – July 2008

# Berejka 14 August 2004 Proposal

## Industrial Irradiation Processing Status and Prospects – 2004

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# Blue Book Publication August 2005

INTERNATIONAL ATOMIC ENERGY AGENCY

*Industrial Irradiation Processing of Polymers  
Status and Prospects*

**REPORT**

# Blue Book Publication August 2005

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# Cleland CERN Lecture

## Industrial Applications of Electron Accelerators

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Ion Beam Applications

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Presented at the CERN Accelerator School  
Small Accelerator Course  
Zeegse, Netherlands  
24 May to 2 June, 2005

# IAEA Consultants Meeting – July 2008



# Industrial Electron Beam Processing

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# Major Sections

1. Introduction
2. Electron Beam Accelerators
3. Materials Effects
4. Process Dosimetry
5. Major End-use Applications
6. Other Application Areas
7. Emerging Application Areas
8. Electron Beam Service Centers
9. References

# 1. Introduction

1.1 Electron Beam Processing Industry

1.2 Energy Transfer

1.3 Electron Beam Parameters

1.4 X-radiation

## 2. Electron Beam Accelerators

2.1 Historical Development

2.2 Electron Beam Sources

2.3 High-energy Accelerators

2.4 Mid-energy Accelerators

2.5 Low-energy Accelerators

2.5.1 Low-energy EB compared to  
Ultraviolet (UV) Radiation

# Low-energy Accelerators

Coolidge Early Developments

High-vacuum X-ray tube

First External EB tube

ESI Elongated Cathode

RPC/PCT Multiple Cathode

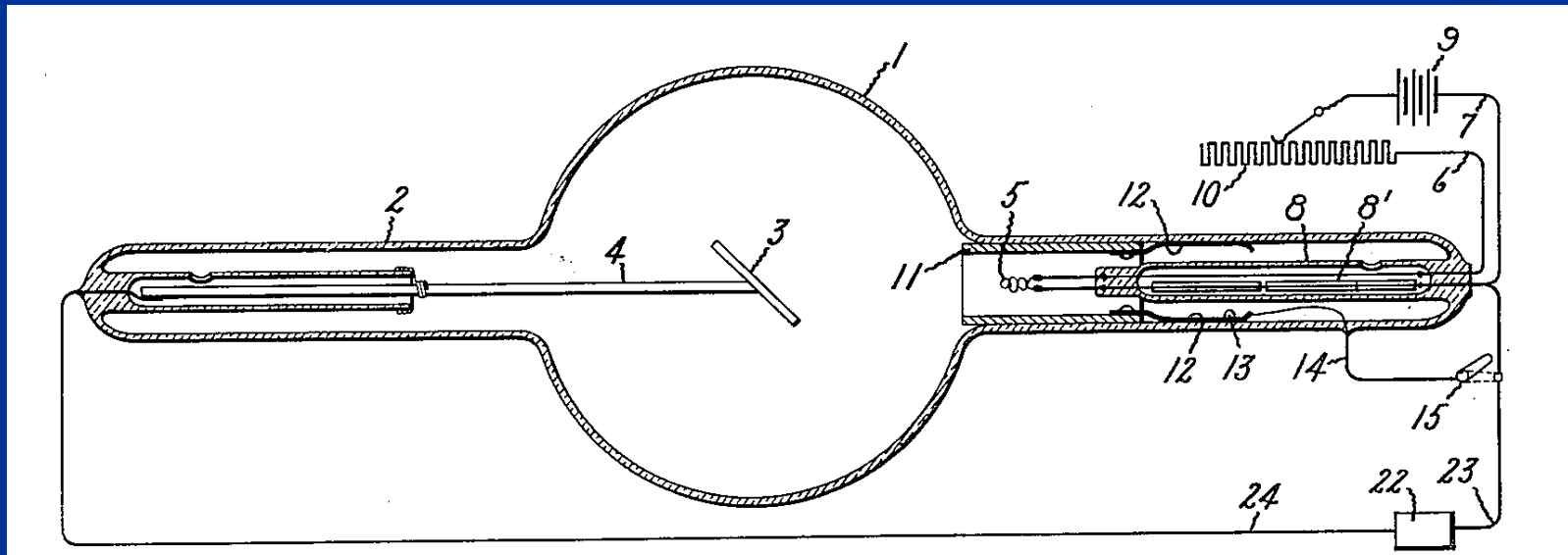
NHV Curetron<sup>TM</sup>

AEB Sealed Emitter

# Early EB Accelerators

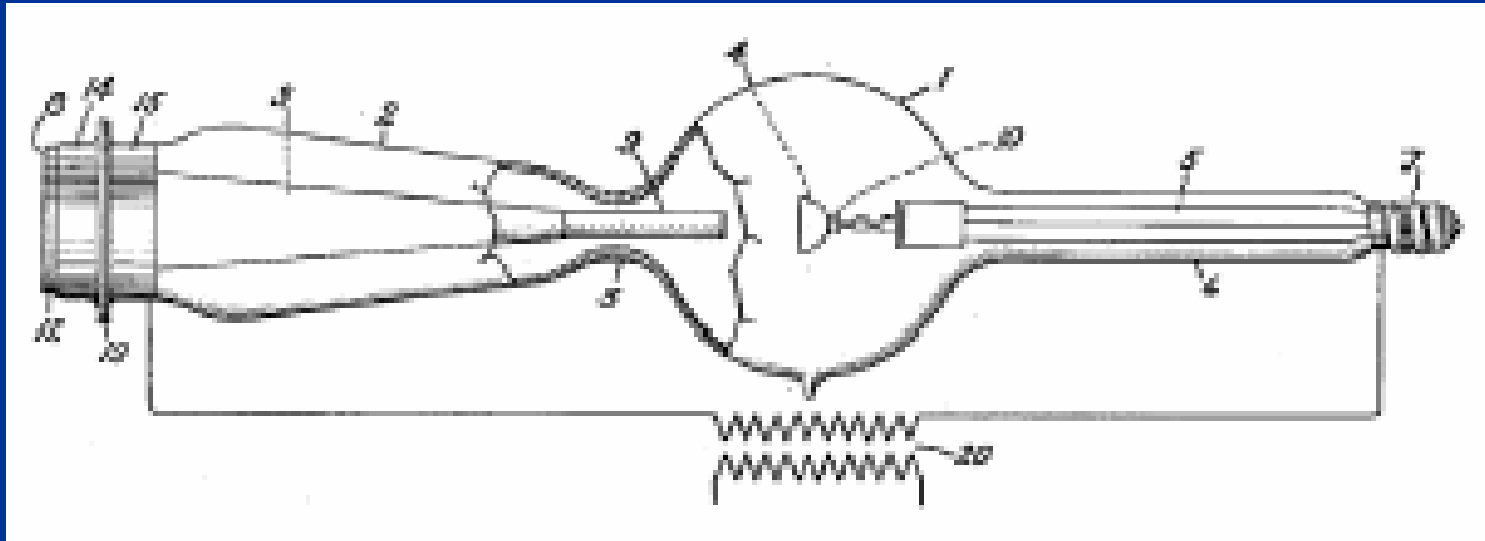
*Coolidge's First High-vacuum,  
Hot-cathode X-ray Tube*

*US Patent Application Filed May 9, 1913*

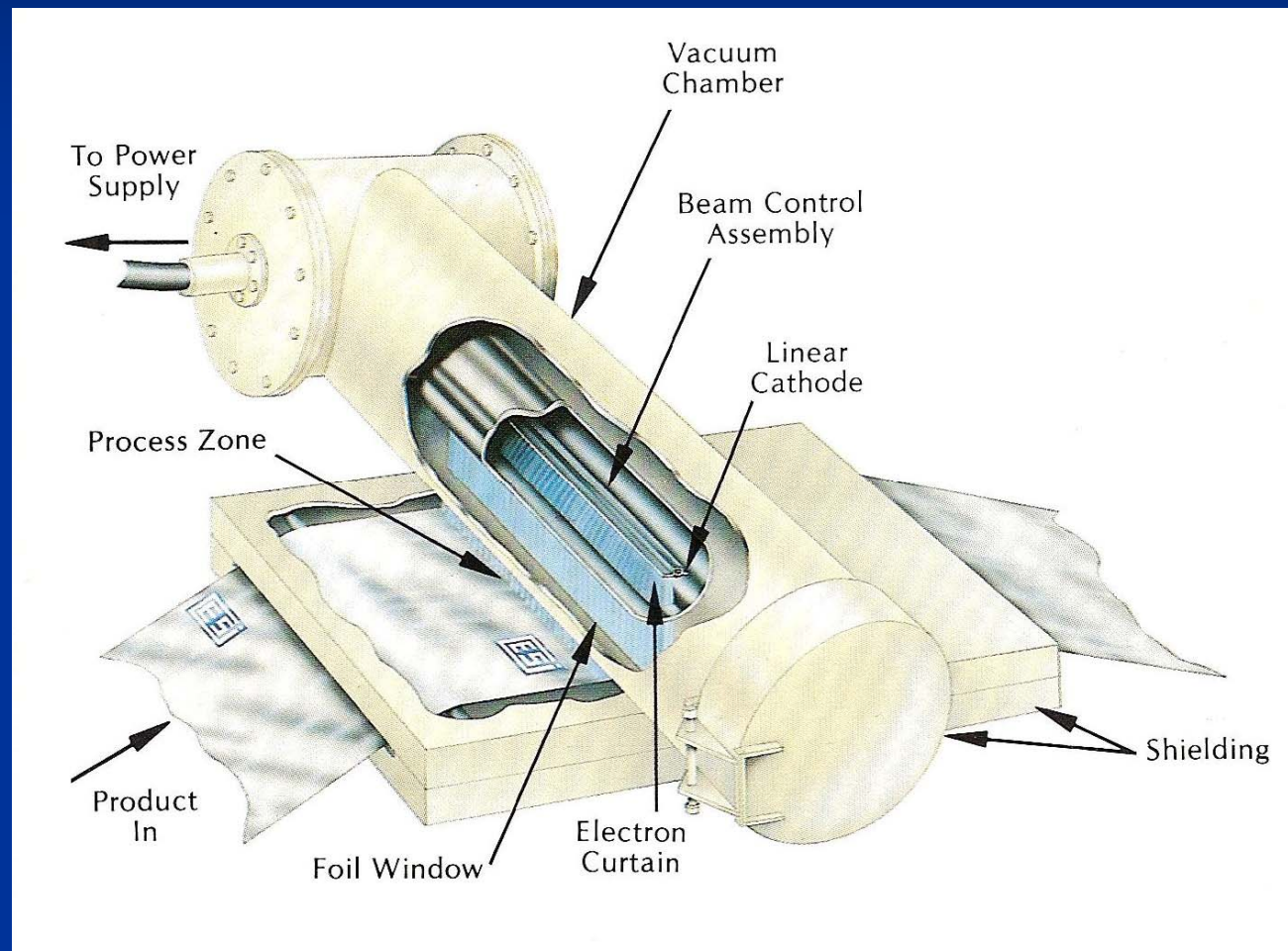


# Early EB Accelerators

*Coolidge's Electron Tube with Foil Window*  
*First External Beam Electron Accelerator*  
*US Patent Application Filed April 28, 1925*



# ESI Elongated Cathode

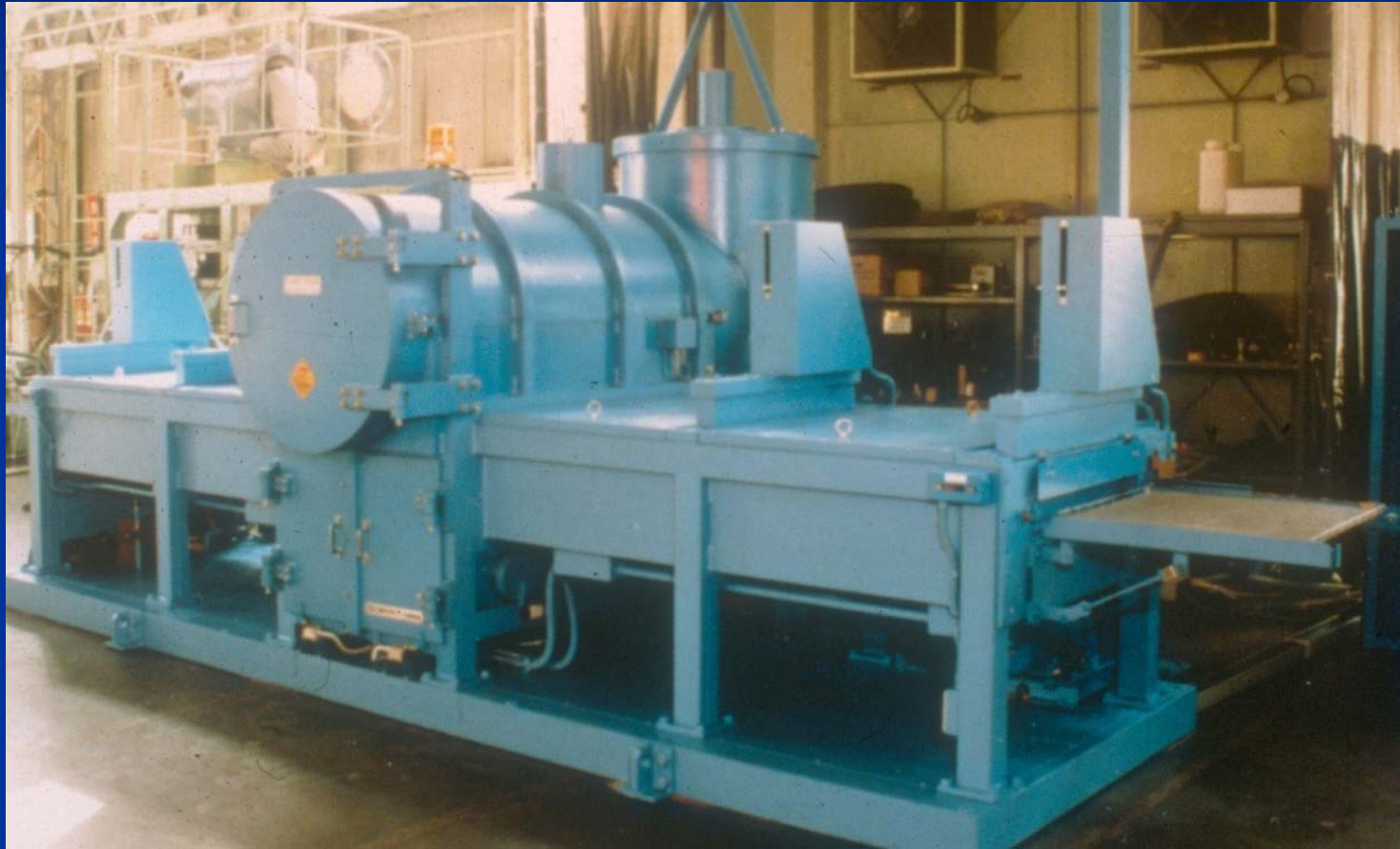




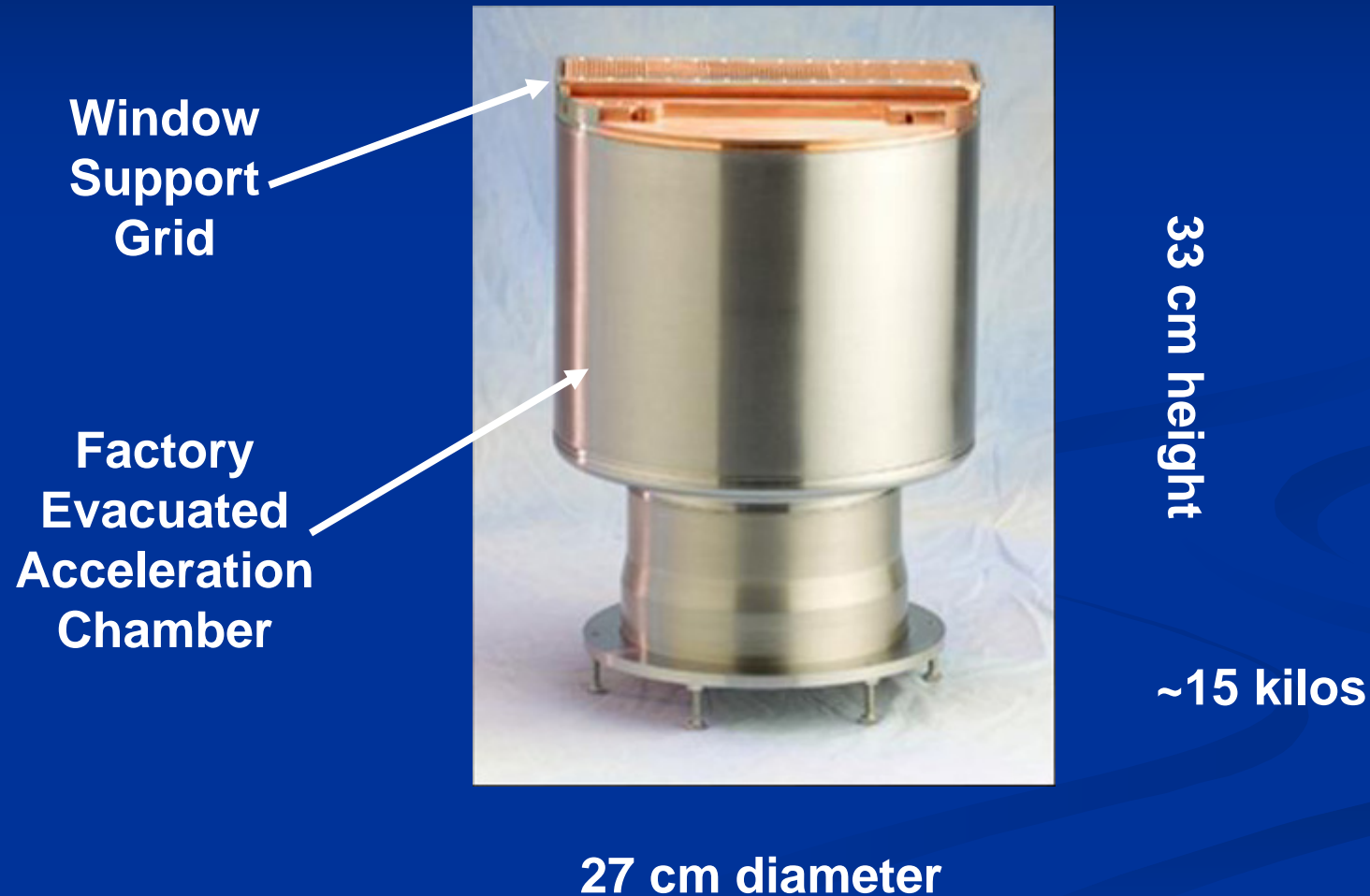
# RPC/PCT Multiple Cathode



# NHV Curetron™



# AEB Sealed Electron Emitter



# AEB Sealed Electron Emitter



# Medium-energy Accelerators

Philips N.V. Cockcroft-Walton

GE Resonant Transformer

IBA/RDI Dynamitron

HVEC Insulating Core Transformer

D. V. Efremov Institute (NIIEFA)

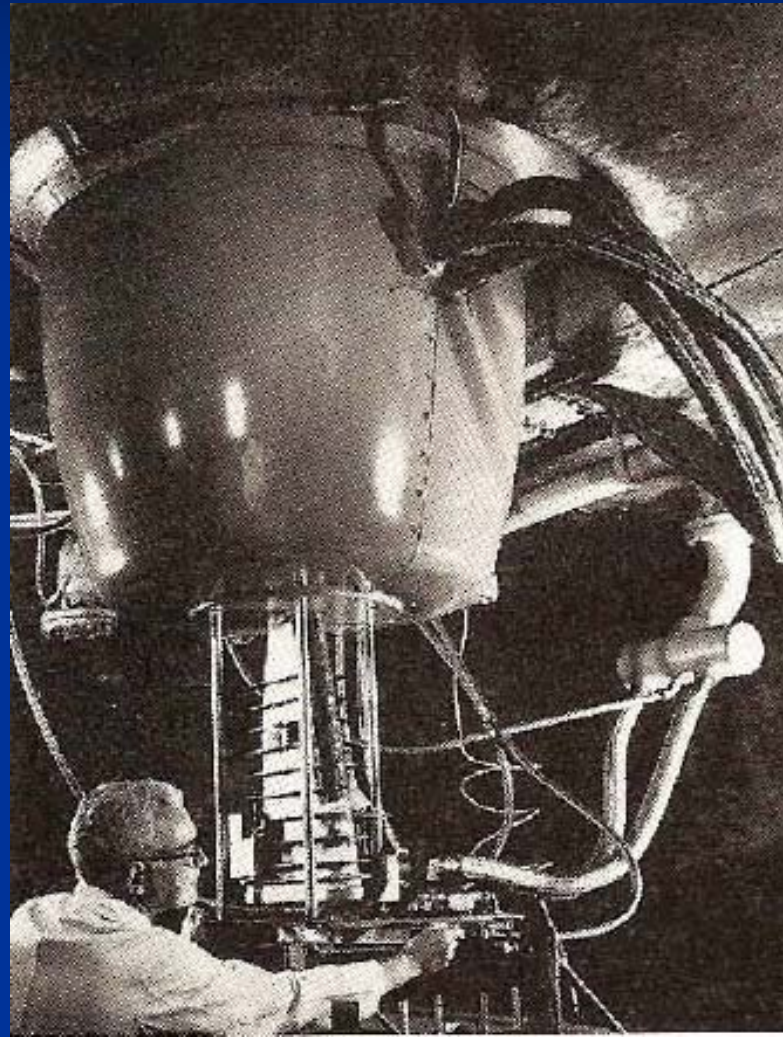
Budker Institute ILU and ELV

NHV Corporation Cockcroft-Walton

# Cockcroft-Walton



# GE Resonant Transformer

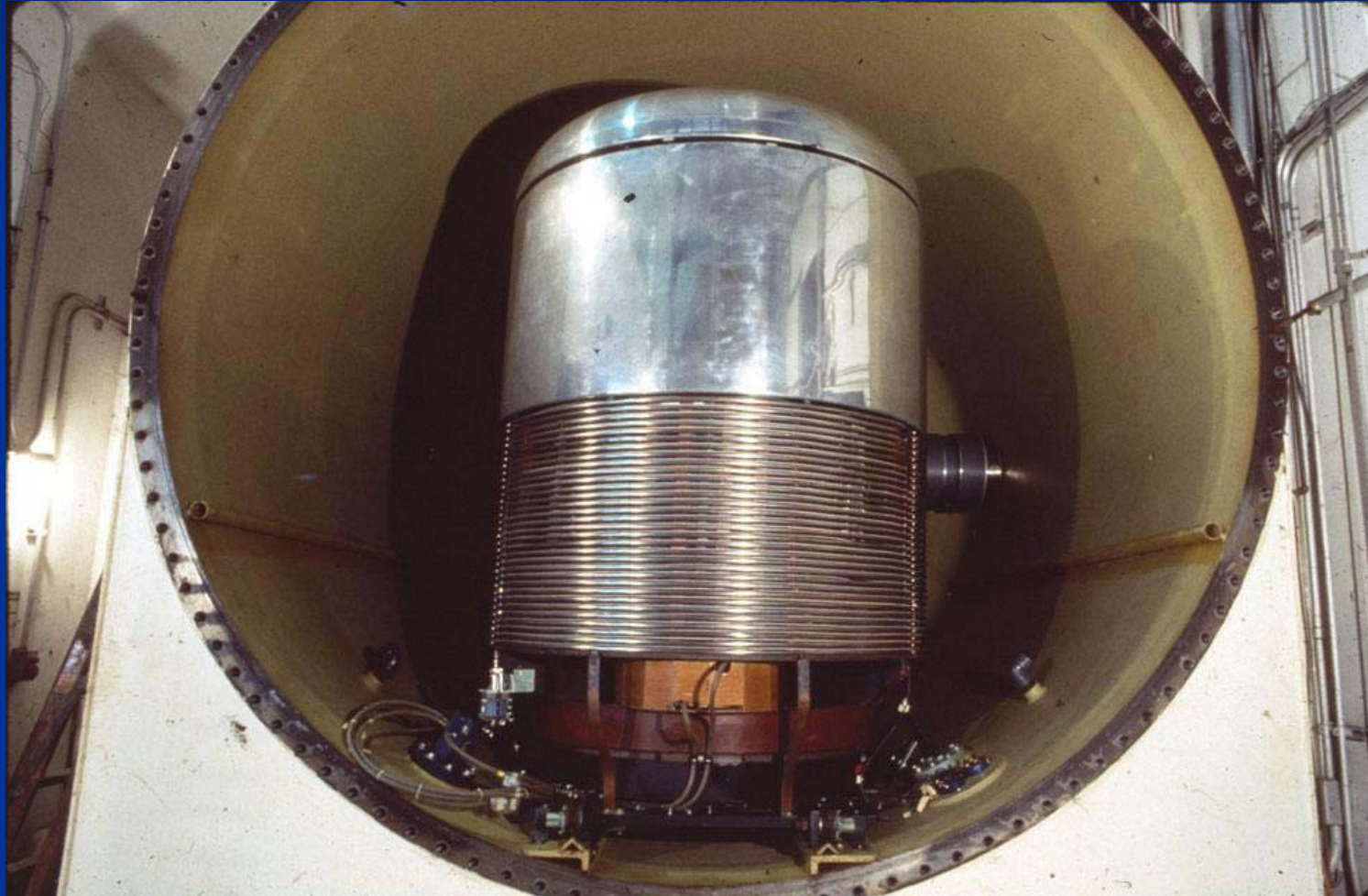


# IBA/RDI Dynamitron<sup>®</sup>

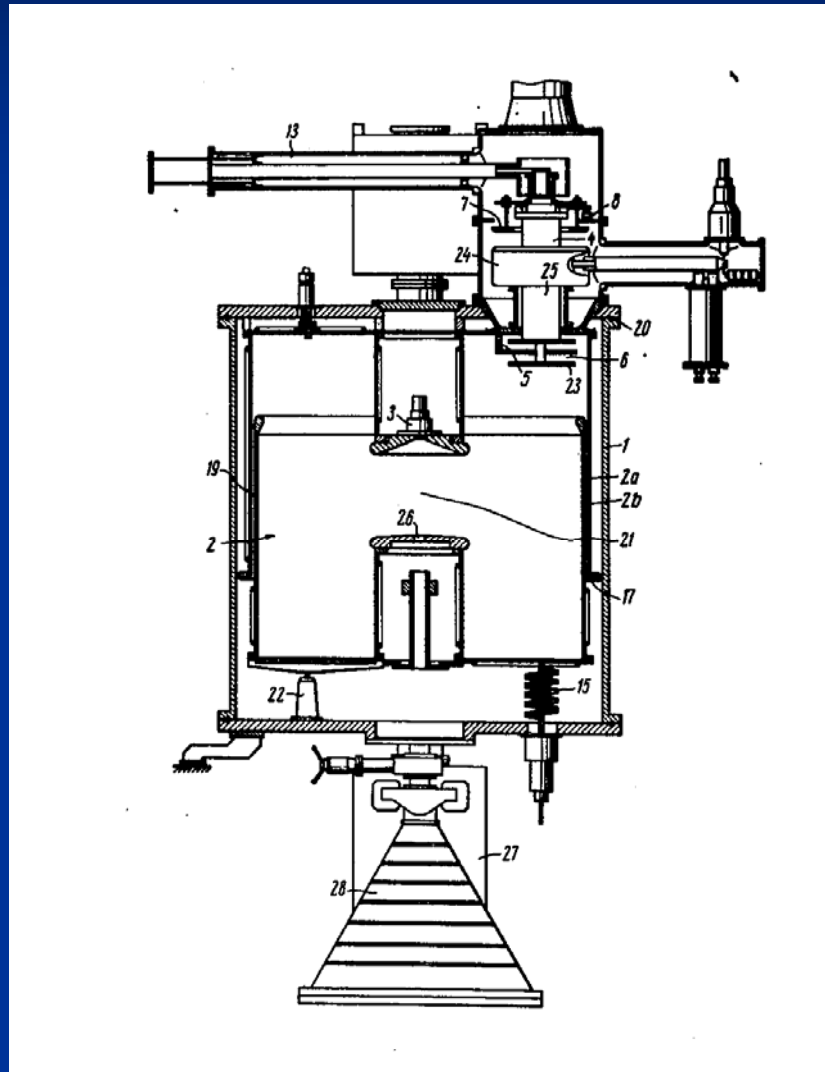




# HVEC Insulating Core Transformer

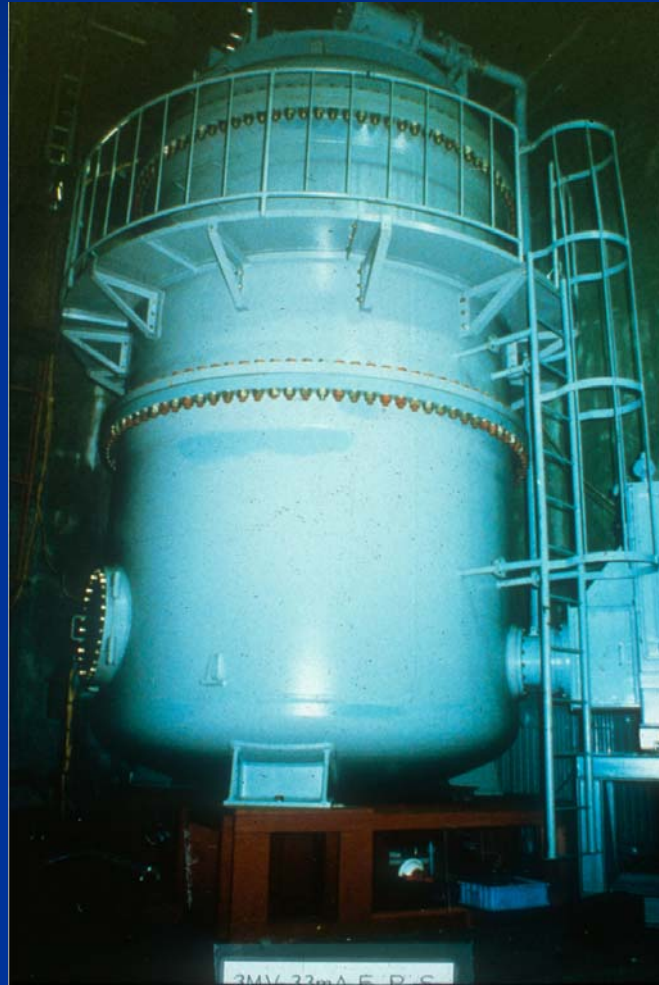


# Budker Institute Single Cavity ILU



# NHV Balanced Cockcroft-Walton

*3 MeV, 150 kW*



# High-energy Accelerators

Varian Associates Linac

CGR MeV (Getinge Linac)

Mevex

Titan Scan (L3 Communications)

IBA Rhodotron

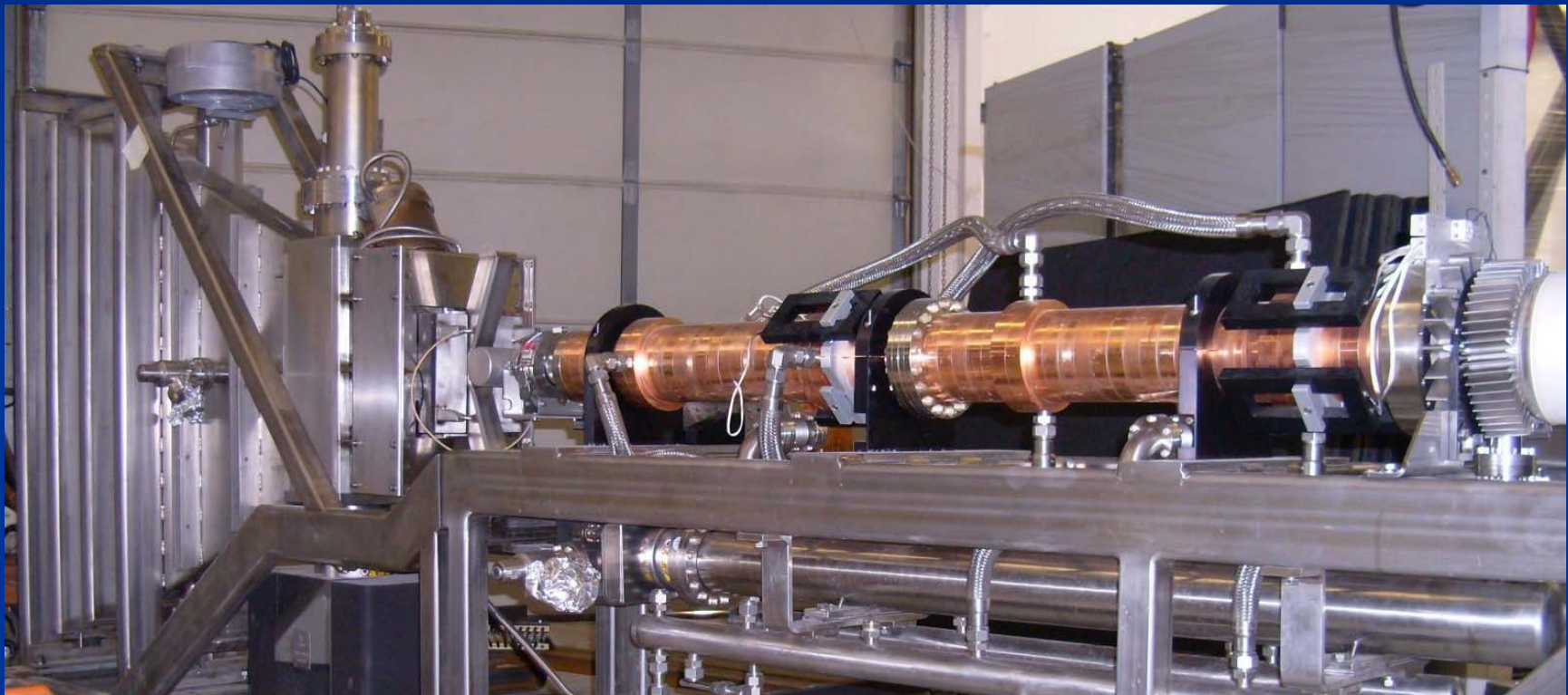
Budker Institute ILU

# CGR MeV (Getinge Linac)

*10 MeV, 20 kW*



# Mevex 10 MeV, 30 kW



# IBA Industrial Rhodotron<sup>®</sup>

*10 Pass, 10 MeV, 200 kW*



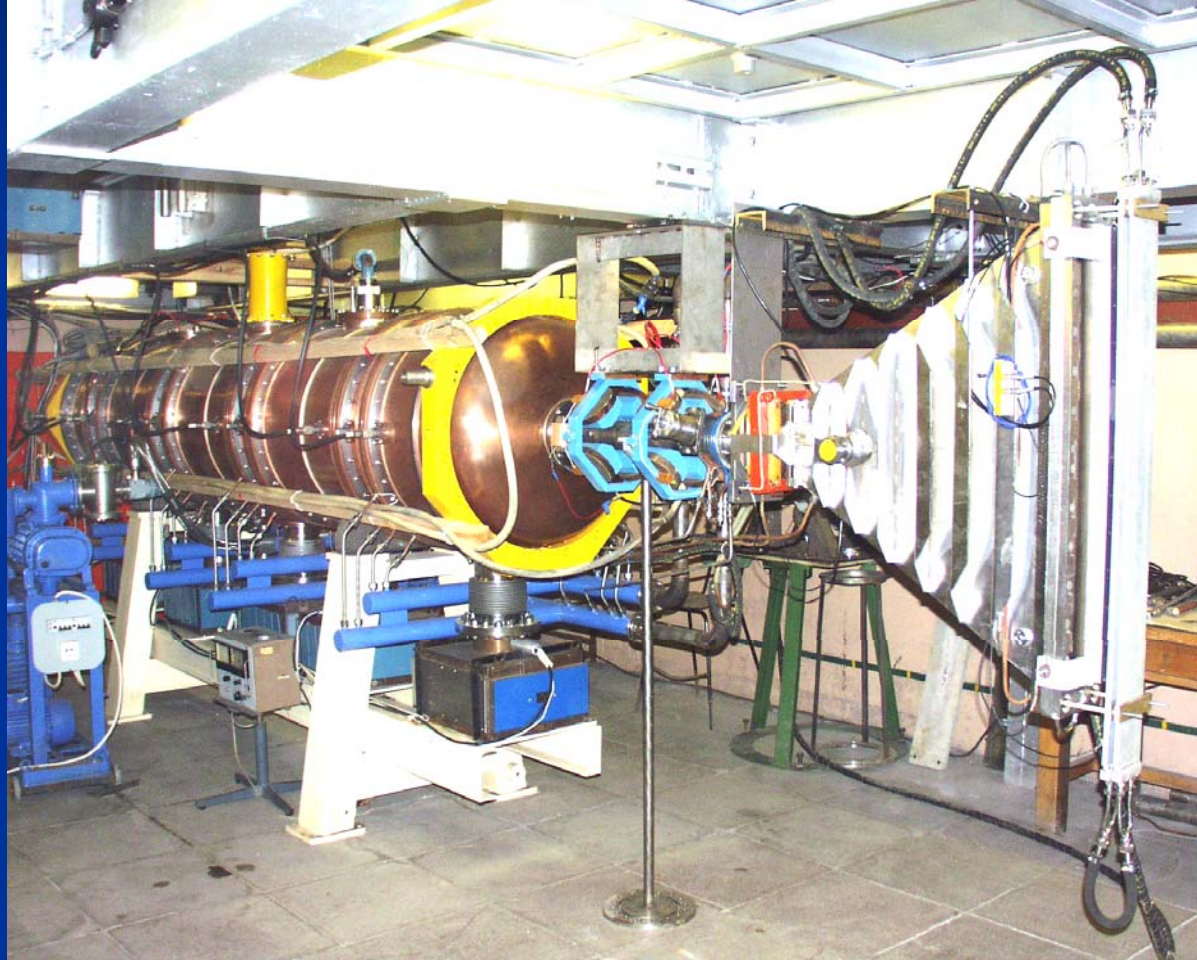
# IBA Industrial Rhodotron<sup>®</sup>

*6 Pass, 7 MeV, 700 kW*





# Budker Institute ILU



# 3. Material Effects

3.1 Polyethylenes

3.2 Polypropylenes

3.3 Halogenated Plastics

3.4 Engineering Thermoplastics

3.5 Elastomers

# 3. Material Effects

3.6 Thermoplastic Elastomers

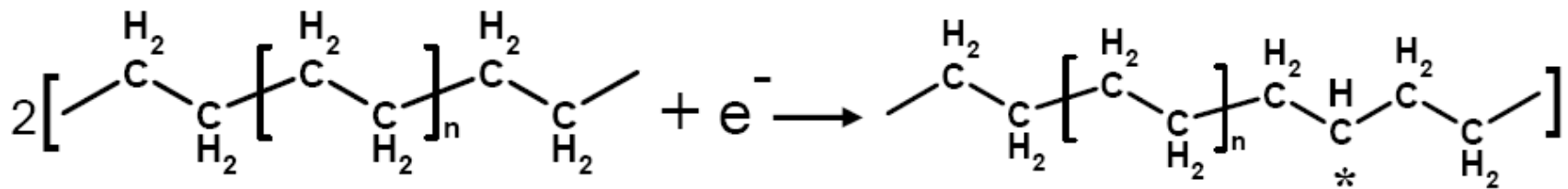
3.7 Monomers and Oligomers

3.8 Water Soluble Polymers

3.9 Natural Polymers

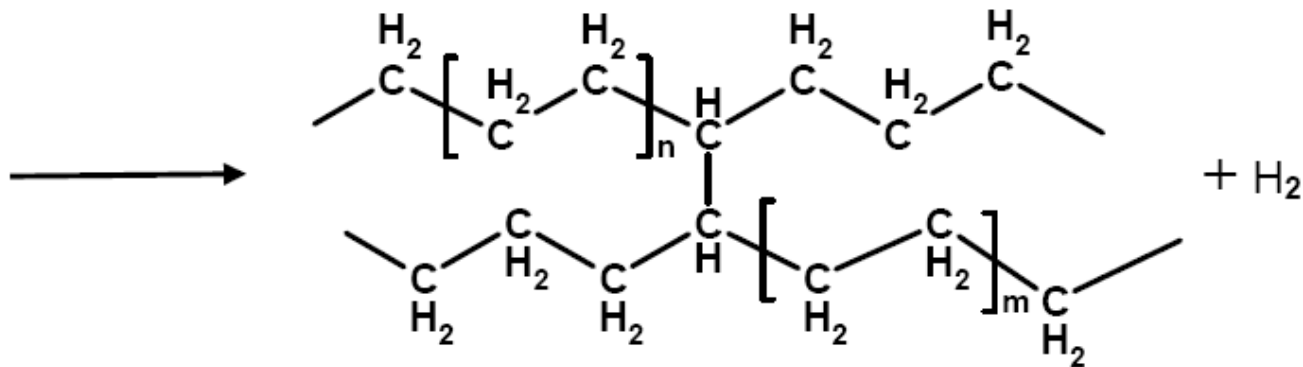
3.10 Living Matter (DNA)

# Polyethylene Crosslinking

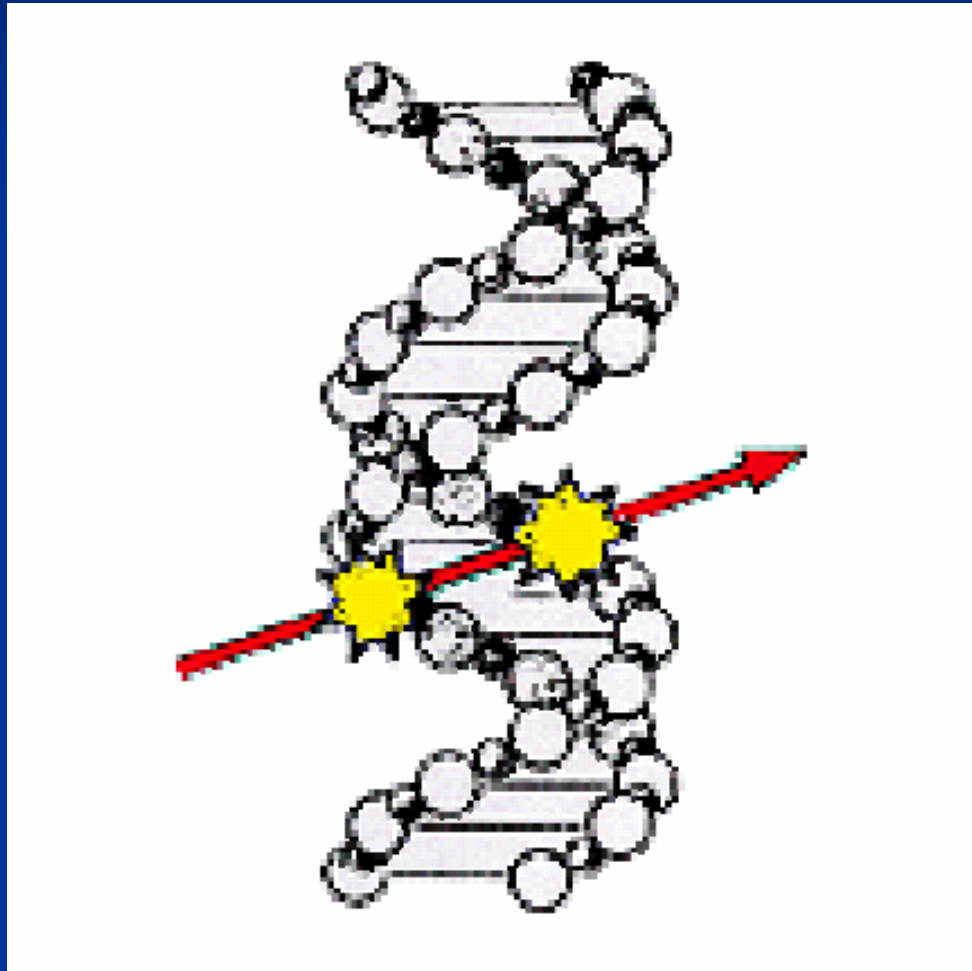


*Polyethylene – amorphous region*

*PE with reactive free radical*



# DNA Scissioning



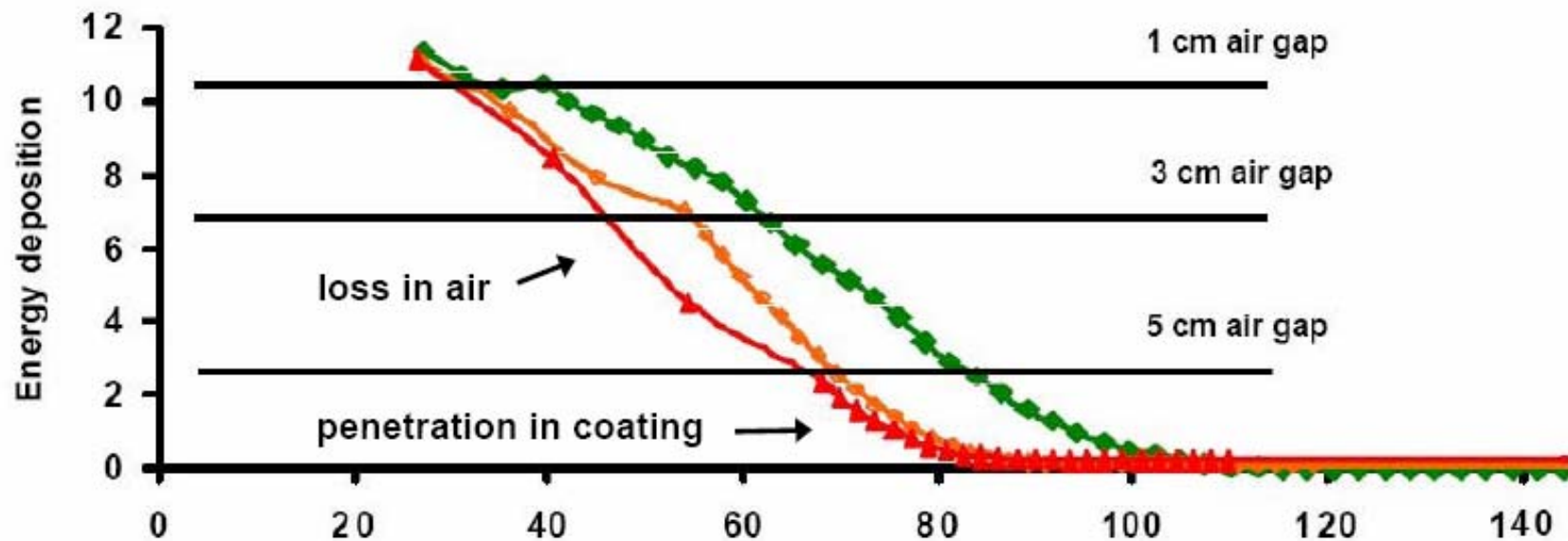
# 4. Process Dosimetry

## 4.1 Alanine

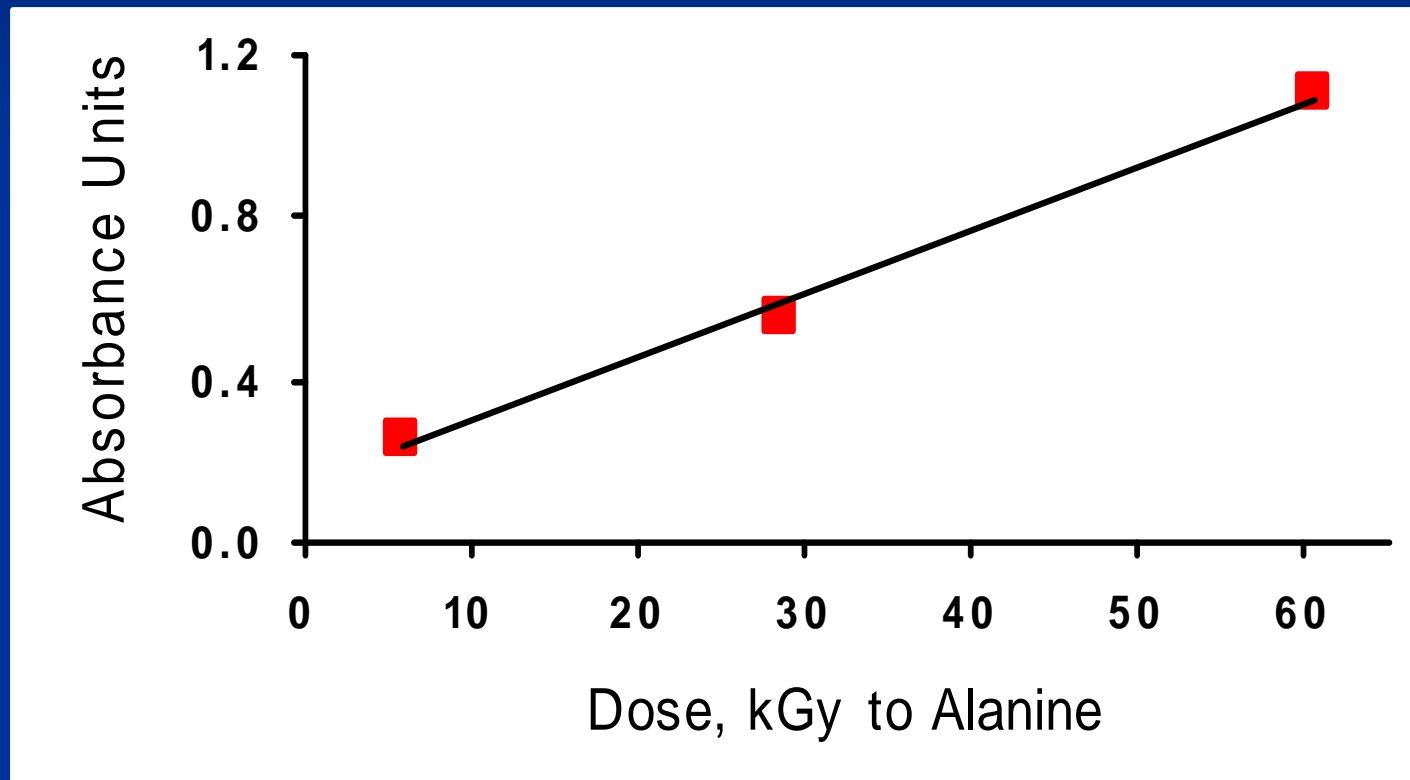
## 4.2 Polyethylene

# Low-energy EB Concerns

*Monte Carlo 80 keV EB Penetration through 6  $\mu\text{m}$  Ti Window into 144  $\mu\text{m}$  Alanine Coating*



# ATR FTIR Absorbance at 965 $\text{cm}^{-1}$ in 38 $\mu\text{m}$ LDPE Film



Multiple passes at 3.0 MV



# 5. Major End-use Applications

5.1 Wire and Cable Insulation

5.2 Heat-Shrinkable Tubing

5.3 Heat-Shrinkable Food Packaging Films

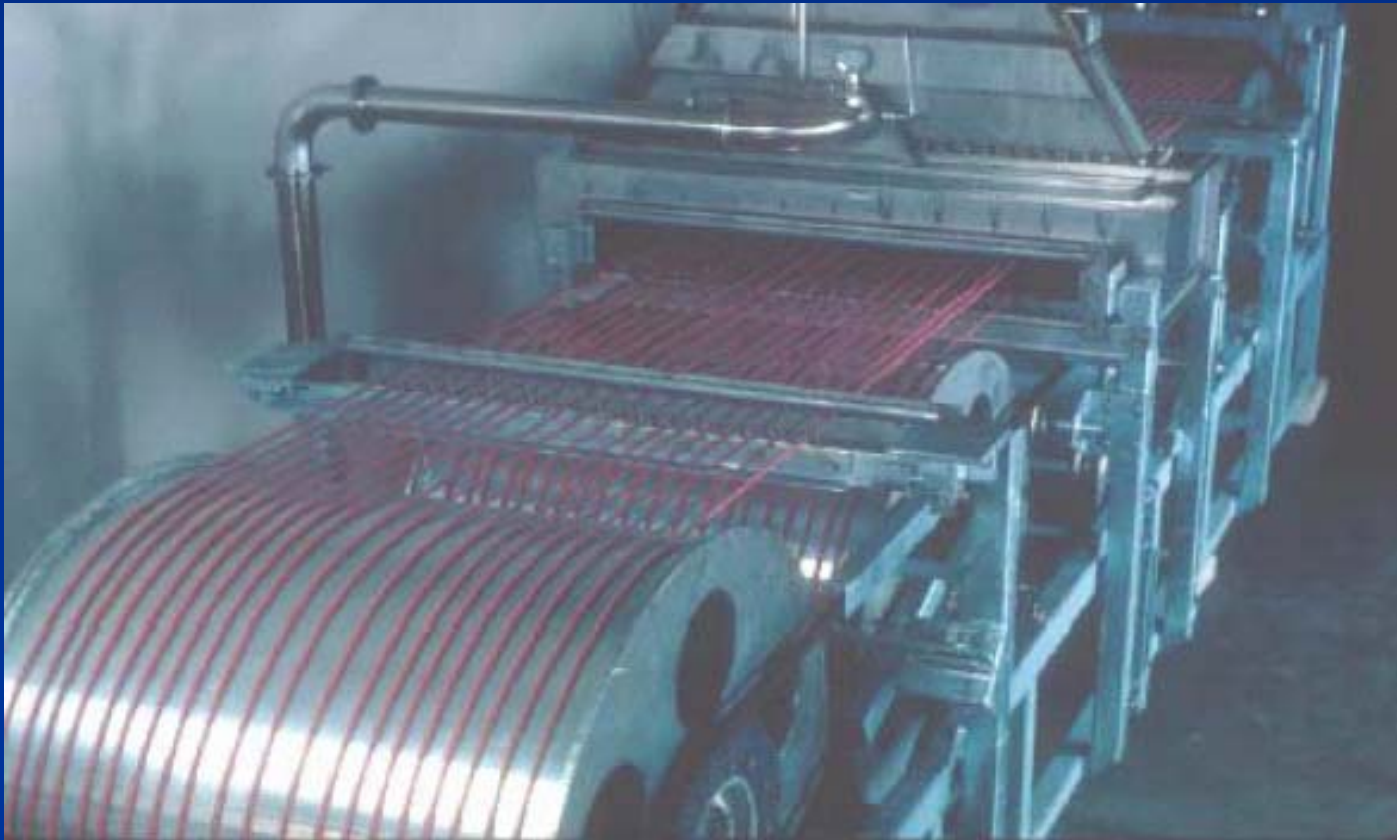
5.4 Closed Cell Polyethylene Foams

5.5 Automobile Tire Components

5.6 Inks, Coatings and Adhesives

5.7 Hydrogels

# Wire and Cable and Tubing Under-beam Handling

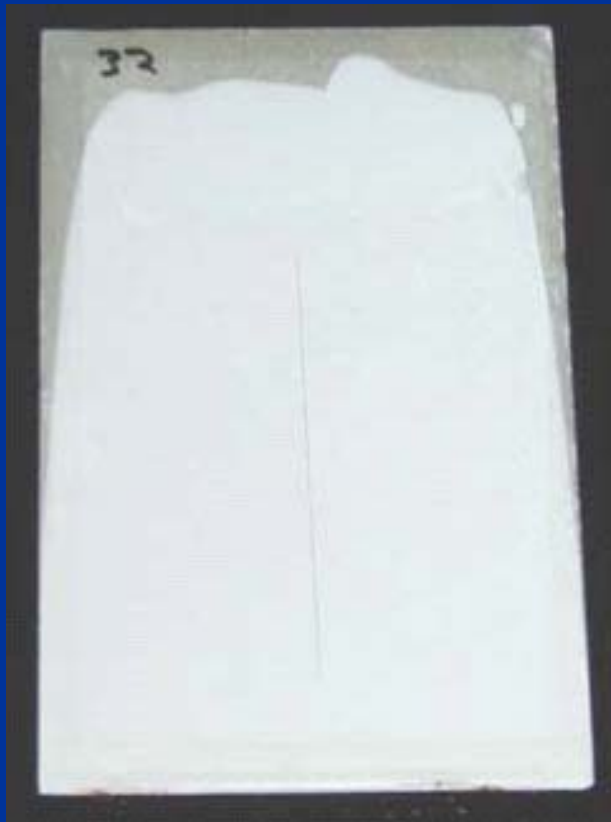


# Closed Cell PE Foam



# Pigmented Coatings

*Low-energy EB Cured Coating  
after 1000 hours Salt-spray Test*



# 5. Major End-use Applications

## 5.8 Medical Device Sterilization

### 5.8.1 Regulatory Compliance for Sterilization

### 5.8.2 In-line Medical Device Sterilization

## 5.9 Food Irradiation

### 5.9.1 Regulatory Compliance for Food

## 5.10 Food and Medical Product Packaging Decontamination

# Medical Packaging Decontamination

*Getinge Linac STERSTAR™ System  
Three 200 keV Triangulated Beams*



# 6. Other Application Areas

6.1 PTFE Degradation

6.2 Water Pipes and Tubing

6.3 Battery Separators

6.4 Filter Membranes

6.5 Semi-conductor Treatment

6.6 Gem Stone Irradiation

# PEX-C PE Pipes

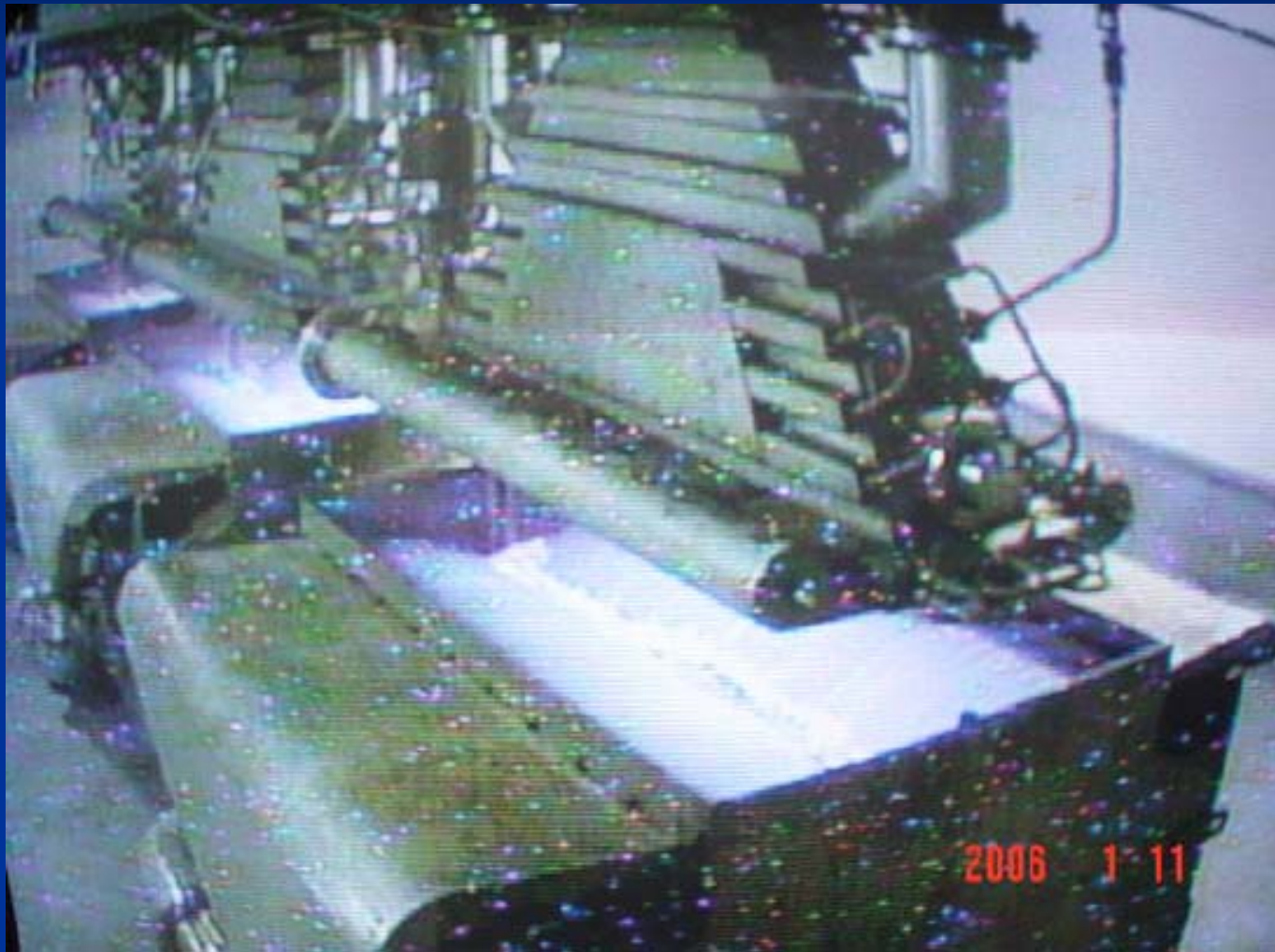




# 7. Emerging Application Areas

- 7.1 Cellulose Degradation for Ethanol/Biofuel Production
- 7.2 Cellulose Degradation for Viscose
- 7.3 Waste-water Treatment
- 7.4 Fossil Fuel Stack Gas Treatment
- 7.5 Exhaust and Gaseous Treatment

# Contaminated Water Treatment



# Fossil Fuel Stack Gas Treatment



# 7. Emerging Application Areas

7.6 Composite Curing

7.7 Carbon Fiber Modification

7.8 Silicon-Carbide Fiber Manufacture

7.9 Fuel Cell Membrane Grafting

7.10 Fuel Cell Catalyst Modification

7.11 PTFE Crosslinking

7.12 Curing Rubber Sheeting

# X-ray Cured Carbon-Fiber Auto Fender

*Cured in the Mold at 30 kGy*



# 7. Emerging Application Areas

7.13 Seed Disinfestation

7.14 Soil Disinfestation

7.15 Grafted Biologically  
Active Compounds

7.16 Human tissue sterilization

7.17 Direct Food Contact Coatings

## 8. Electron Beam Service Centers

North and South America	18
Western Europe	24
Asia-Pacific and Elsewhere	11
Total	53

# Document Summary

104 Pages

13 Tables

108 Figures

269 References

20.8 MB MS Word File

13 EB Manufacturers