Sterilization and disinfection by electron beam irradiation

Seminar „Fighting pathogens – sterilization, disinfection and biocide approaches“ 29th March 2022

Dr. Steffen Günther

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº101016203.

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Outline

- Electron beam – some basics
- Comparison of sterilization methods
- Examples of Electron beam sterilization or disinfection
- Summary and Closing

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Electron beam – some basics

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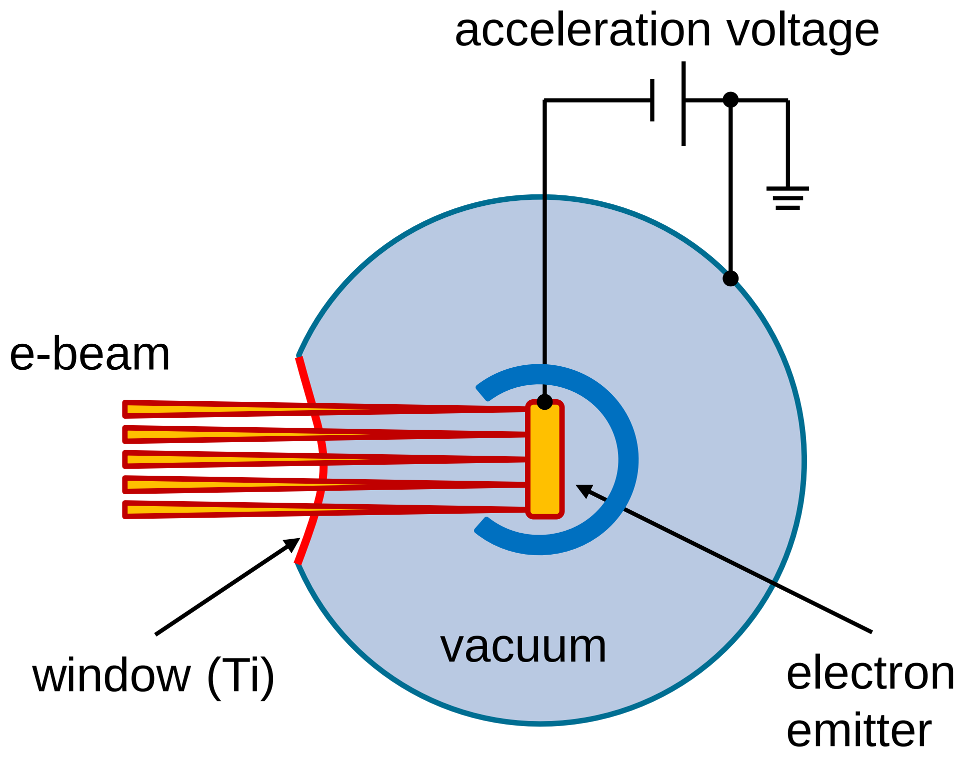
Generation of electron beams at atmospheric pressure



- generation in vacuum through glow discharge or thermionic emission
- acceleration by high voltage (50 … 300 kV … 10 MV)
- transfer through electron-transparent window to atmosphere

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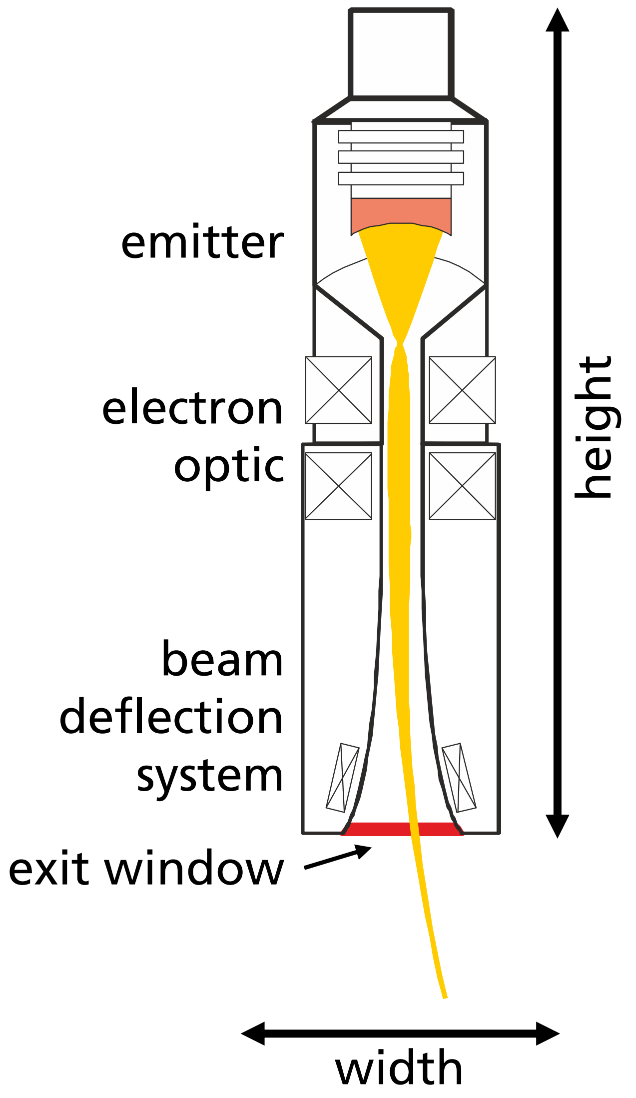
Electron beam device – types, typical parameters

Scanner type

- electron emission from “point source”
- acceleration voltage up to 10 MV
- complex and sophisticated electron optic
- increased radiation width is linked to increased height
- high uniformity
- limited radiation dose @ increased width



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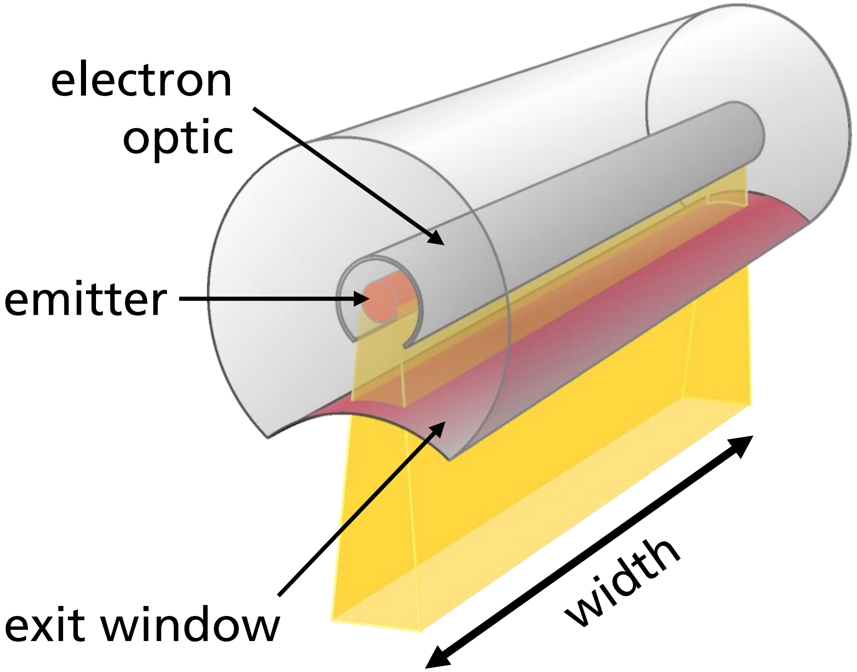
Electron beam device – types, typical parameters

Linear type

- electron emission from “line source”
- acceleration voltage mostly limited to 300 kV
- simple electron optic
- radiation widths up to 3,3 m
- limited uniformity
- radiation dose nearly independent from width



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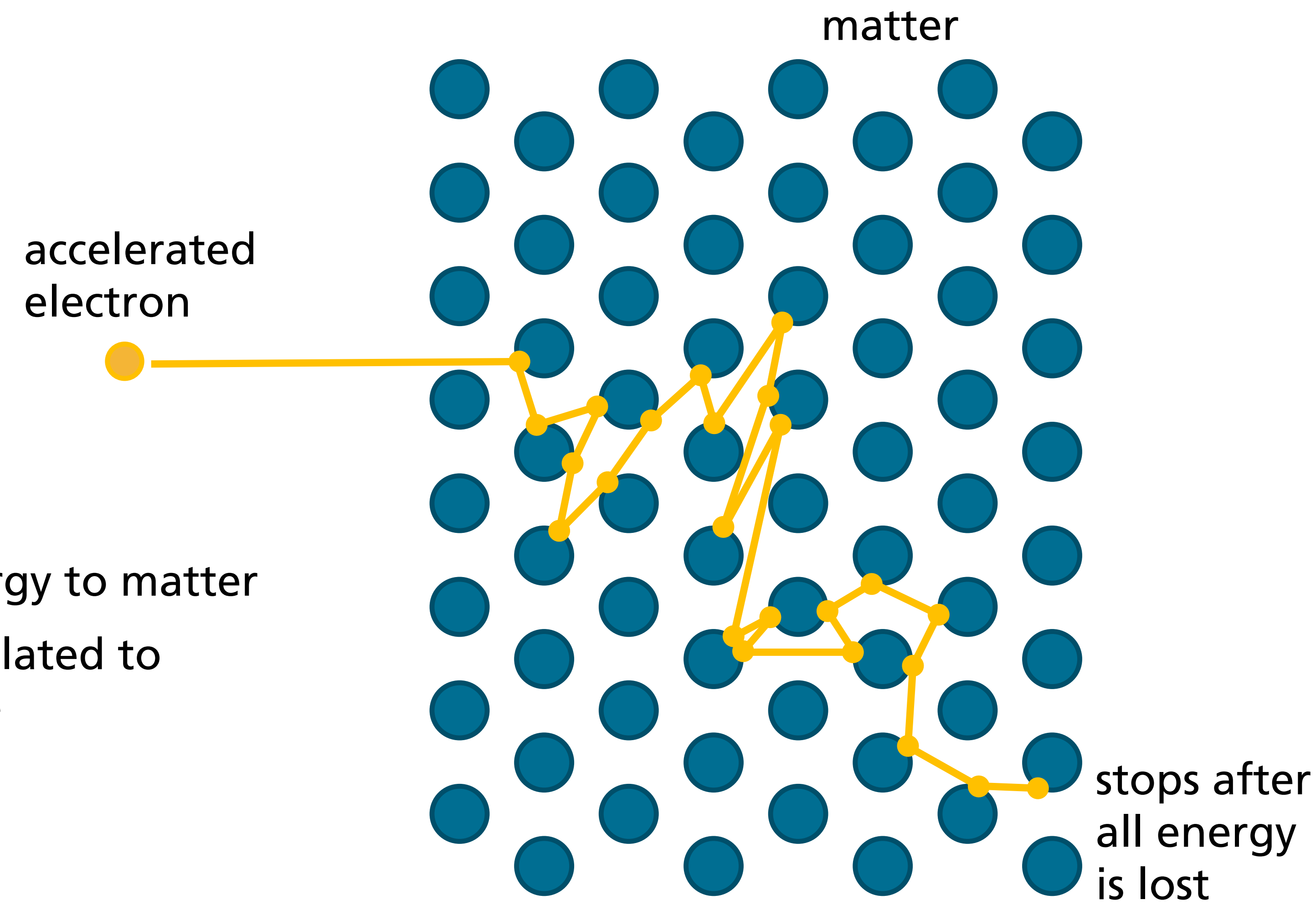
Interaction of electron beams with matter

- primary electron hit matter
- ionize atoms (some energy loss)
- create secondary electrons



- accelerated electrons transfer energy to matter
- amount of transferred energy is related to irradiated mass ➔ irradiation dose
- unit definition: 1 J/g = 1 kGy

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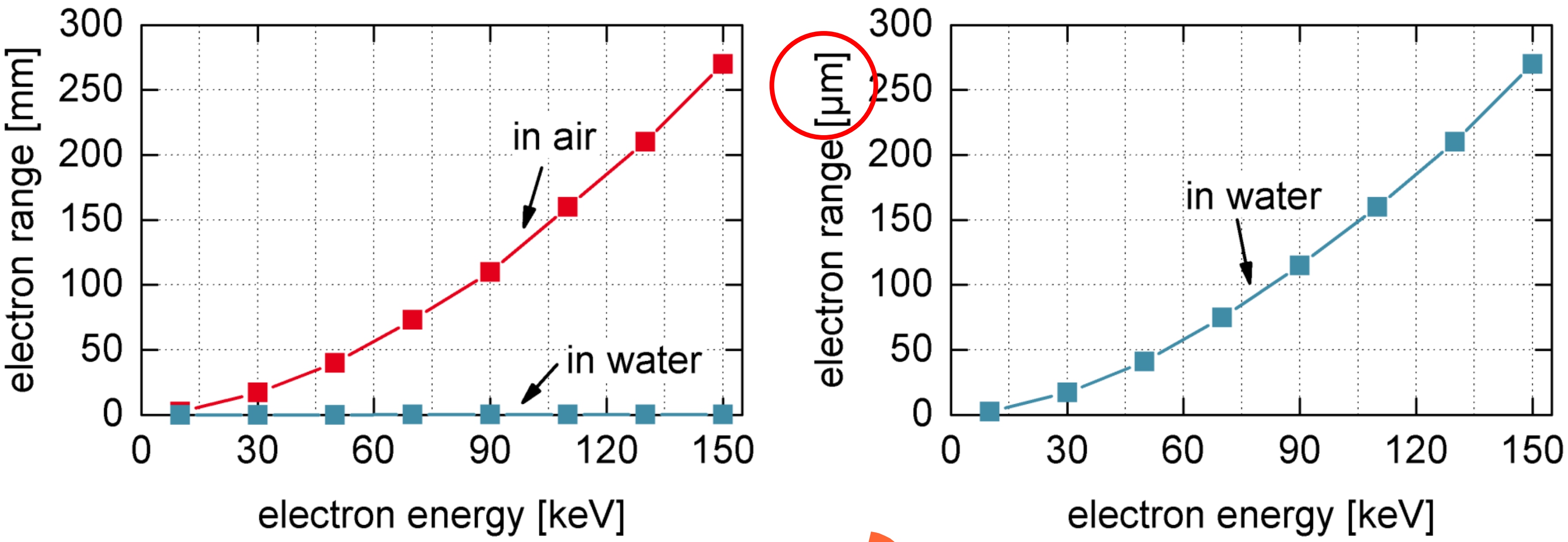
Interaction of electron beams with matter



- electron range depends on
  - density of material
  - acceleration voltage / electron energy

rule of thumb
1 µm per 1 keV @ 1 g/cm³

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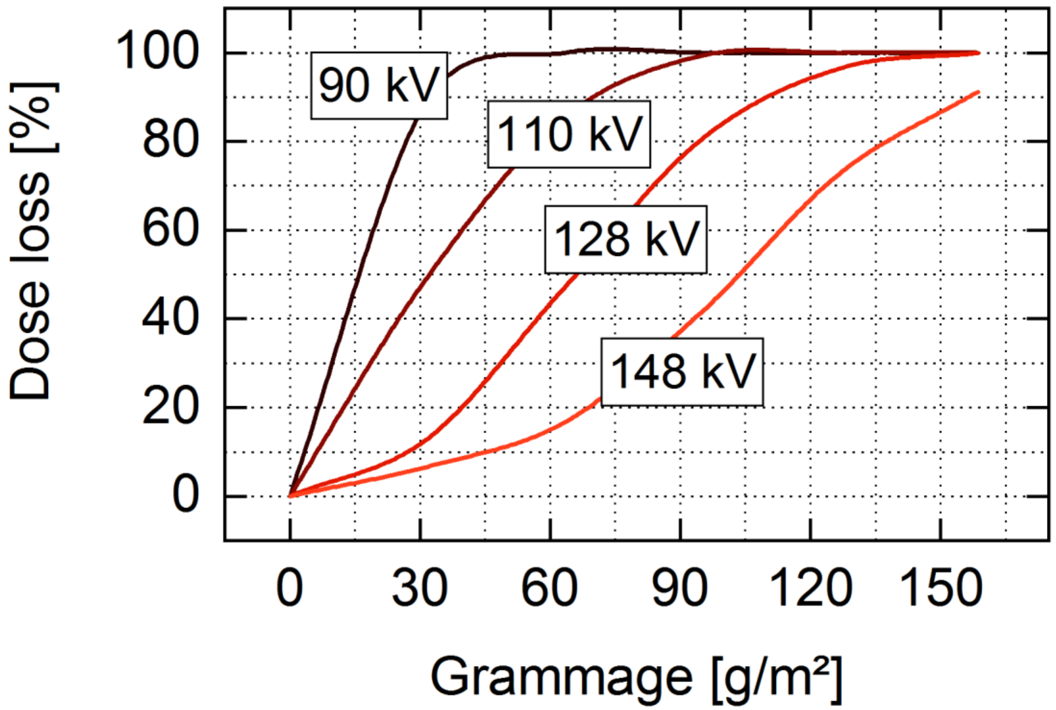
Interaction of electron beams with matter



- irradiation intensity decreases with penetration depth
- decrease rate is energy dependent

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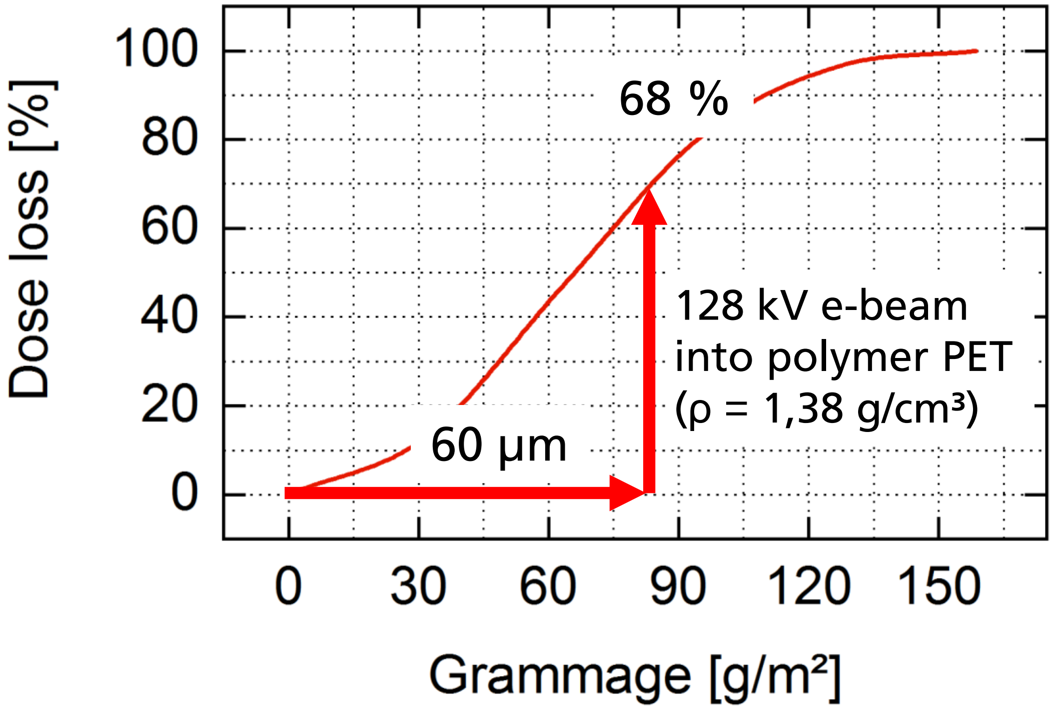
Interaction of electron beams with matter



- if material thickness is less than maximum penetration depth, only fraction of energy is absorbed by the material
- example: 60 µm thickness ➔ only 68 % of energy absorption ➔ determine dose; 32 % of energy is transmitted ➔ has to be handled

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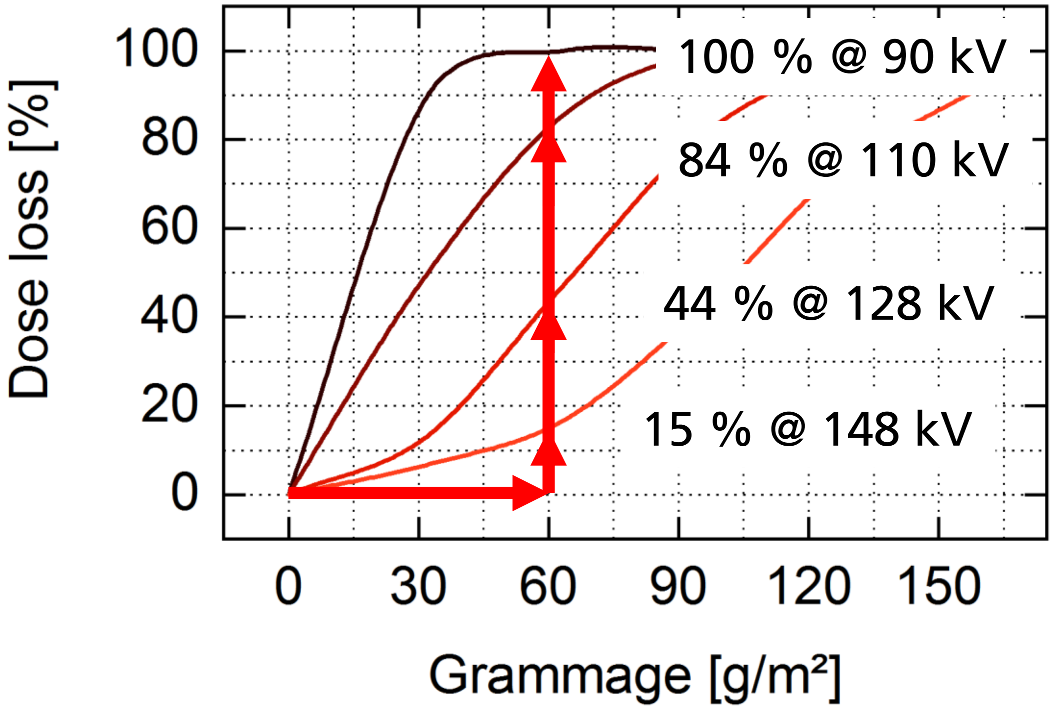
Interaction of electron beams with matter



- absorbed energy (dose) decreases with increased acceleration voltage
- optimization of voltage and beam power is possible

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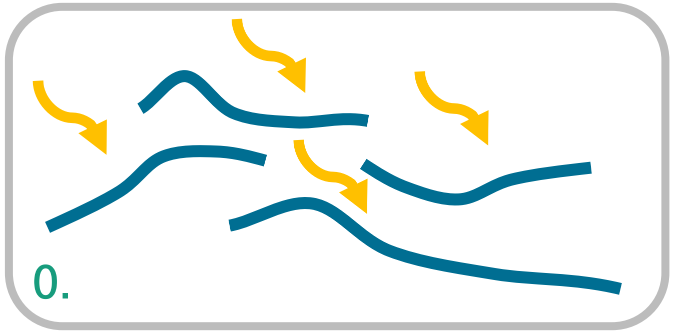
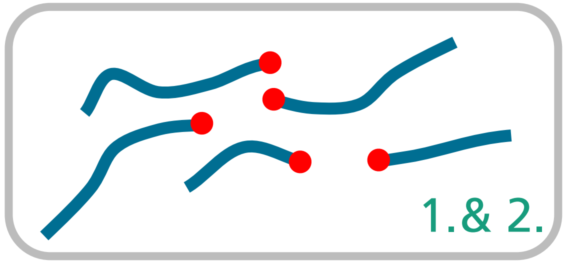
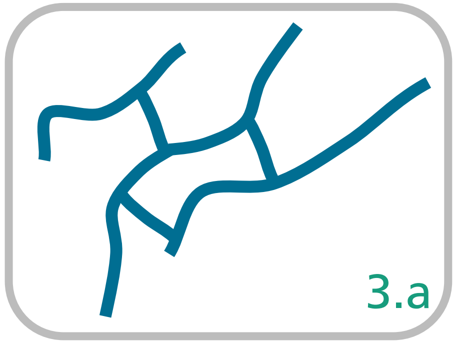
Molecular effects by irradiation of organic materials by electron beams

1. breaking of bonds
2. formation of radicals

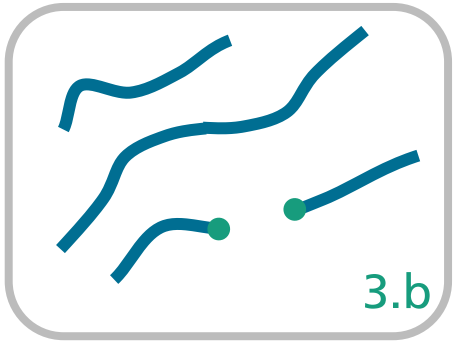
3. effects depend on radiation intensity, molecular structure, chemical nature etc.
   a. curing / cross-linking
   b. chain scission
   c. de-polymerization



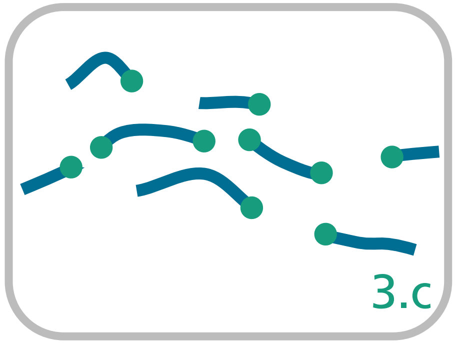




e.g. increase stiffness



e.g. reduce tear strength



e.g. PTFE powder production

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Comparison of sterilization methods

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Comparison of sterilization methods

Sterilization method	Parameter	Time effort
Ethylene oxide	54 °C, 6 % C_2H_4O + CO_2	1 to 6 hour
Dry heat	180 °C	30 to 120 min
Formaldehyde	60 °C, 30 ppm CH_2O	60 min
Steam pressure	121 °C	3 to 20 min
Electron beam	-	1 to 3 sec

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Comparison of sterilization methods

Investment costs

Electron beam

Ethylene oxide

Form-aldehyde

Steam pressure

Dry heat

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Comparison of sterilization methods

Sterilization method	Materials / goods to be sterilized							
	Metal	Polymers	Textiles	Ceramics	Powder	Liquids	Electro-nics	Bio-material
Ethylene oxide	[green]	[green]	[green]	[green]	[red]	[red]	[green]	[red]
Dry heat	[green]	[red]	[yellow]	[green]	[green]	[yellow]	[red]	[red]
Formaldehyde	[green]	[green]	[green]	[green]	[red]	[red]	[green]	[red]
Steam pressure	[yellow]	[red]	[green]	[green]	[red]	[green]	[red]	[red]
Electron beam	[green]	[green]	[green]	[green]	[yellow]	[yellow]	[green]	[green]

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Examples of Electron beam sterilization or disinfection

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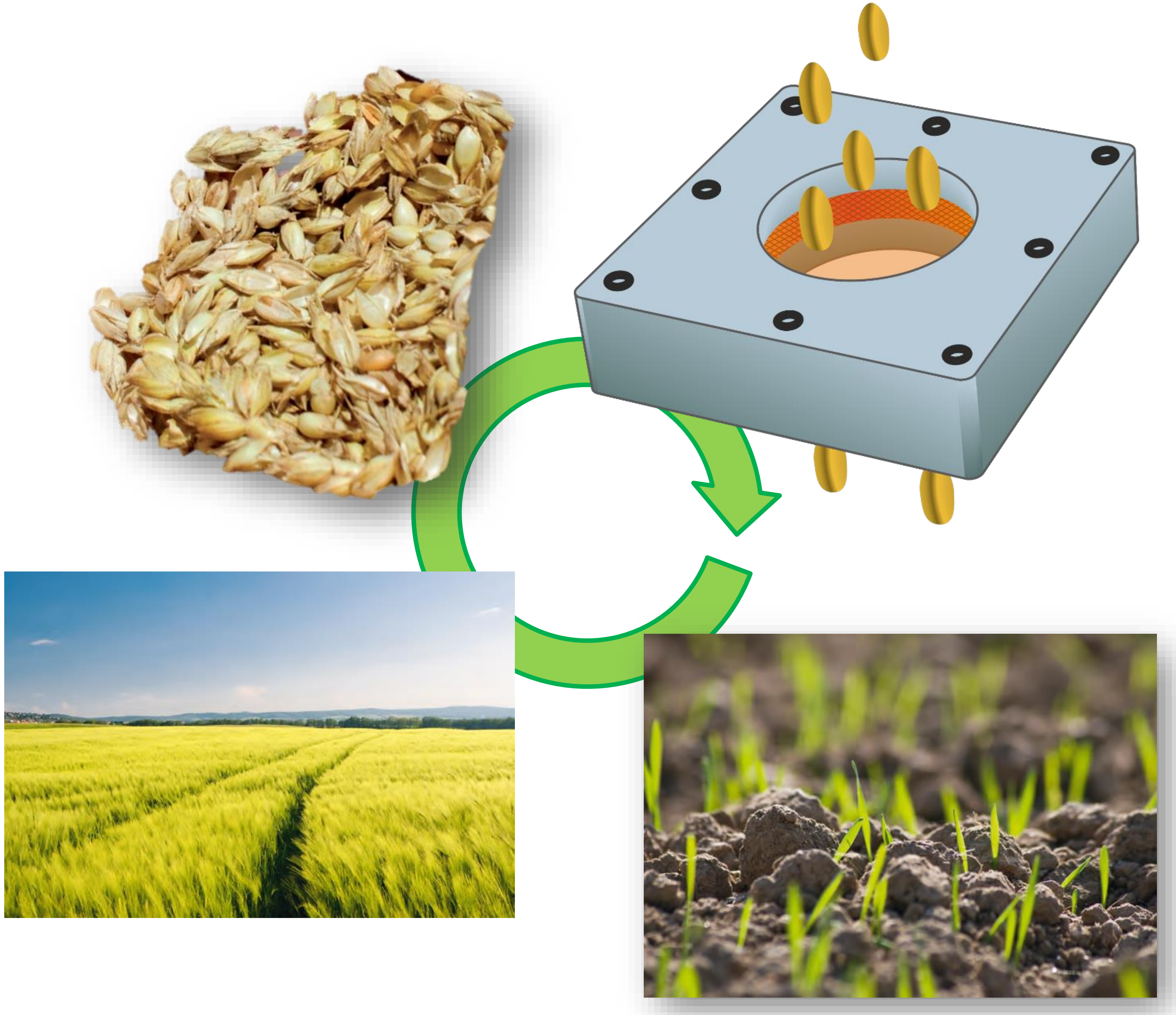
Sterilization of seeds and grains

- Benefit from well-defined electron penetration depth
- Destroying all pathogens within or on top the seed shell
- No harming of embryo within the seed
- Alternative green method for chemical treatment
- Max. throughput several 10 tons per hour



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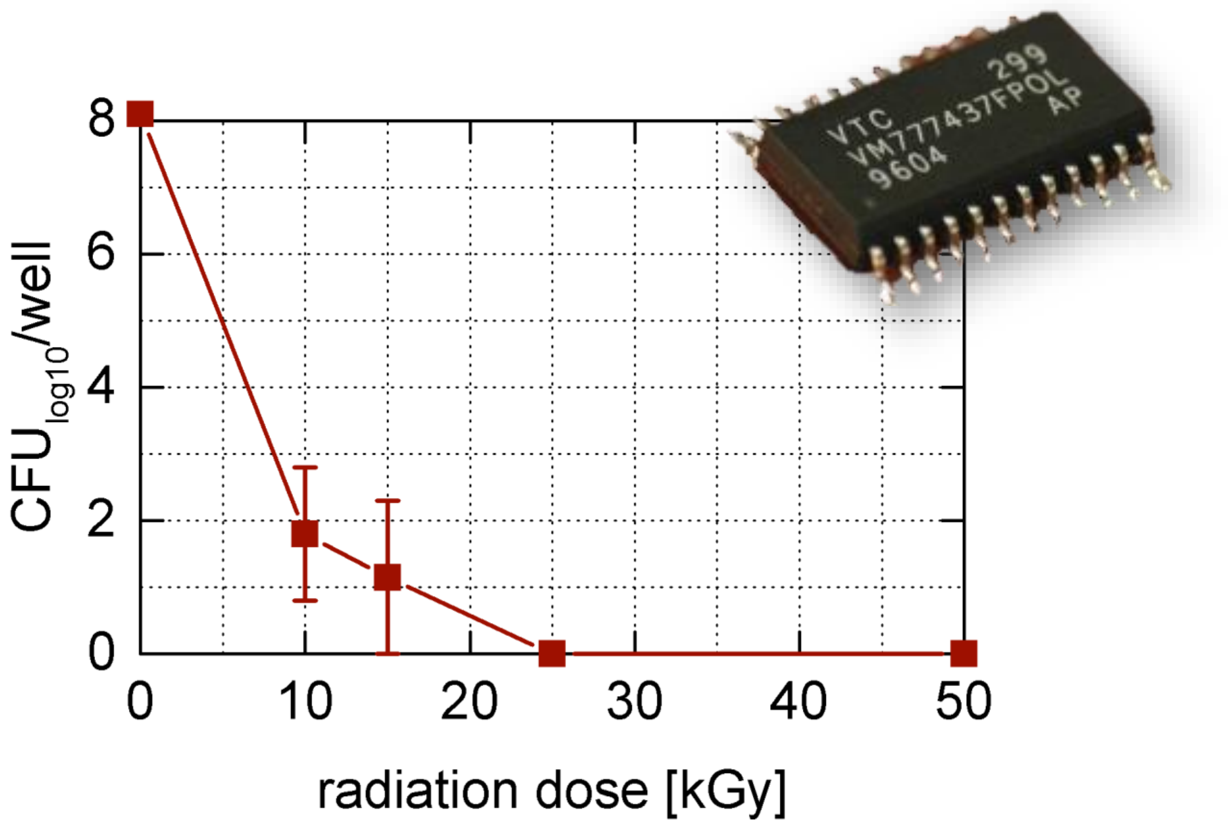
Sterilization of electronic devices

- Benefits also from well-defined electron penetration depth
- 8-log pathogen reduction
- ➢ fully functional after irradiation



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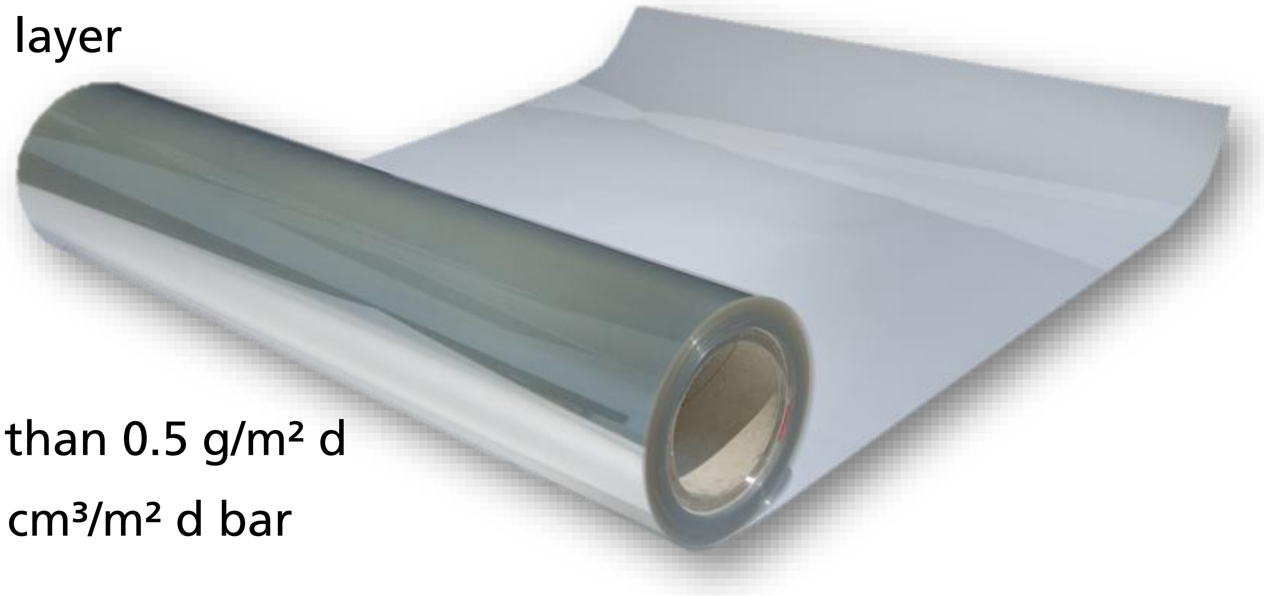
Sterilization of permeation barrier films for packaging

<u>Background</u>

- 17 µm thin biaxially oriented polypropylene film (BOPP)
- Coated with 10 nm thin AlO_x permeation barrier layer
- Application areas
  - Food packaging
  - Medical packaging
- Most demanded properties
  - Water vapour permeation barrier (WVTR) less than 0.5 g/m² d
  - Oxygen permeation barrier (OTR) less than 50 cm³/m² d bar
  - High optical transparency more than 90 %



Source: M. Dietze, Bachelor thesis, 2014

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Sterilization of permeation barrier films for packaging

<u>Topic</u>

- Comparison of sterilization methods
  - Steam pressure (DIN EN 285-2009)
    121 °C, 20 min
  - Dry air (DIN 58947-1990)
    180 °C, 30 min
  - Electron beam (DIN EN ISO 11137-2013)
    25 kGy
  - All samples protected by sterilization package

Varioklav™ 75S

Heraeus UT6200

- Investigation of sterilization success but also property changes like transparency and permeation barrier

Source: M. Dietze, Bachelor thesis, 2014

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Sterilization of permeation barrier films for packaging

<u>Results</u>

	Dry air	Steam pressure	Electron beam
Sterilization	Unknown – Films melted	okay	okay
OTR		> 1000 cm³/m²d	okay (< 50 cm³/m²dbar)*
WVTR		> 3 g/m²d	okay (< 0.5 g/m²d)
Transparency		okay (> 90 %)	okay (> 90 %)

* Sample w/o protection
(w. prot. 120 cm³/m²dbar;
may be handling issue)

Source: M. Dietze, Bachelor thesis, 2014

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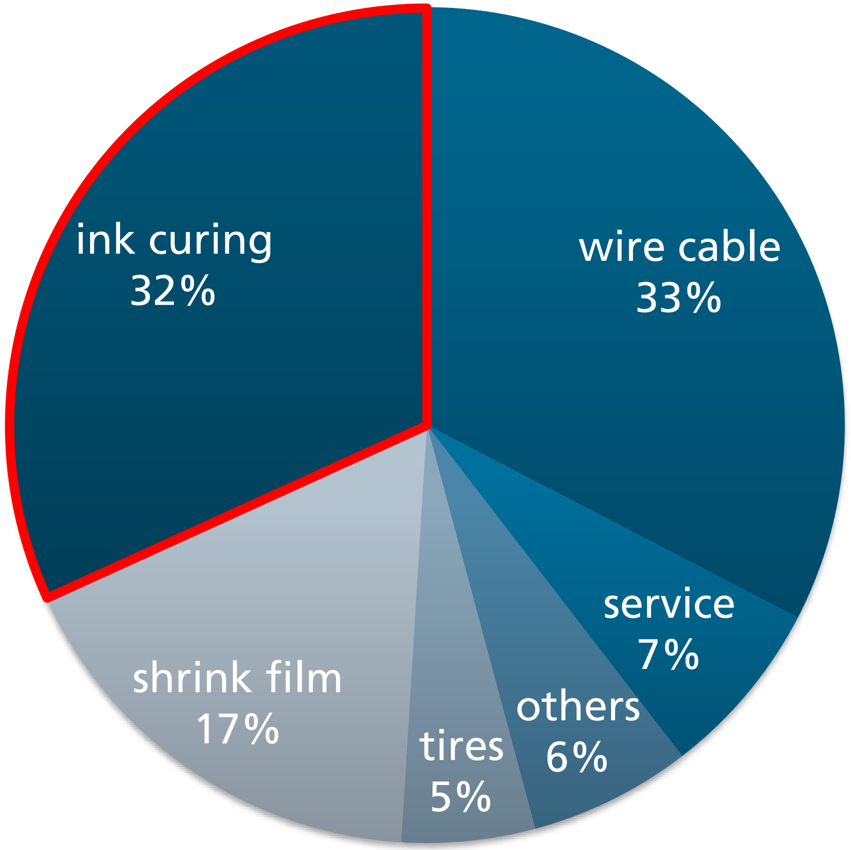
Roll-to-roll sterilization by electron beams of fabrics



Industrial Electron Beam Accelerator End-Use Markets
Source: IAEA 2011

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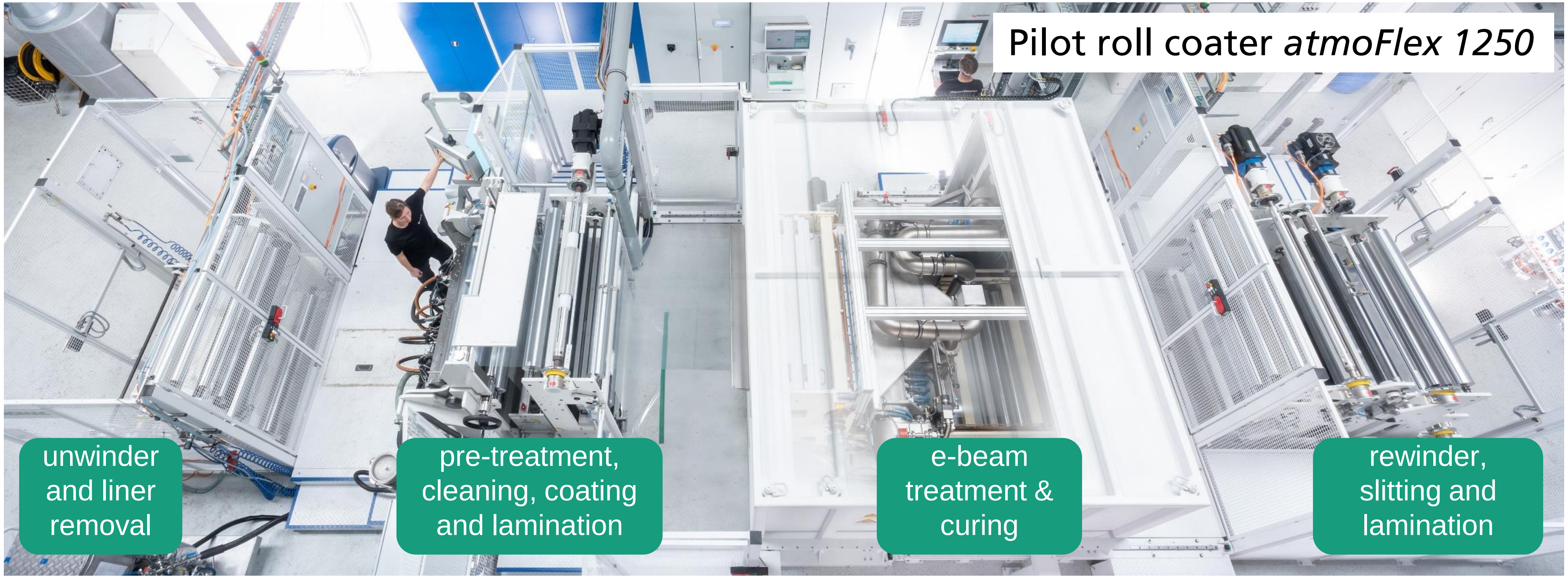
Roll-to-roll sterilization by electron beams of fabrics

- 1250 mm web width
- web speed up to 150 m/min
- wet/dry lamination
- slot die coating @ 1200 mm coating width
- electron beam treatment & curing
- typical substrates: polymer films, paper, metal foils



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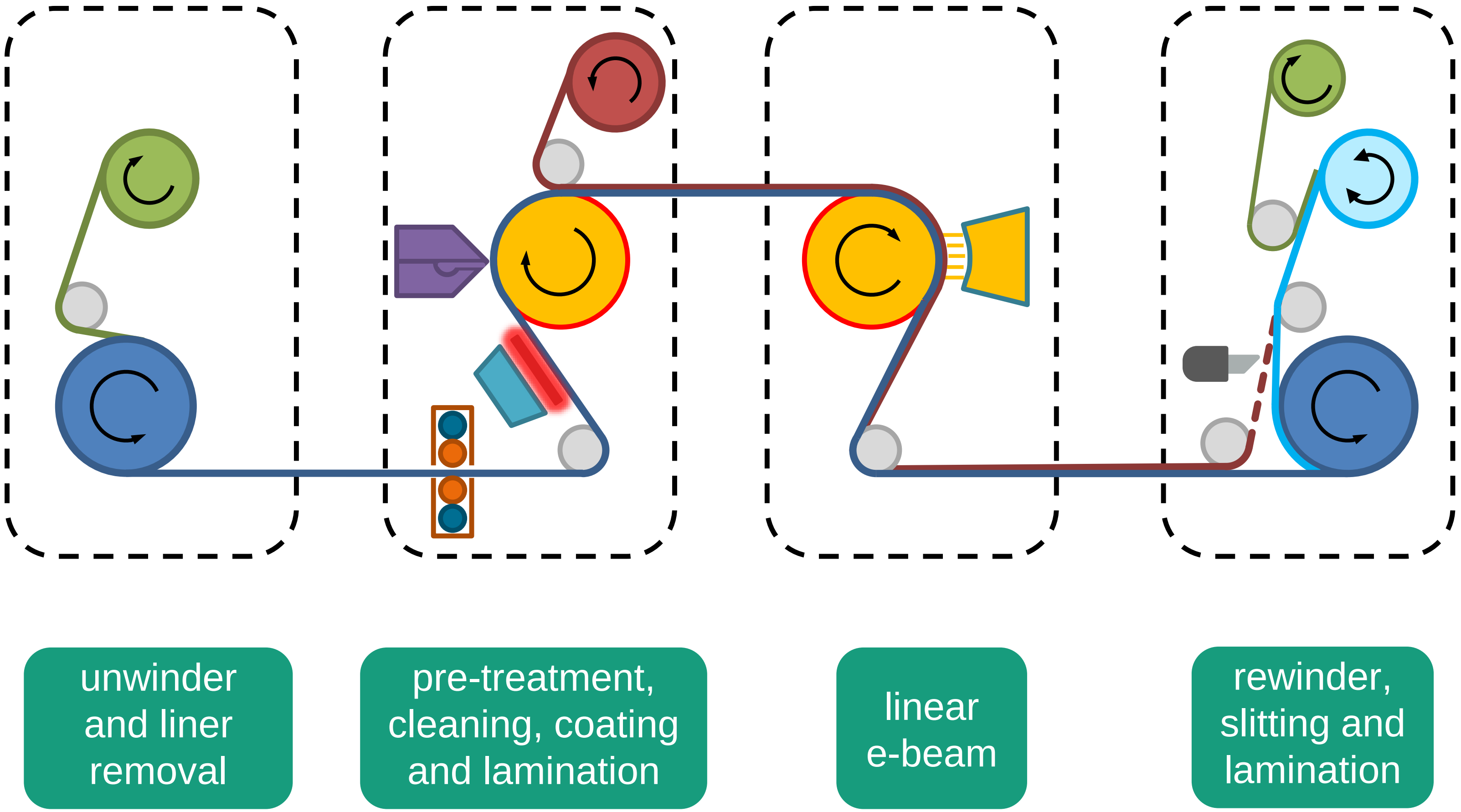

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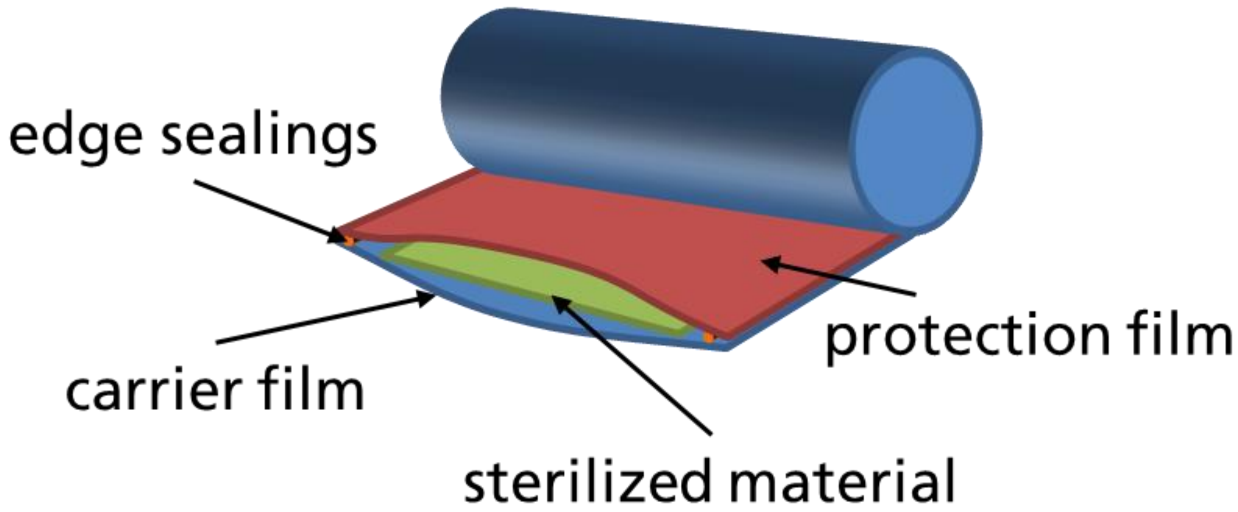
Roll-to-roll sterilization by electron beams of fabrics

<u>Idea</u>

- Continuously running process for simultaneously
  - Sterilization and
  - protection of
  - flexible materials like fabrics or membrans
  - within an unprotected environment

- Take advantage of electron beam penetrating capability



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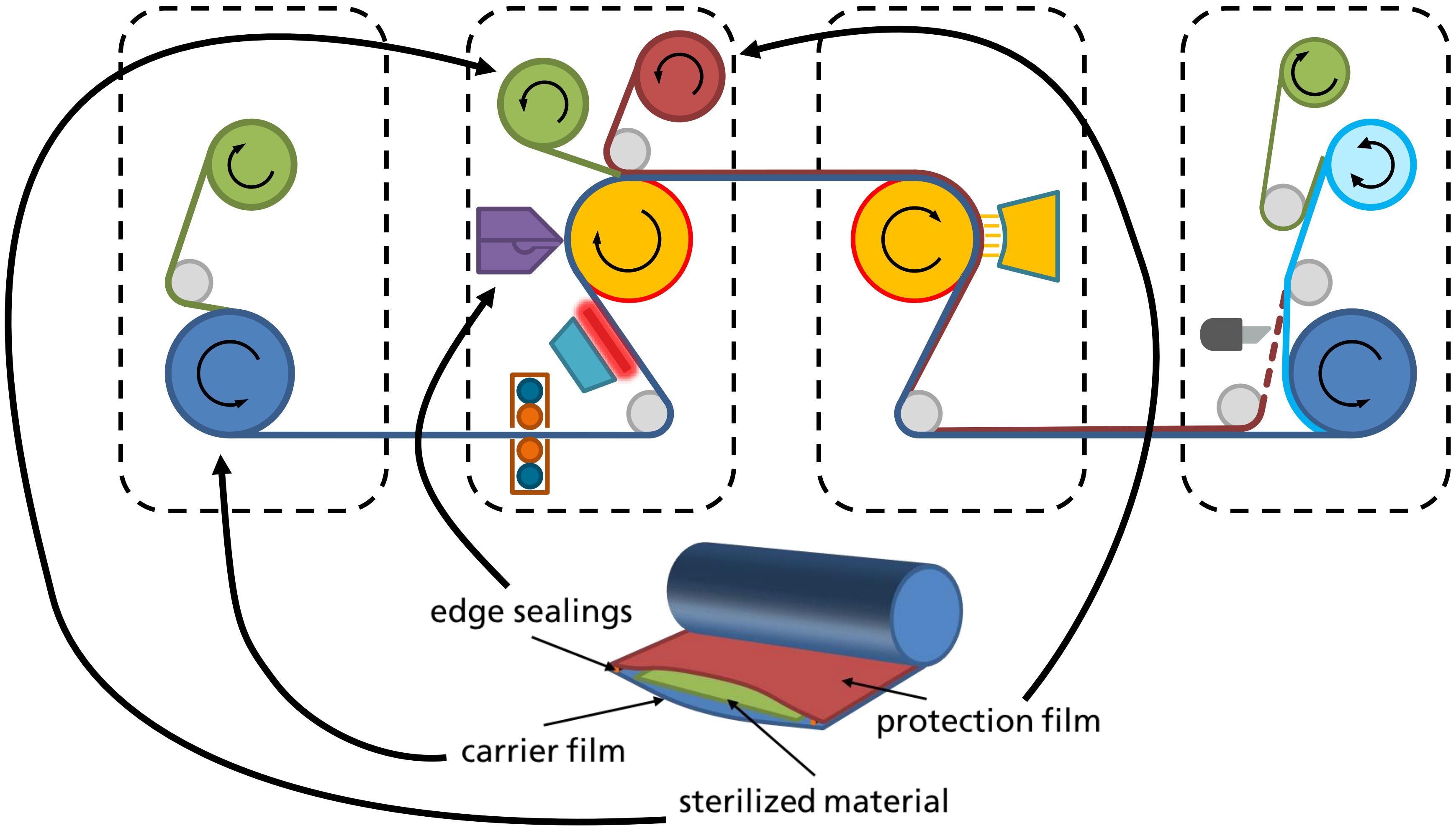

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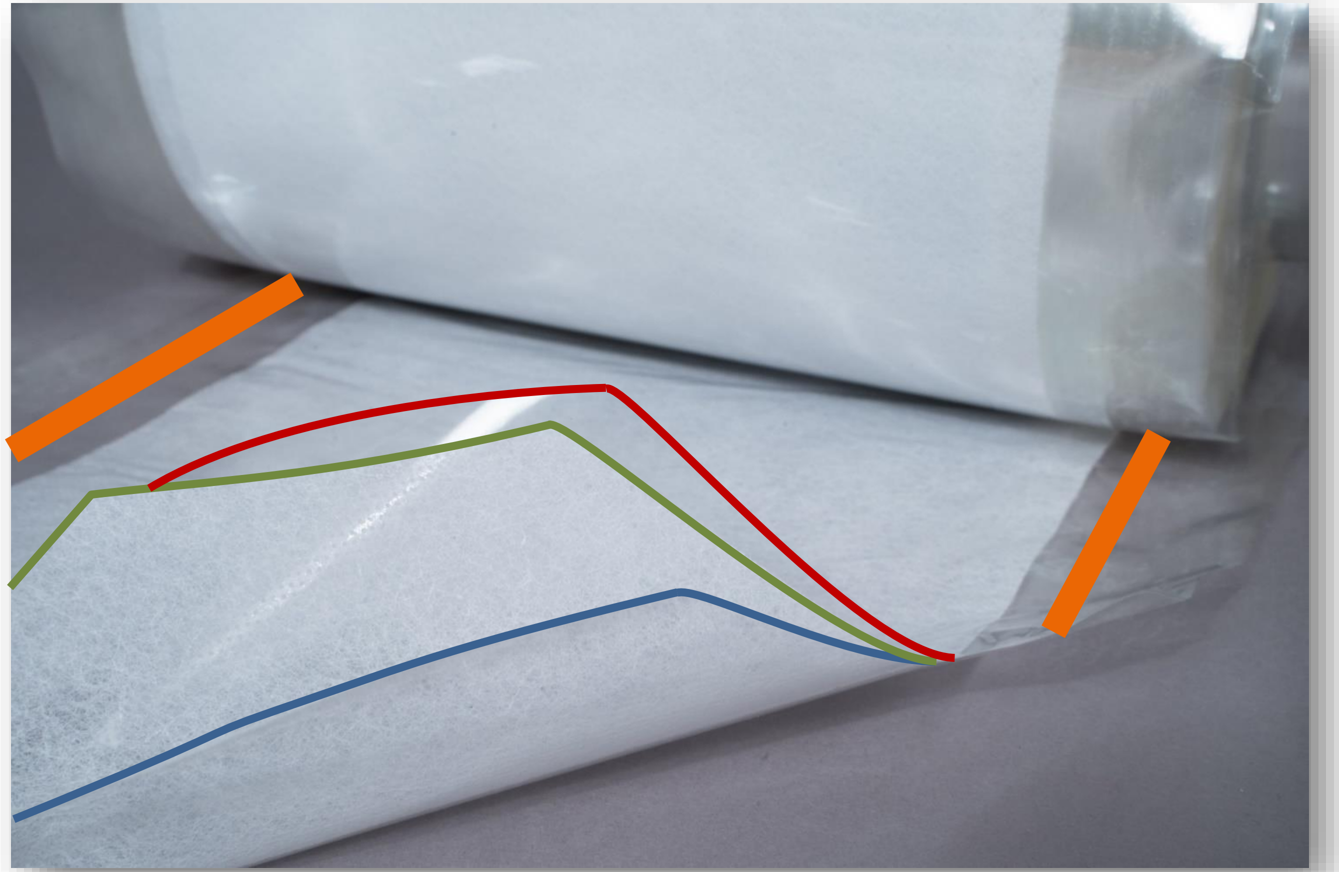
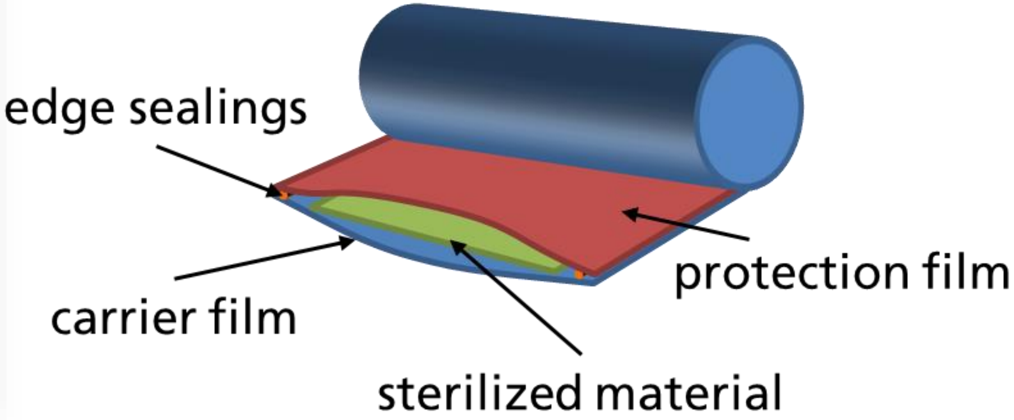
Roll-to-roll sterilization by electron beams of fabrics

Example





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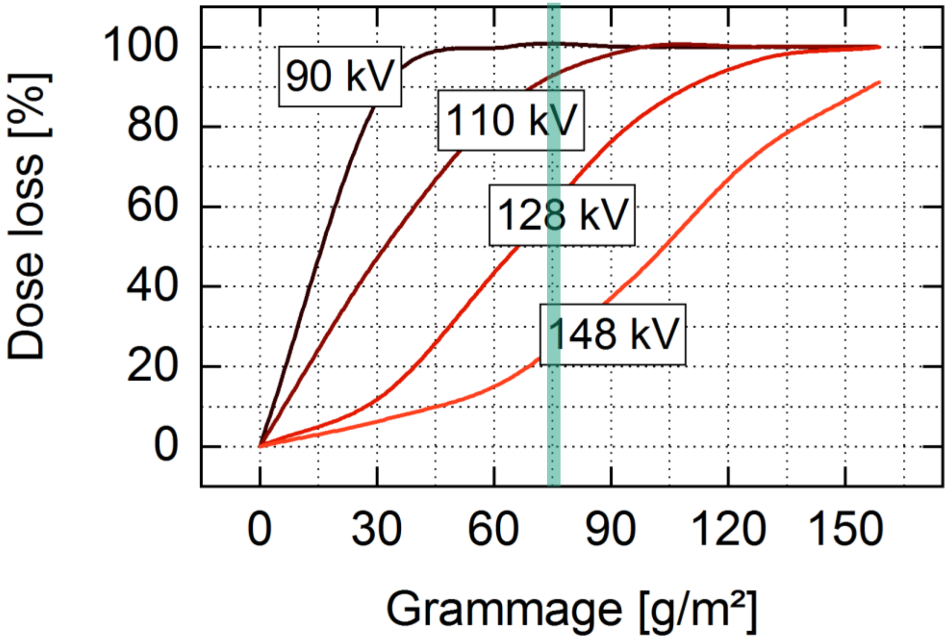
Roll-to-roll sterilization by electron beams of fabrics

Parameters

- 148 kV acceleration voltage
- approx. 75 g/m² grammage of protection film and fabric ➔ Dose loss approx. 25 %
- Fabric samples preloaded with 3..5 × 10^7 bacteria (5 × 10^8 before drying)

Results

- All fabric steril after irradiation with 35 down to 7 kGy (50 to 10 kGy on top)
- Max. throughput 7.000 up to 10.000 m² per hour (limited by max. web speed of the machine, theoretically limit of e-beam 35.000 m² per hour)



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Summary and Closing

- Electron beam sterilization is one of several sterilization methods
- Sterilization at low temperature
- No additional chemicals needed
- Acceleration voltage determines penetration – choice between surface or bulk sterilization
- High throughput method

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Thanks for watching and stay healthy!

Sterilization and disinfection by electron beam irradiation

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