MID 42332

PART V:

Industrial Applications

Defining Industrial Applications of Accelerators?

- Generally, high energy particle beams induce nuclear reactions and activation
- In contrast, in industrial applications, nuclear reactions and activation are undesirable and avoided, but other effects of ionizing radiations are researched
- These desired effects include:
  - Sterilization
  - Cross linking of polymers
  - Curing of composite materials
  - Modification of crystals
  - Improvement of semi conductors
  - Beam aided chemical reactions

Which beams are used?

- The choice of particle beams used in industrial applications is defined, to a large extent, by the desire to avoid nuclear reactions and activation.
- Commonly used beams include:
  - Electron beams below 10MeV.
  - X-Rays from e-beams below 7.5MeV.
  - Intense, low energy proton beams.
  - Heavy ion beams well below the Coulomb barrier.
- Also, for industrial applications, large beam currents/powers are needed to reach industrial scale production rates. Beam powers from 50 kW to 1 MW are common.

Key E-beam and X-ray Industrial Applications

- **Sterilization**
  - Sterilization of Medical Devices
  - Surface Sterilization
  - Food Pasteurization
- **E-beam induced chemistry**
  - Reticulation of Polymers
  - Curing of composites
  - Environment remediation
- **E-Beam induced crystal defects**
  - Improvement of Semiconductors
  - Coloring of Gemstones

The options for the sterilization of medical devices

- Steam (incompatible with most polymers)
- Ethylene Oxyde
  - Inexpensive
  - EtO is explosive, toxic and harmful to the environment
  - EtO sterilization may leave harmful residues
- Irradiation
  - Cobalt
  - E-beam
  - X-ray

The options for sterilization by irradiation (1)

- **Gammas from Co60** ($T_{1/2}$=5.2 y; γ_1=1.33 MeV; γ_2=1.17 MeV)
  - Low investment cost, specially for low capacities
  - Simple and reliable, scalable from 100 kCuries to 6 MCuries (about 5 kg of Co-60)
  - Isotropic radiation > inefficiencies in use
  - Pallet irradiation, but low dose rate > slow process
  - Absolutely no activation
  - Cannot be turned OFF > inefficient if not used 24/7
  - Growing security concern: the cobalt from a sterilization plant could be used to make dirty bombs

The options for sterilization by irradiation (2)

- **Electron beams**
  - Directed radiation > Efficient use
  - Lowest cost of sterilization for large capacities
  - Can be turned OFF > safer
  - Short range (4.5 g/cm² at 10 MeV) > 2-sided irradiation of boxes
  - More complex dose mapping
  - Minimal, hardly measurable, but non zero activation

The options for sterilization by irradiation (3)

- **X-Rays from E-beams**
  - Excellent penetration
  - Simple dose mapping
  - Pallet irradiation
  - Directed radiation > Efficient use
  - Loss of a factor 10 in energy when converting e-beams to photons
  - Cost of sterilization higher than electrons
  - Cost of sterilization is generally higher by X-Rays than Cobalt if used 24/7, excepted for very large capacities
  - Can be turned OFF > safer
  - Minimal, hardly measurable, but non zero activation

Food irradiation applications

Low Dose Applications (< 1kGy)

- **Phytosanitary** Insect Disinfection for grains, papayas, mangoes, avocados...
- **Sprouting Inhibition** for potatoes, onions, garlic...
- **Delaying of Maturation**, parasite disinfection.

Medium Dose Applications (1 – 10 kGy)

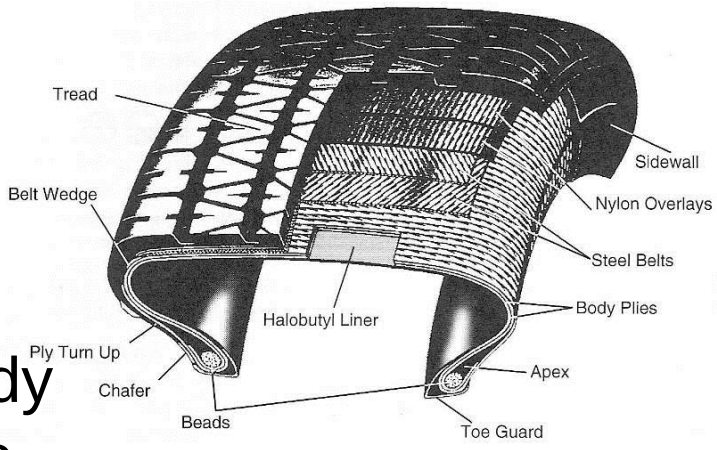
- **Control of Foodborne Pathogens** for beef, eggs, crab-meat, oysters...
- **Shelf-life Extension** for chicken and pork, low fat fish, strawberries, carrots, mushrooms, papayas...
- **Spice Irradiation**

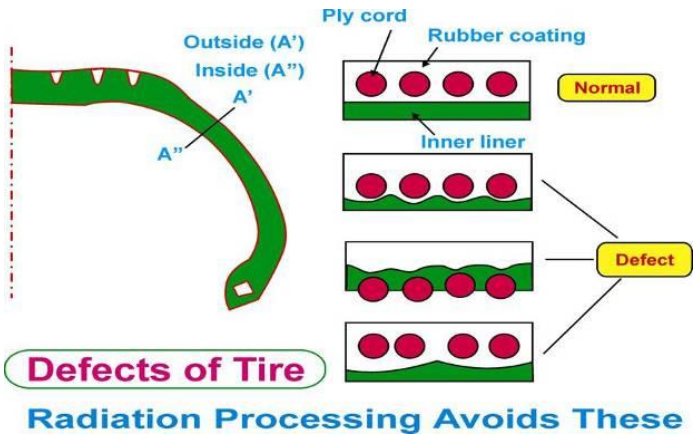
High Dose Applications (> 10 kGy)

- **Food sterilization** of meat, poultry and some seafood is typically required for hospitalized patients or astronauts.

E beam treatment of Tires

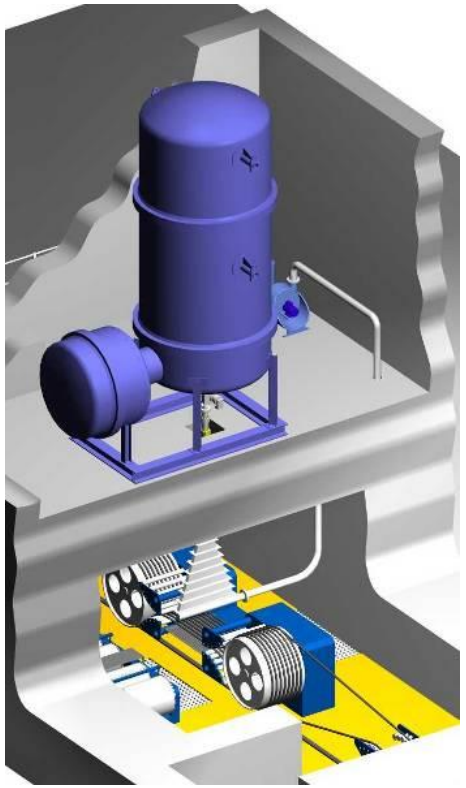
- Reduction in material hence in the weight of the tire
- Relatively low cost synthetic rubber can be used instead of costly natural rubber without a loss in strength
- The radiation pre-vulcanization of body ply is achieved by simply passing the body ply sheet under the scan horn of an electron accelerator to expose the sheet to high-energy electrons
- Higher production rates
- Construction of green tires
- Reduction of production defects





Polymer Cross-Linking

- **Wires** stand higher temperature after irradiation
- **Pipes** for central heating and plumbing
- **Heatshrink elastomers** are given a memory



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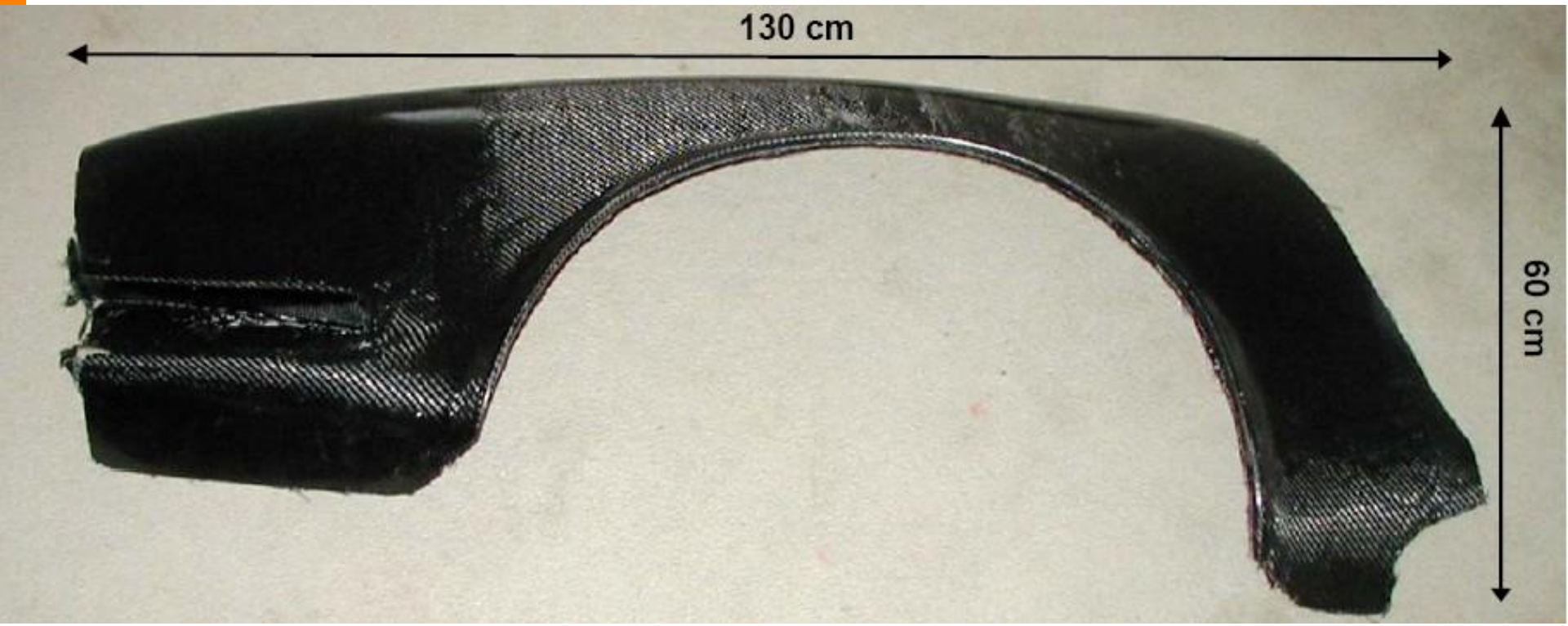
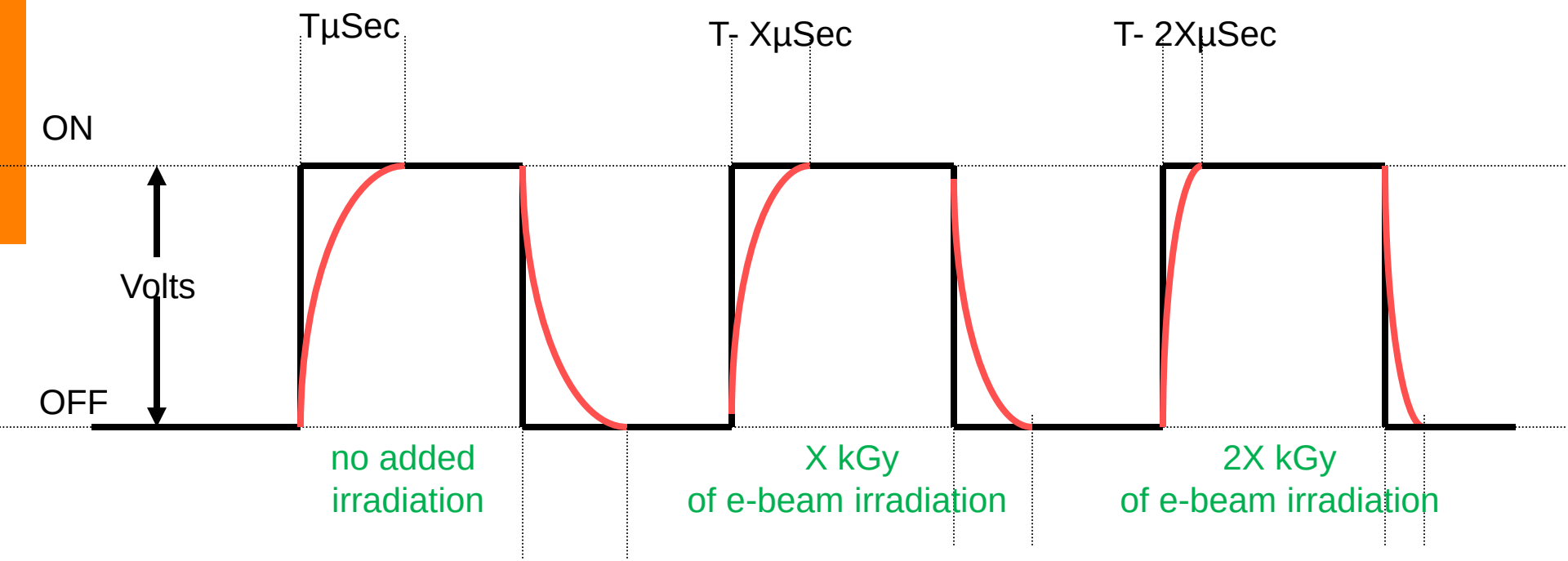
Composite curing: X-ray Cured Carbon Fiber

- Sports Car Fender made light, restistant and requiring less fuel



E-beam irradiation improves SC switching speed

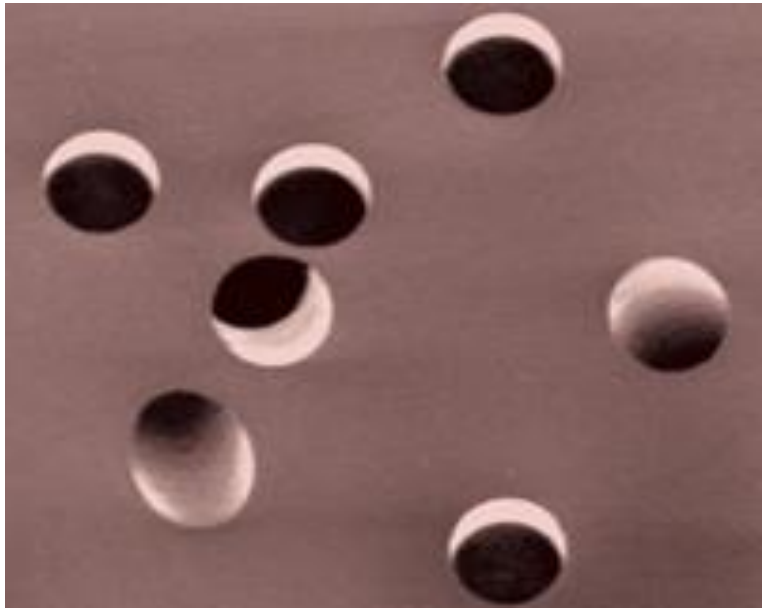


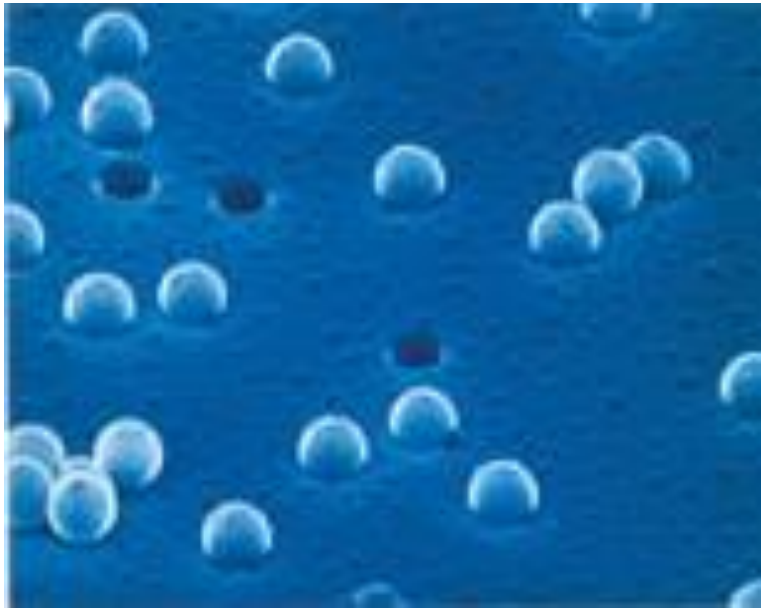
Typical semicondutors:

- fast recovery diodes
- power diodes
- Bipolar power transistors
- power MOSFETs
- power rectifiers
- IGBT's
- thyristors
- silicon-controlled rectifiers

Microfiltration membranes by heavy ions

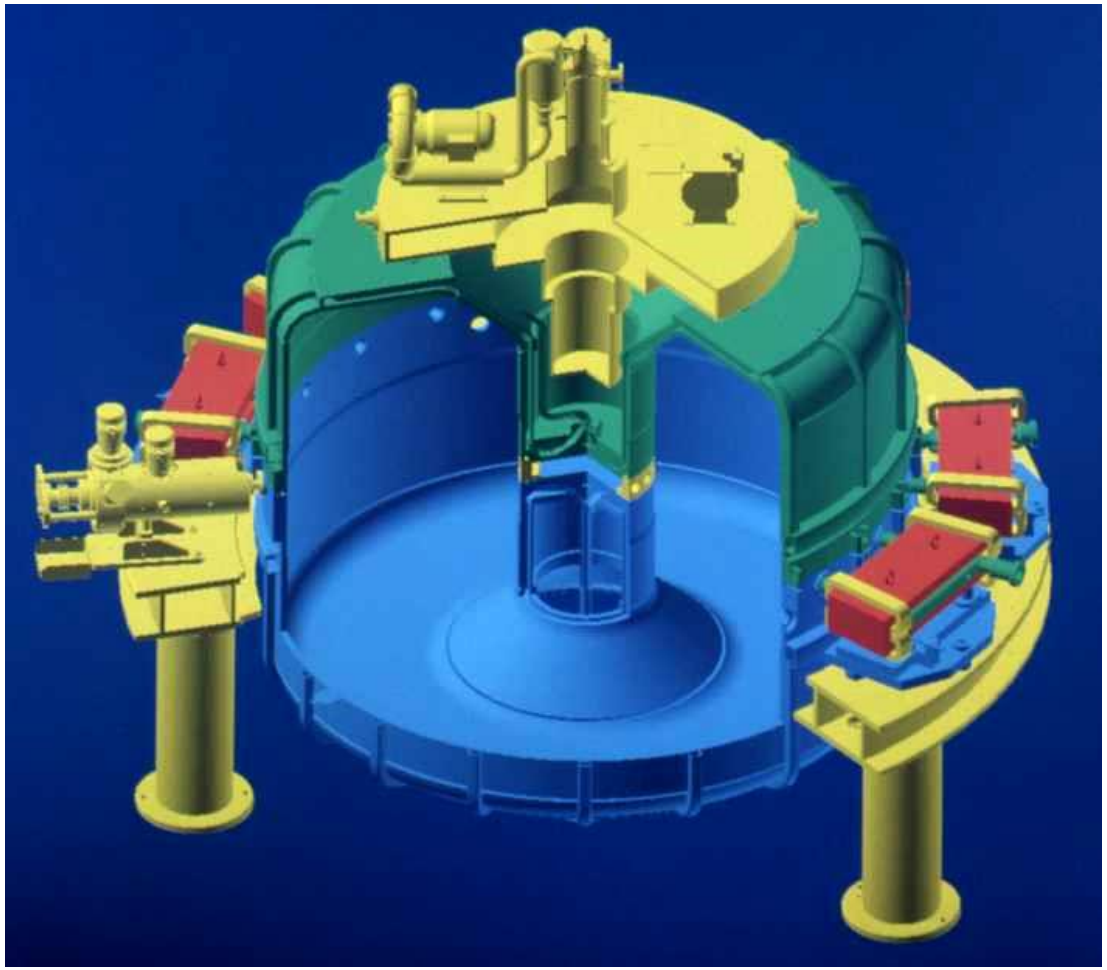
- Heavy ion beams are used to produce track-etched microfiltration membranes, commercialized i.a. under the brand name “ Cyclopore”
- In these membranes, tracks of slow, heavy ions crossing a sheet of polymer are chemically etched, giving cylindrical pores of very accurate diameter





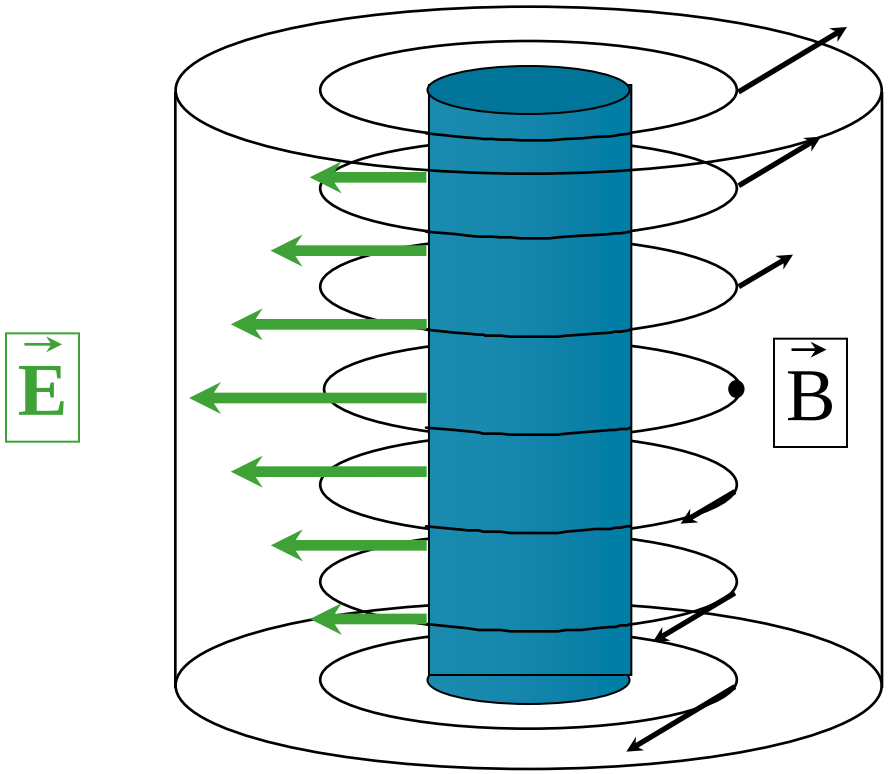
High power E-beam accelerators: 1) the Rhodotron

- **Typical applications of the Rhodotron:**



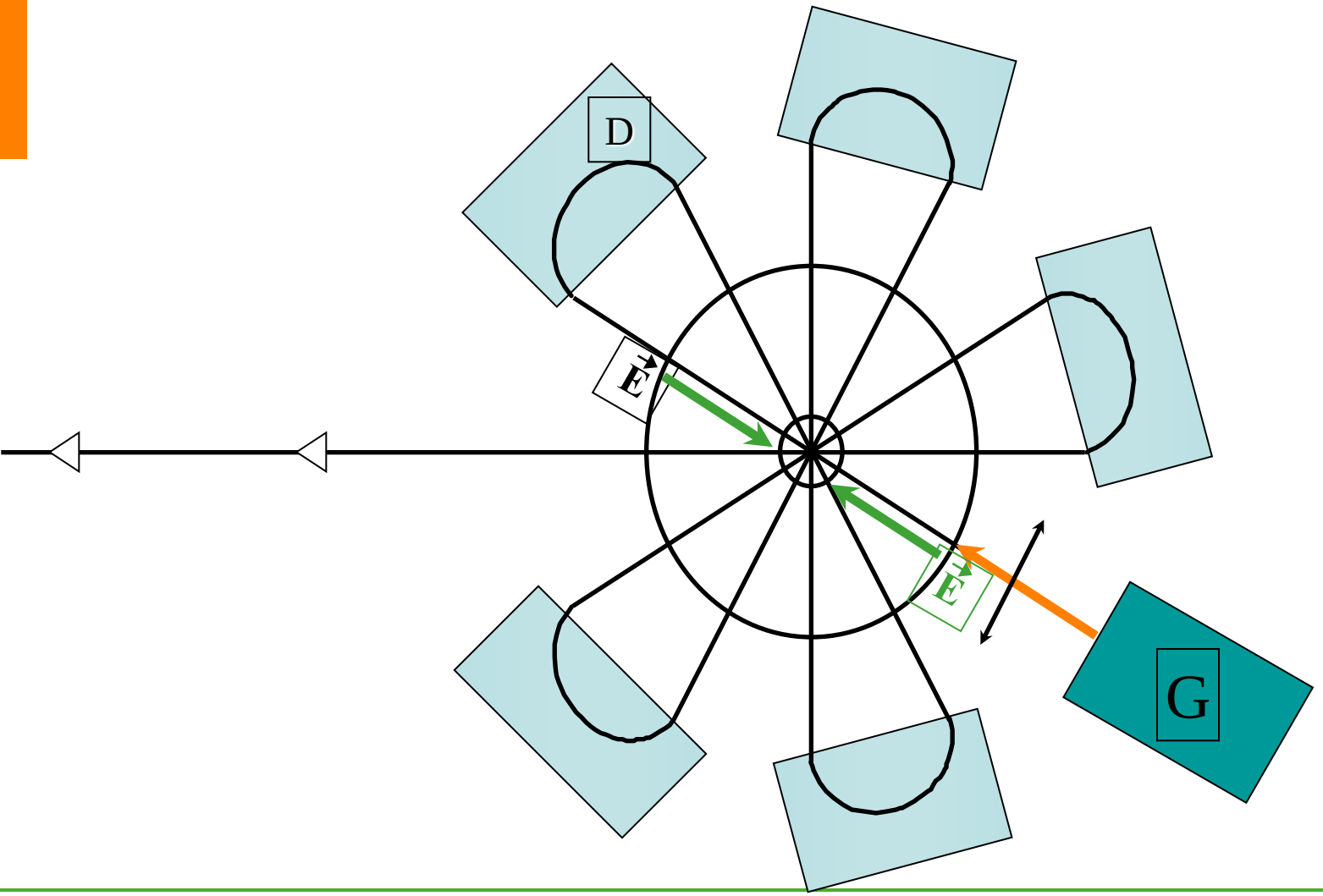
- Modification of polymers
- Sterilization of medical devices
- Preservation of foods
- Treatment of waste materials
- Gemstones and semiconductors

Acceleration principles



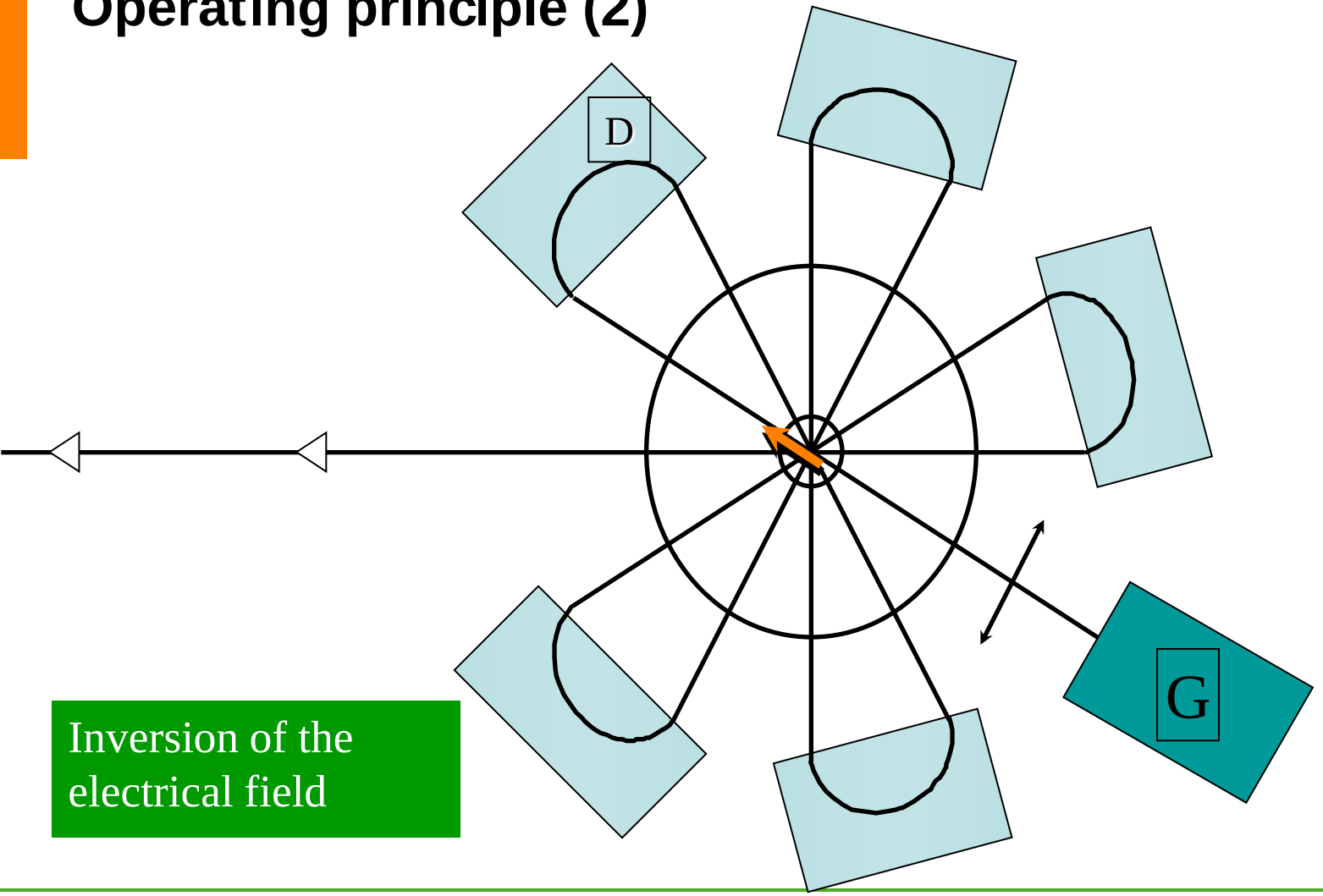
Electric ($\vec{E}$) and magnetic ($\vec{B}$) fields
in Rhodotron coaxial cavity

Acceleration principles



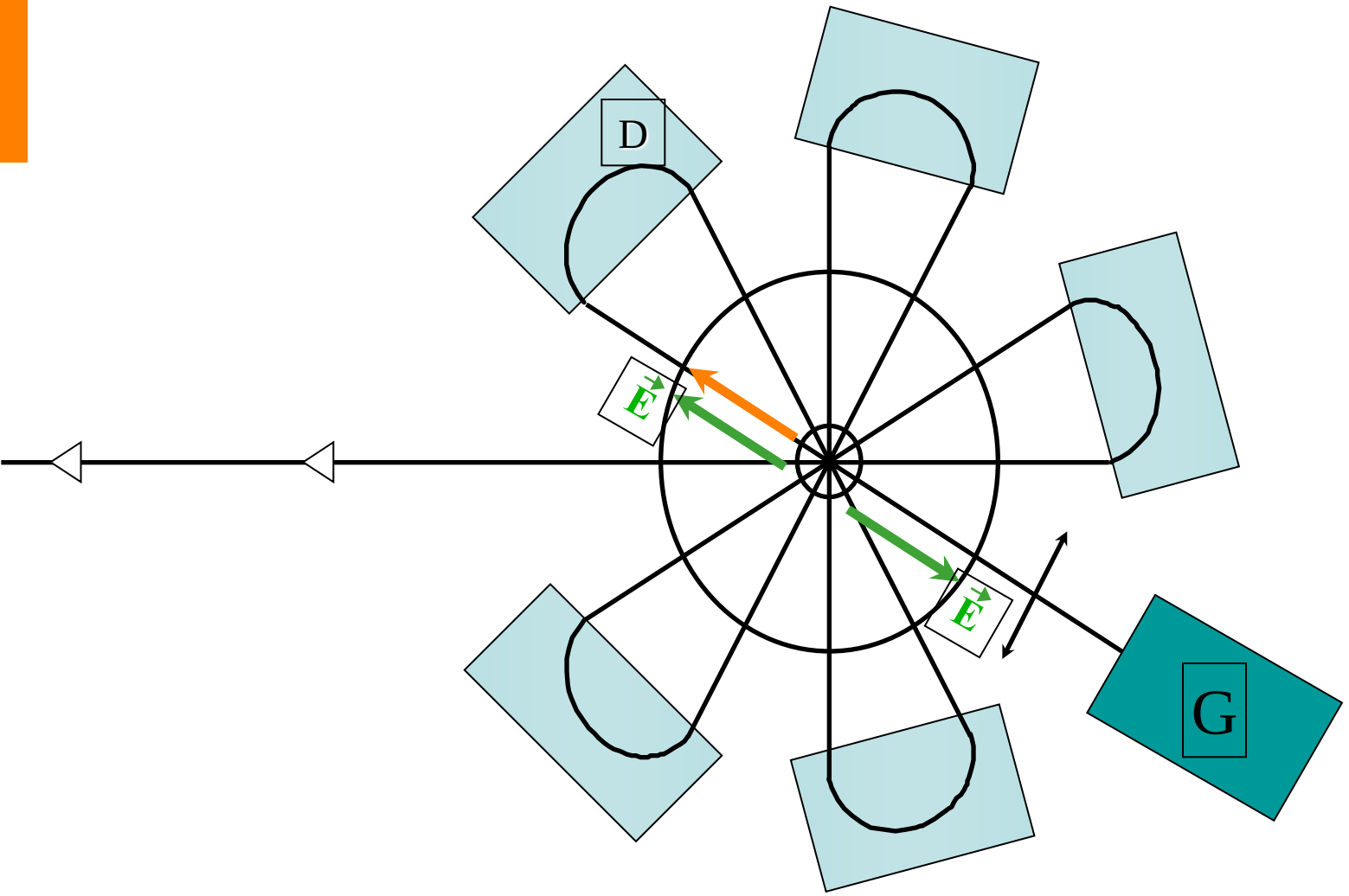
Acceleration principles

Operating principle (2)

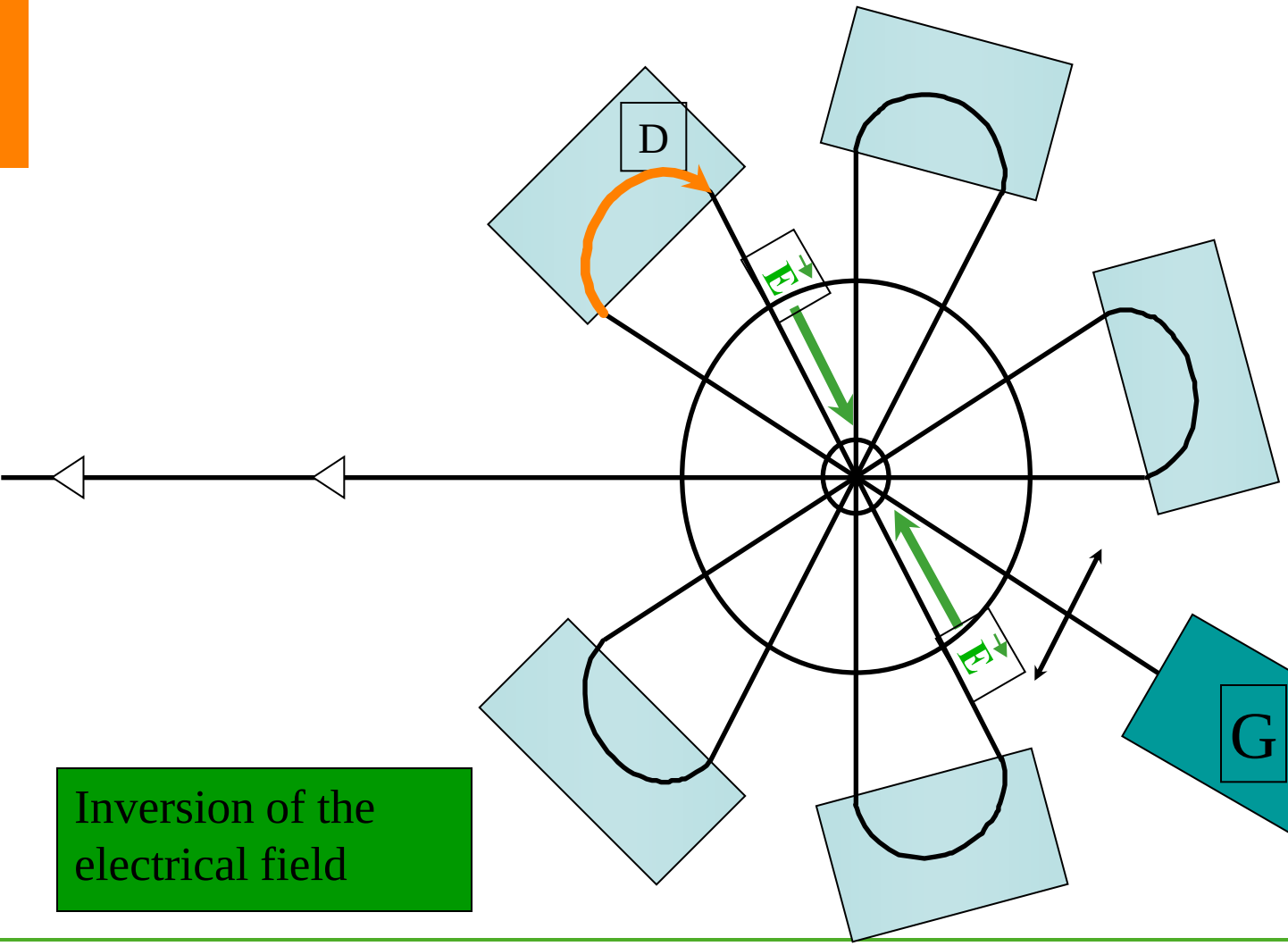


Inversion of the electrical field

Acceleration principles



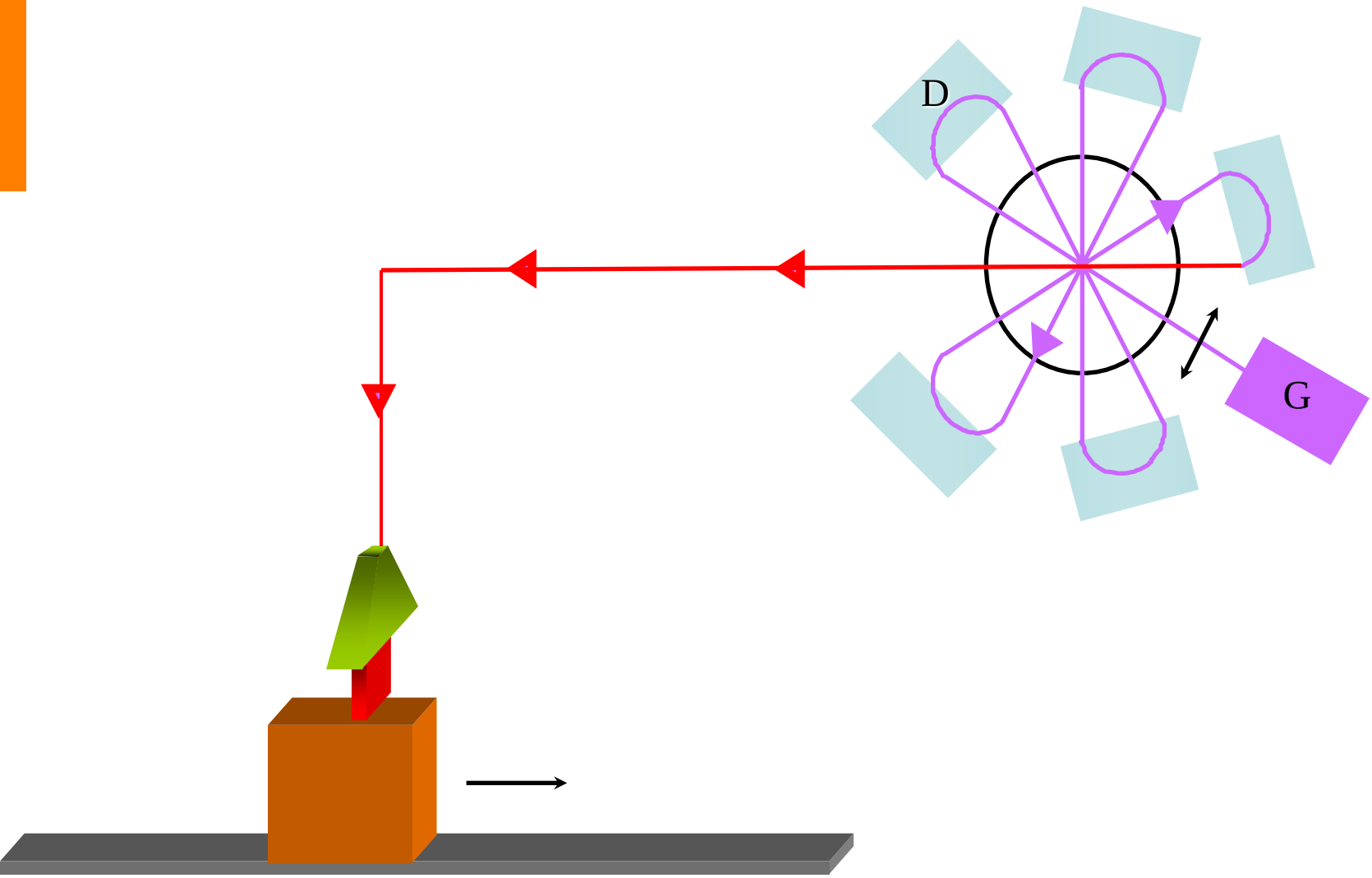
Acceleration principles



Inversion of the electrical field

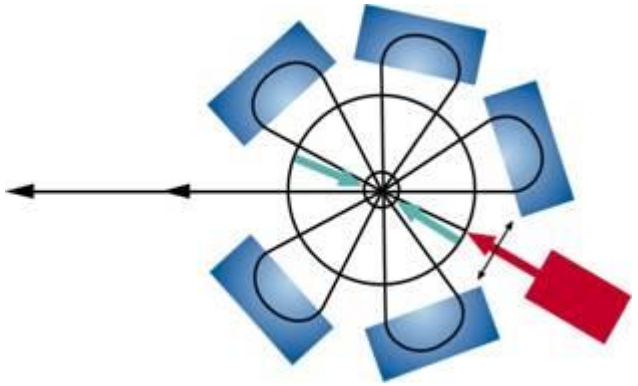
Deflection of the electrons

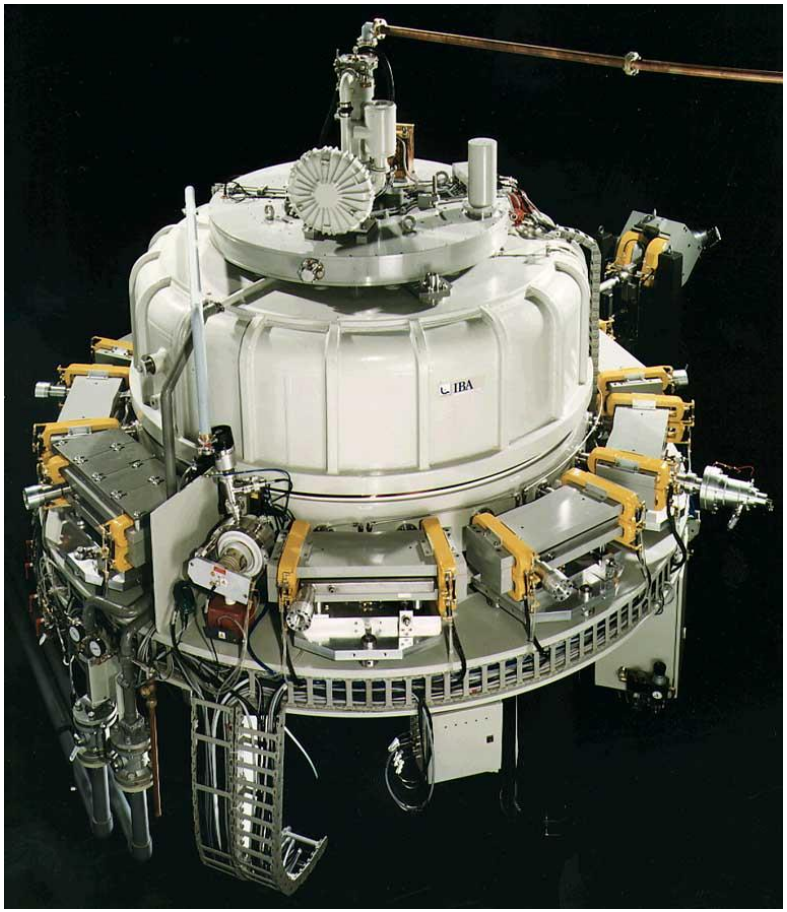
Acceleration principles



Rhodotron

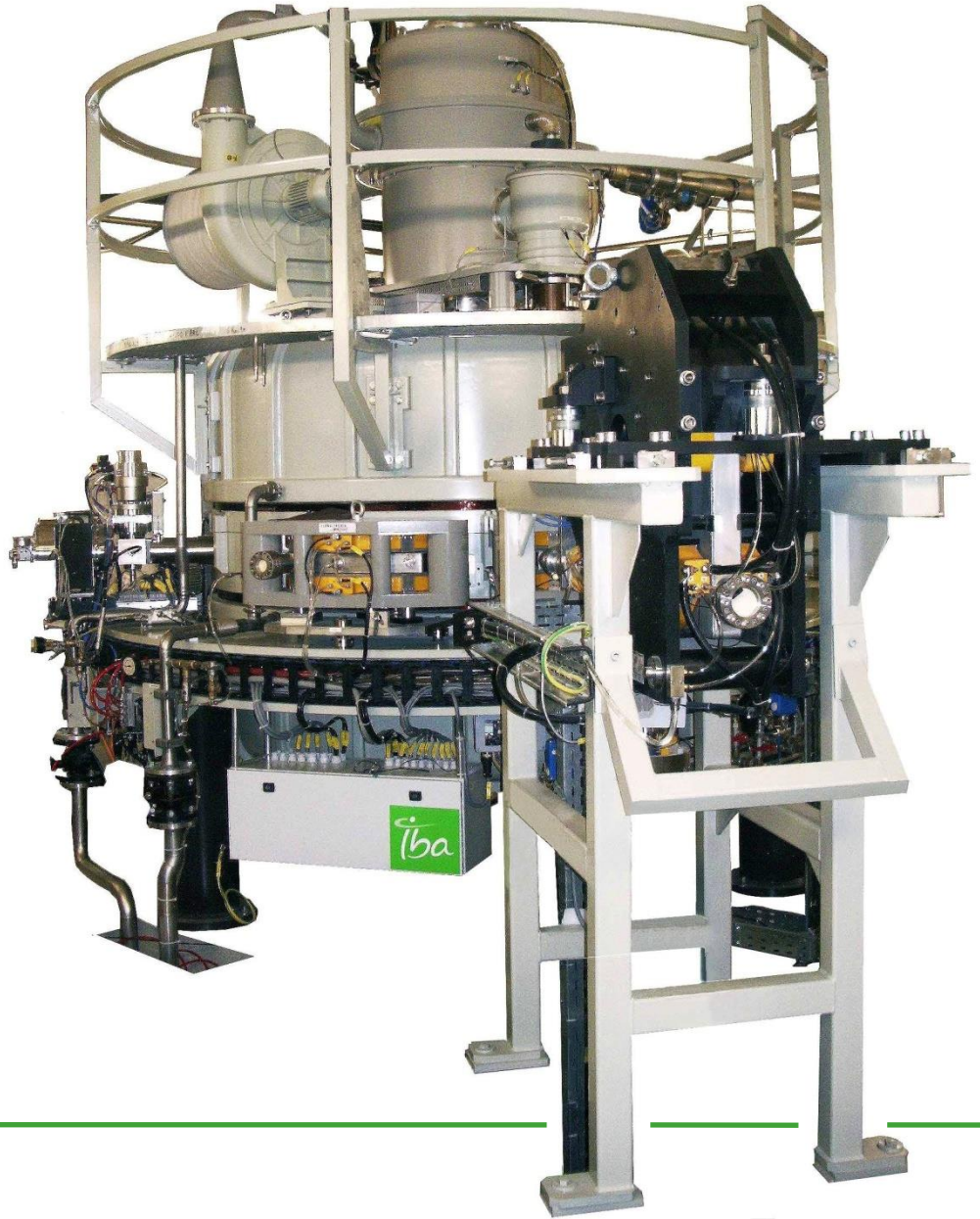
- TT200 – TT300





Rhodotron

- **TT1000**



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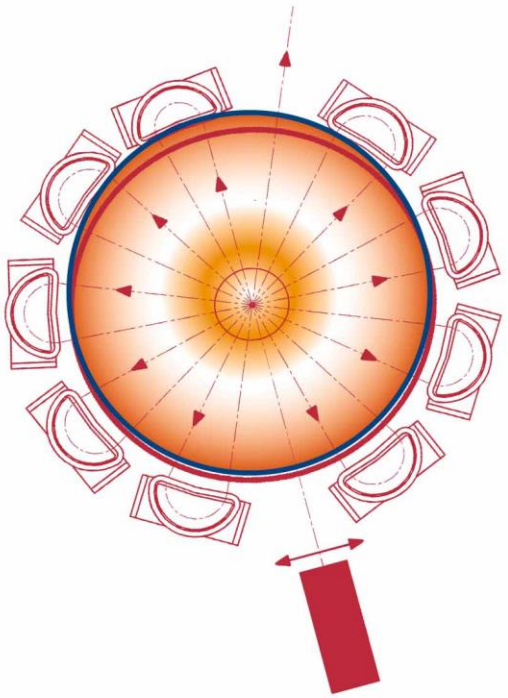
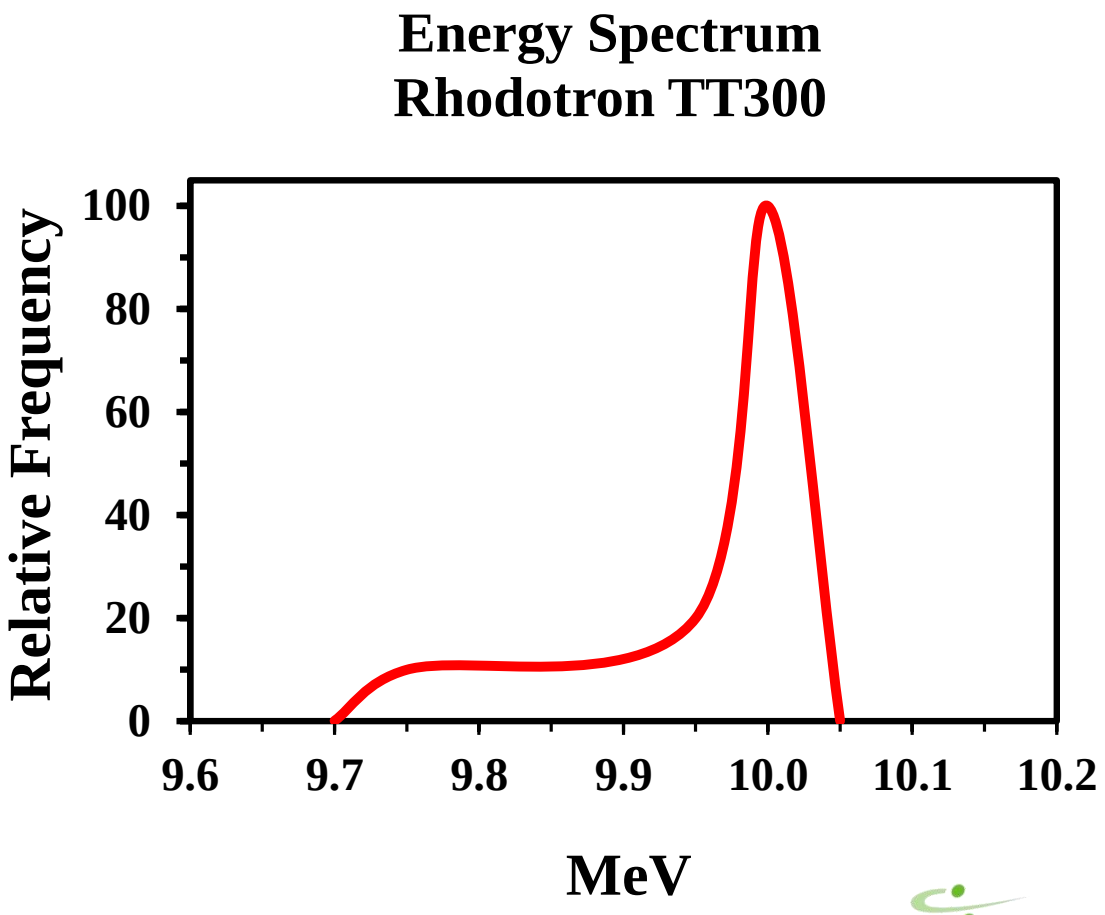
Rhodotron

	TT100	TT200	TT300	TT1000
Beam energy (MeV)	3~10	3~10	3~10	2.4~7
Maximum beam power (kW)	35	80	190	700
Design value (kW)	45	100	200	1000
Cavity diameter (m)	1.60	3.00	3.00	3.00
Cavity height (m)	1.75	2.40	2.40	2.40
Weight (T)	2.5	11	11	12
MeV/pass	0.833	1.0	1.0	1.167
Number of passes	12	10	10	6
Electrical power at full beam	<210	<260	<440	<1300

Rhodotron

- **Multiple checks on beam energy**
  - Each magnet is a energy filter

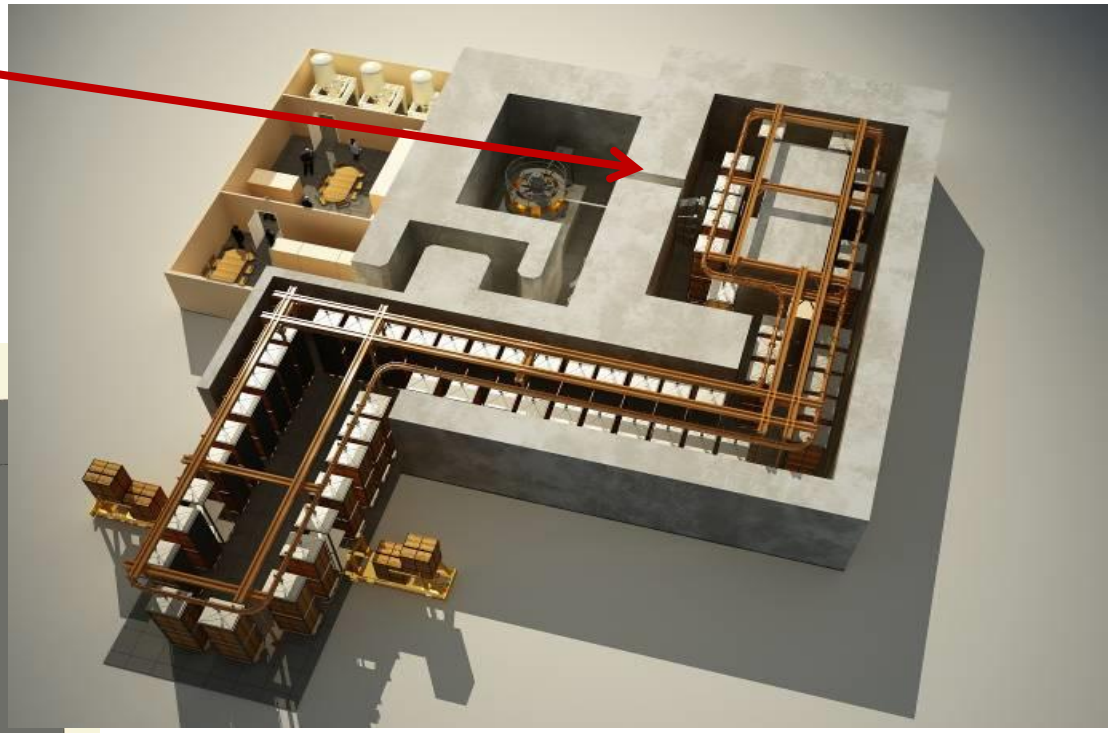


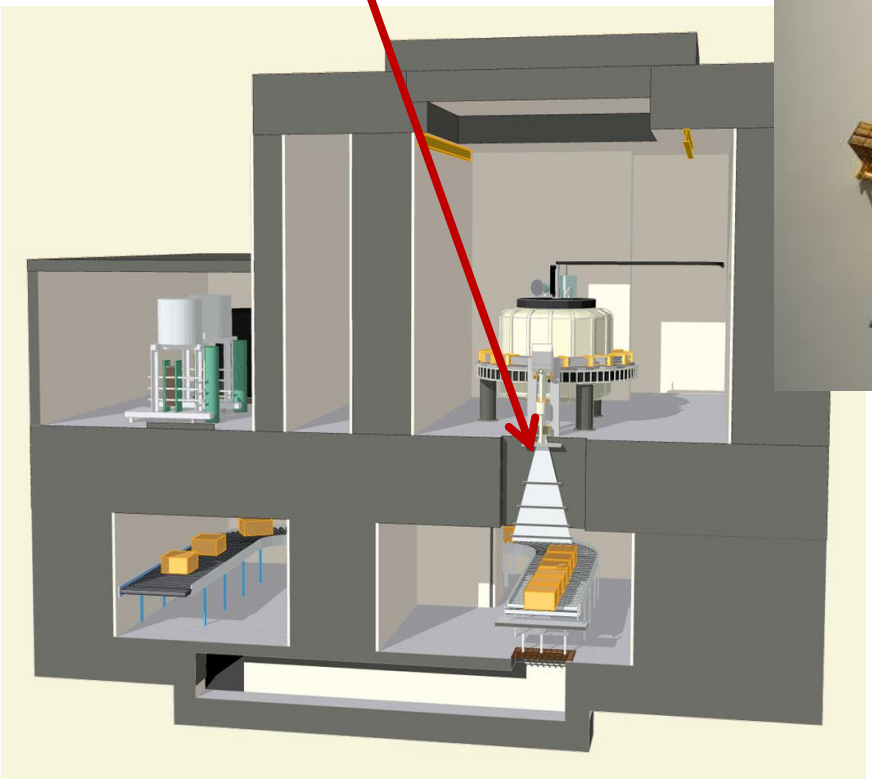


Rhodotron: typical layouts of irradiation centers

Irradiation from the side

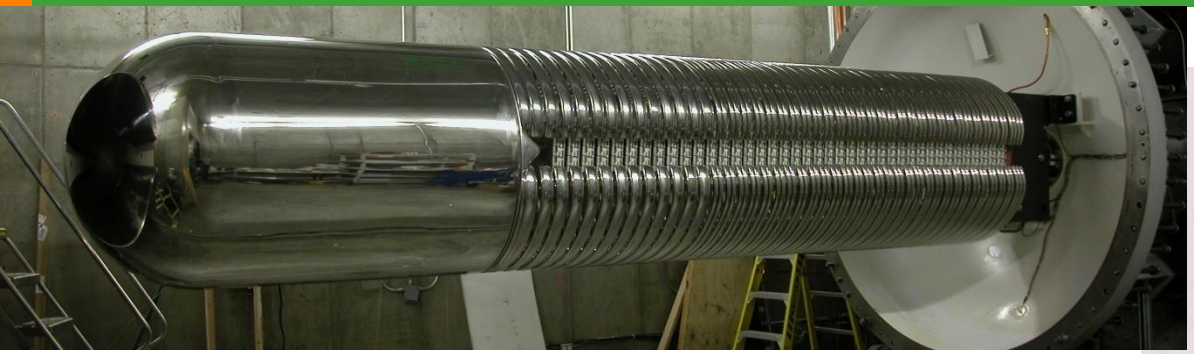
Irradiation from above

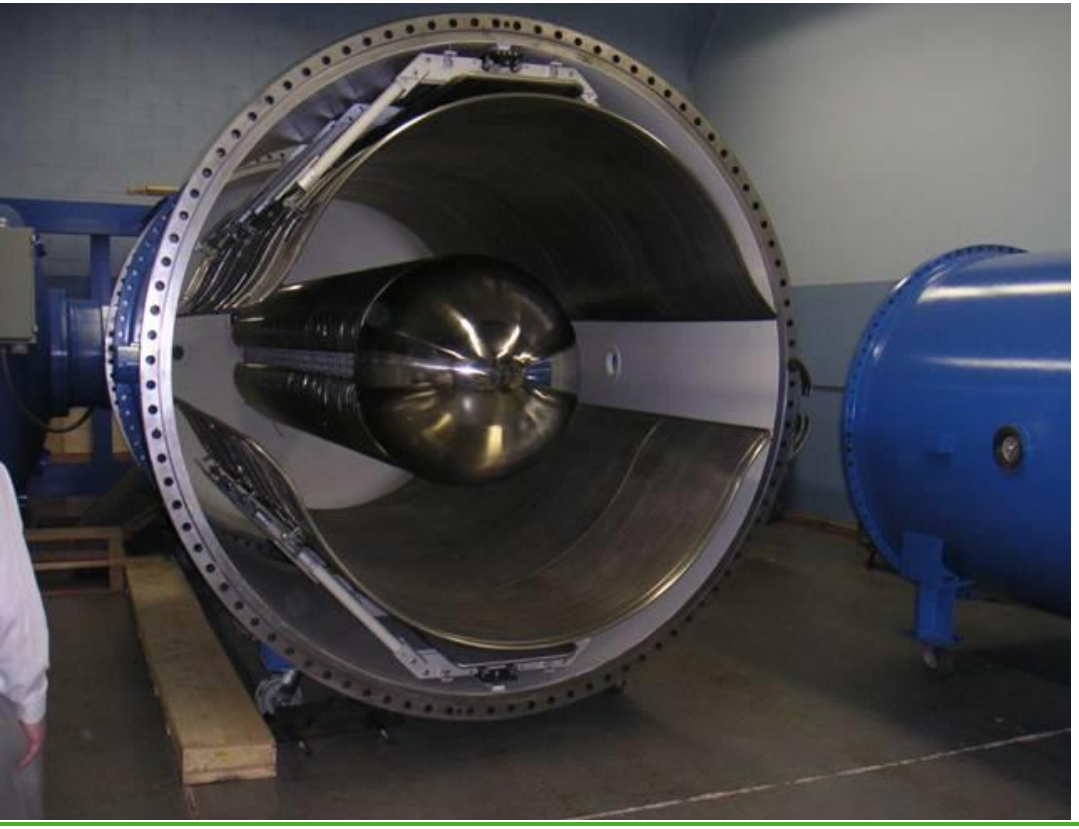


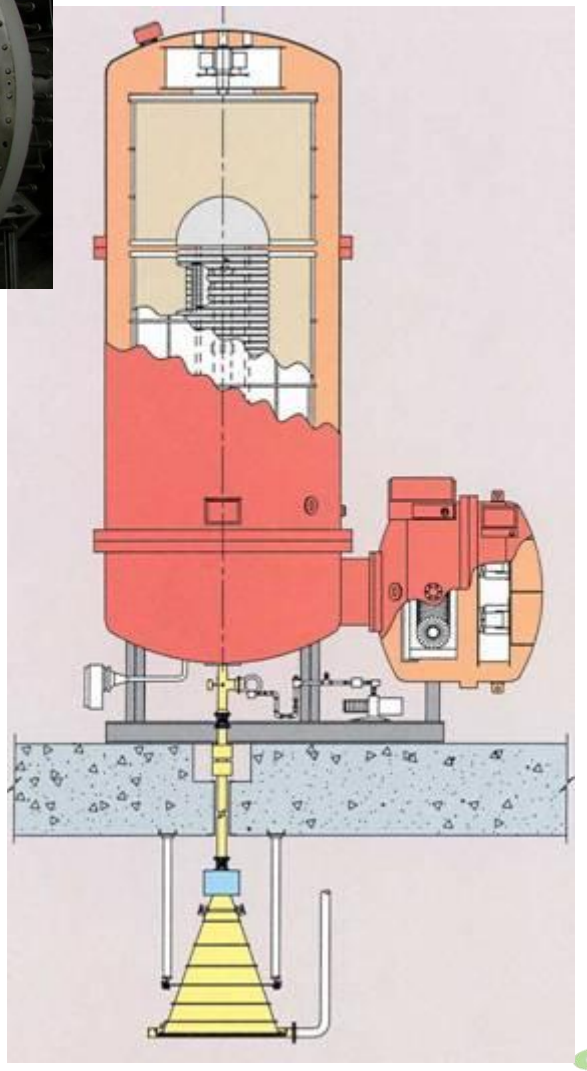


Spreading of the beam by a magnetic scanning system

High power E-beam accelerators: 2) the Dynamitron







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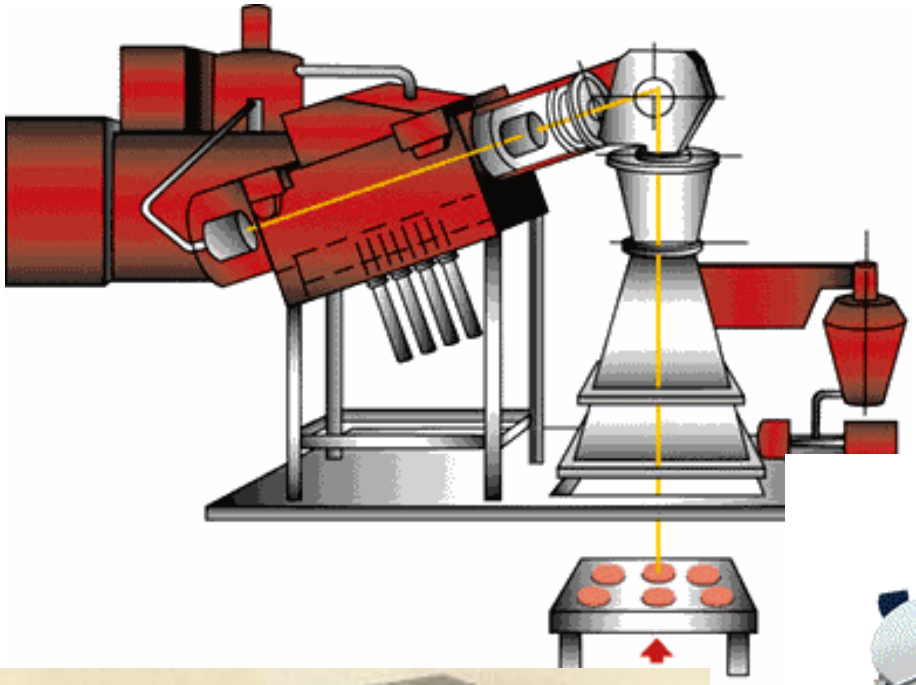
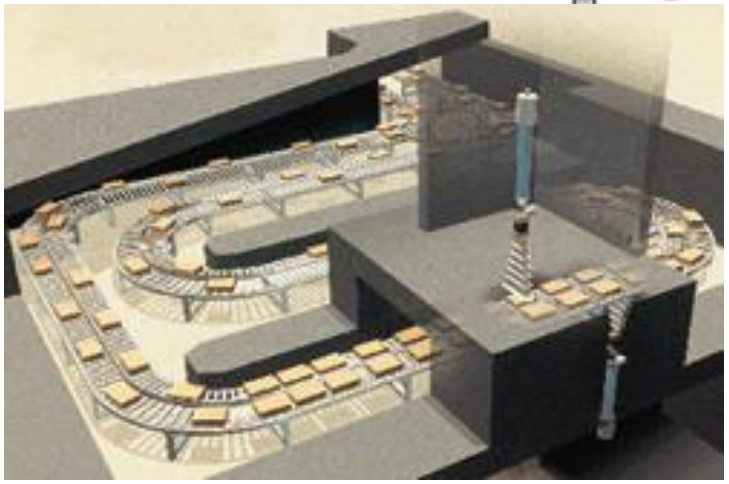
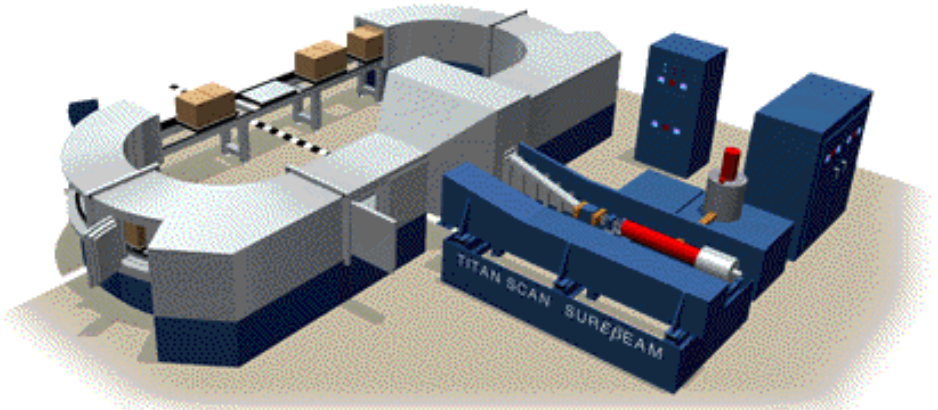
High power E-beam accelerators: 3) the Linacs







On-Site is a complete turn key operating system validated to ISO 11137 and delivered with all required training, documentation, dosimetry system and process certification.

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Thank you !

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