Sterilization basics
Radiation Technology & Gas

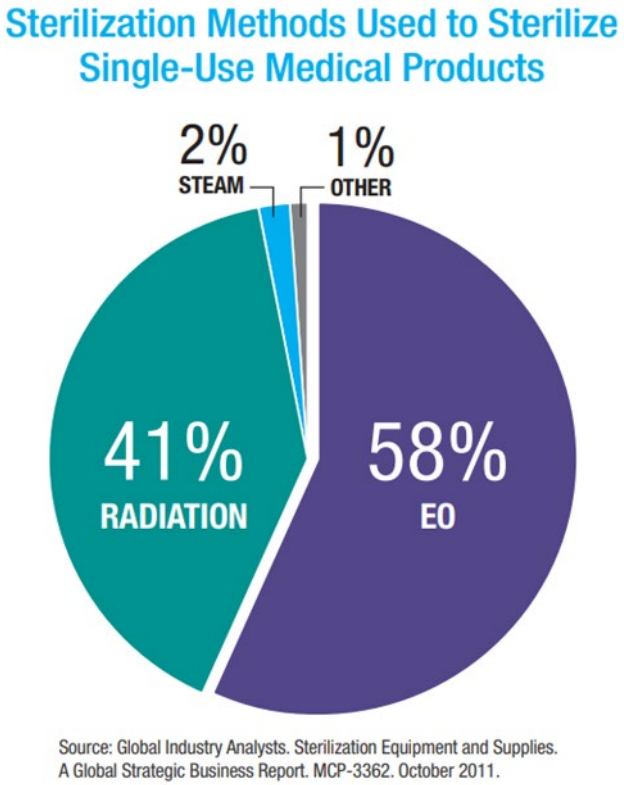
A.Gillet, Technical Director Gas, Pharma - STERIGENICS

Introduction

Market Segments :

Sterilization :
- Medical Devices
- Drug/Pharmaceuticals

Decontamination:
- Vaccines & biologics
- Advanced Application
- Tissue
- Food
- Cosmetics



Introduction

Where you probably do not expect us !

Spices decontamination

Gemstones colour change

Frog Leggs

Mail Anthrax decontamination

Cosmetic packaging

Physical properties change

Bioburden reduction

Introduction

Aseptic Assembly

SAL

Sterile

Decontaminated

Ionization

Terminal Sterilization

Radioactive

Clean

Content

- Basics of sterilization
  - Distinguish disinfection, sterilization and decontamination
  - Definition
  - Selection of sterilization method
  - Difference between Aseptic Assembly and Terminal Sterilization

- Sterilization using Irradiation
  - Gamma
  - E-Beam

Coffee break

Content

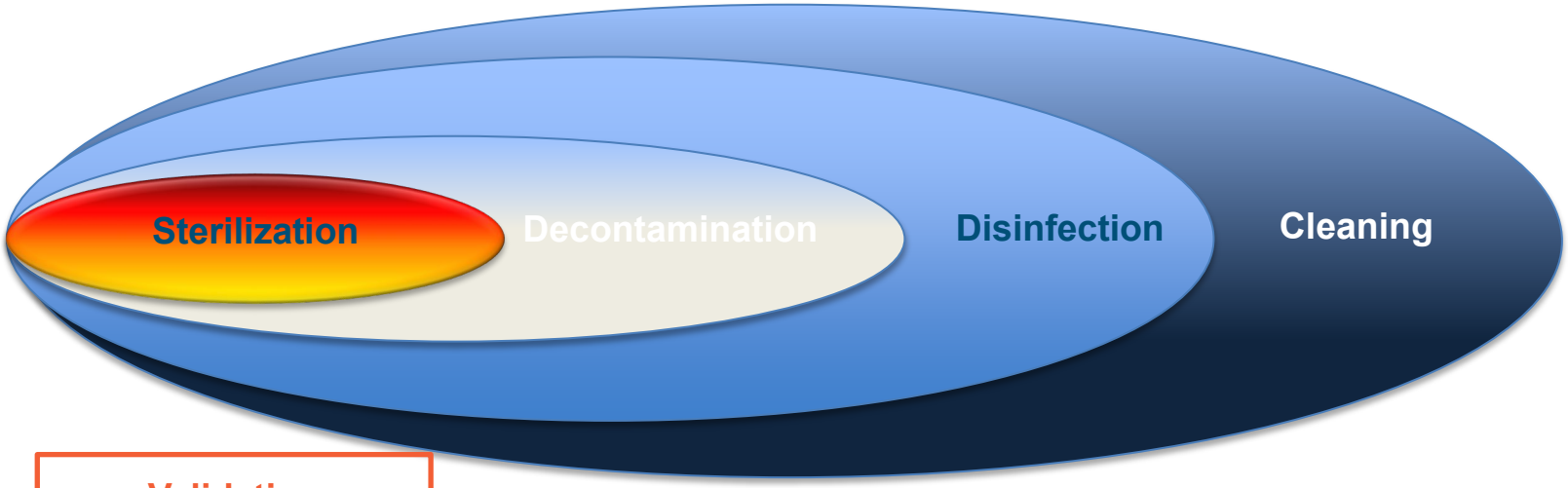
- Sterilization by gas
  - Ethylene oxide
  - Novel technologies (NO_2)
- Comparison between technologies

Sterilization Basics

- Decontamination Vs Sterilization
- Terminal Sterilization Vs Aseptic Assembly
- Method selection

Sterilization – Basics

Decontamination Vs Sterilization



Validation

Sterilization	Decontamination	Disinfection	Cleaning
The application of a lethal sterilizing agent to finished product within a sealed container to achieve a predetermined **sterility assurance level** (SAL) of 10^{-6} or better – *GMP Annex 1 Draft*	A process that **eliminates viable bioburden** via use of chemical agents *GMP Annex 1 Draft*	The process by which **surface** bioburden is **reduced** to a safe level *GMP Annex 1 Draft*	Removal of **contamination** from an item to the extent necessary for further processing or for intended use *ISO 11139:2006*

Sterilization – Basics

A sterile product is one that is free of viable microorganisms

Absolute sterility can never be guaranteed !

- 100% control of the batch is not possible
- No assurance that any microorganism can be detected during Sterility Test

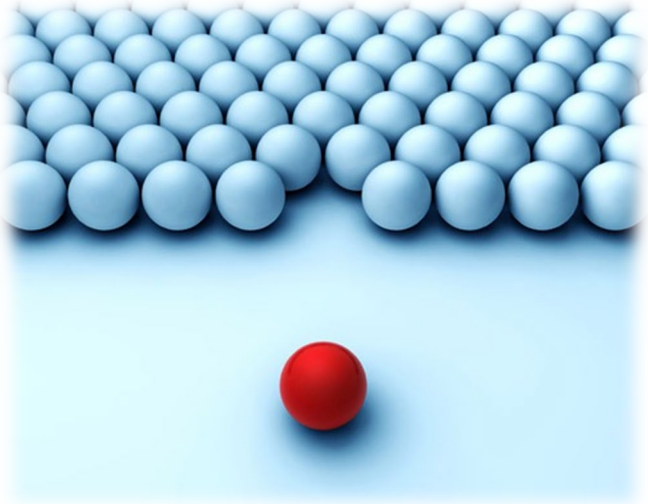
Sterilization – Basics

Sterility Assurance Level (SAL) = The **probability** of a single item in a batch being non-sterile after being subjected to a sterilization process.

Sterile: SAL ≤ 10^{-6}

SAL likelihood of surviving organisms

10^{-1} = 1:10
10^{-2} = 1:100
10^{-3} = 1:1,000
10^{-4} = 1:10,000
10^{-5} = 1:100,000
10^{-6} = 1:1,000,000



Sterilization – Basics

Sterility is much more than just a process!

Initial contamination level

- Microbiological status raw material and components
- Cleaning and disinfection procedures
- Environment control
- Personnel Hygiene

Equipment

- Control
- Maintenance
- Calibration

Product preservation

- Packaging
- Storage

Sterilization – Basics

Selection of the Sterilization Method

- **Think about sterilization process selection up front / early during product development**

Sterilization – Basics

Sterile means : Safe Product **&** Functional product

Selection of the right sterilization method is critical !

Sterilization – Basics

Regulatory update:

GMP EudraLex Volume 4 – Annex 1 – Aug 2022

ISO 11135:2014 -> FDIS under revision (2023)

Sterilization – Basics

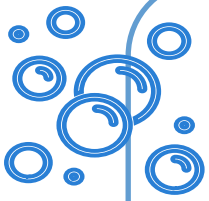
No single sterilization method will be compatible with every product on the market

Heat

- Dry
- Moist Heat

Irradiation

- Gamma ray
- E-beam
- X-rays



Gaseous (EO)

- Alkylative

Gaseous (NO_2)

- Oxidative

New technologies

- VHP
- Gas plasma
- Others

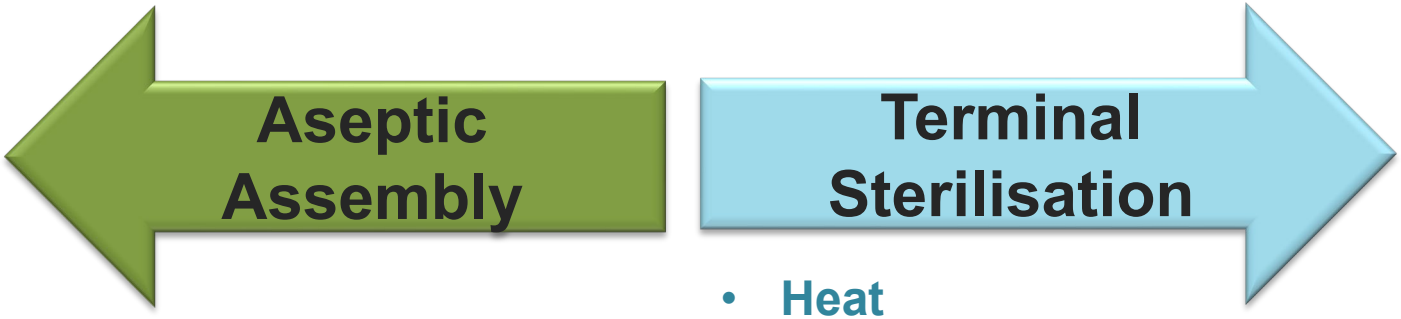
In House /Low volume

Industrial sterilization (large volume)

Innovative methods R&D

Sterilization – Basics

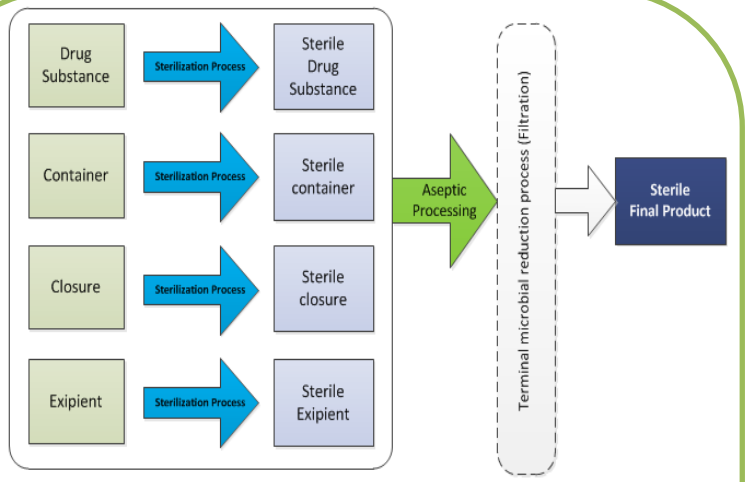
There are two (2) methods to produce a sterile drug product:



- Heat
- Irradiation
- Gas (EO, NO_2 …)

Sterilization – Basics

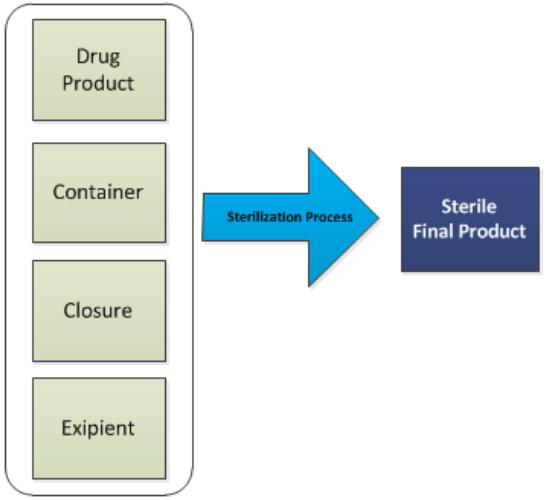
Aseptic Assembly



Maintain sterility of a product that is assembled from components, each of which has been previously sterilized

Sterile

Terminal Sterilization



Exposure to a physical or chemical sterilizing agent for a predetermined extent of treatment

Sterilized

Sterilization – Basics

Selection of the Sterilization Method:

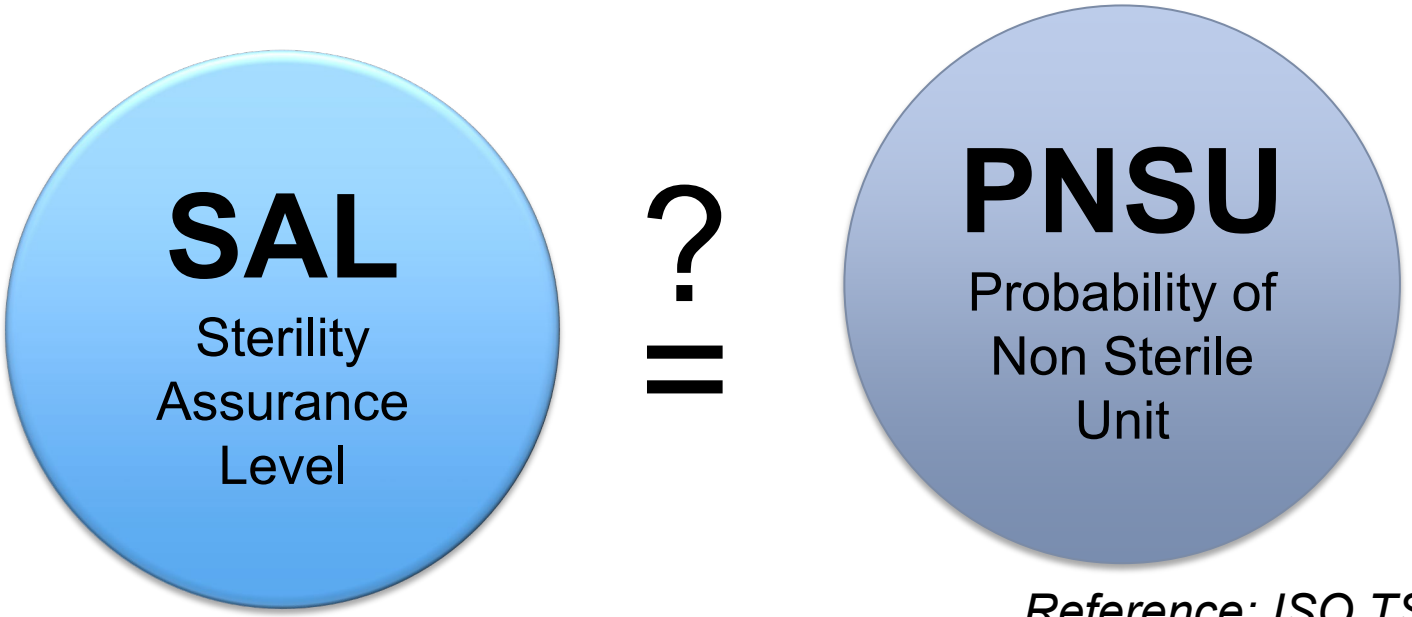
"Wherever possible, a process in which the product is sterilized in its final container (terminal sterilization) is chosen"

European Pharmacopoeia 9.7

Per PDA 2017 Survey – 30% of Aseptically assembled product could be Terminally sterilized !

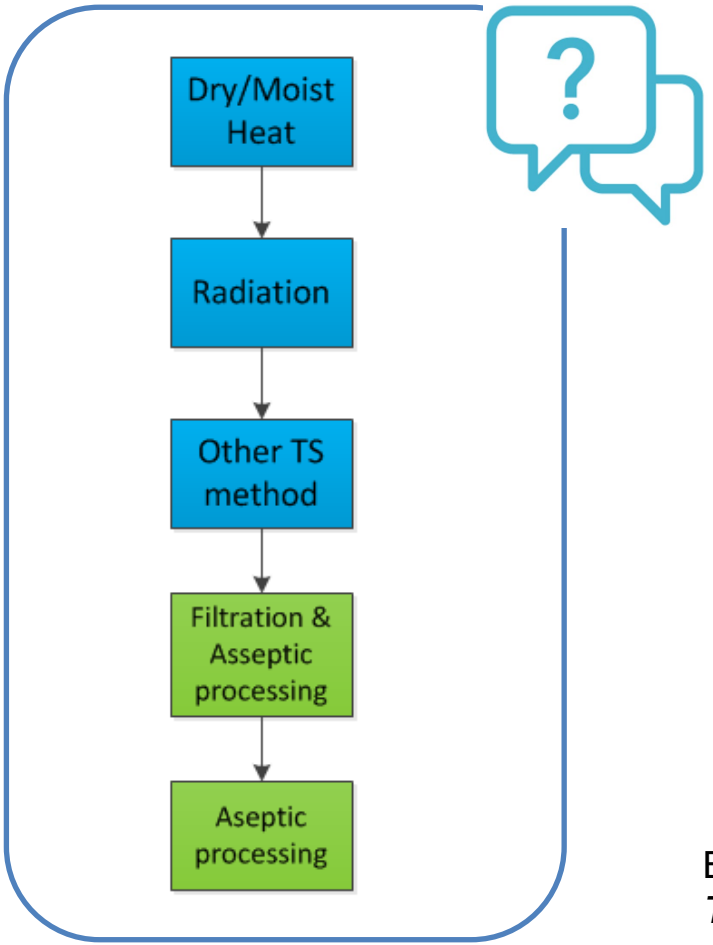
Sterilization – Basics

Is the effectiveness of a sterilization process assessed the same way for AA or TS products?



Reference: ISO TS 19930:2017

Sterilization – Basics



Selection of the Sterilization Method:

Use a **structured approach** to select the most appropriate sterilisation method

Based on EMA - *CPMP/QWP/054/98 Decision Tree for the selection of sterilisation methods*

Sterilization – Basics

Prior to making your choice, consider mitigation options:

- Can your **formula** be adapted (limit degradation and impurities)?
- Can the **container** be adapted ?
- Can you select compatible **component** with selected sterilization process ?
- Can the **process** can be optimized (limit impact)?

Radiation Technology

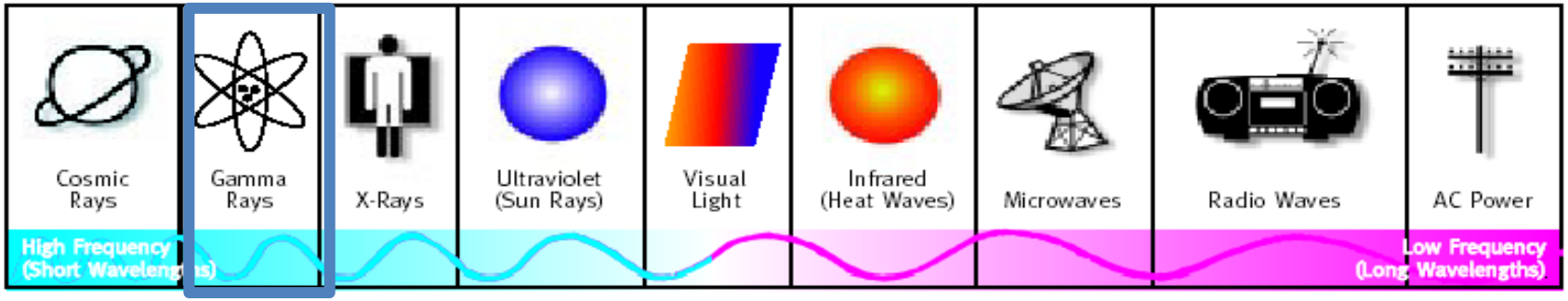
- General principles
- Gamma
- E-Beam
- Sterilization validation

Sterilization by Irradiation

General Terminology

Radioactivity:

Electromagnetic radiation (photons) produced by radioactive decay.



Ionising

Non-Ionising

E-beam = Electrons (with a mass)

Sterilization by Irradiation

General Terminology

Radiation

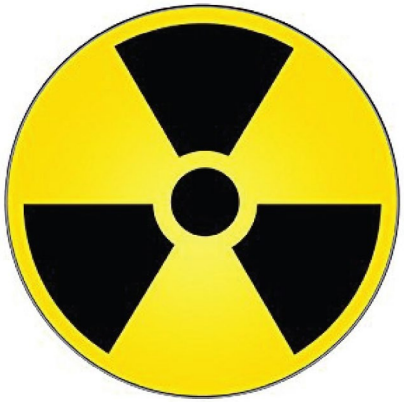
Energy in the form of waves or moving subatomic particles

Radioactive

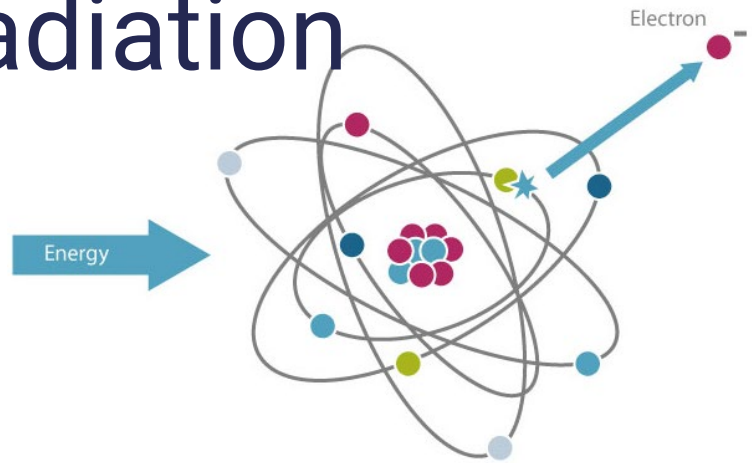
Substance emitting radiation

Irradiation

Exposure to radiation
≠ Making something radioactive



Sterilization by Irradiation



General Terminology

Ionising Radiation

Radiation capable of knocking electrons out of their thermal orbits in atoms or molecules. It creates ions and free radicals. Breaks chemical bonds and may change material properties

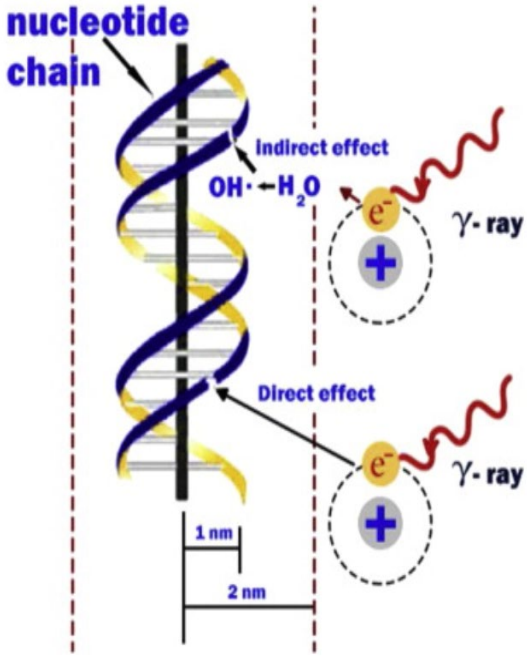
(Absorbed) Dose

Measure of the amount of energy that is absorbed by the material while exposed to a radiation source.

Unit: Gray **1 Gy = 1 Joule per Kg material**

Sterilization by Irradiation

How Radiation can be used to Damage DNA in Living Cells for Sterilization

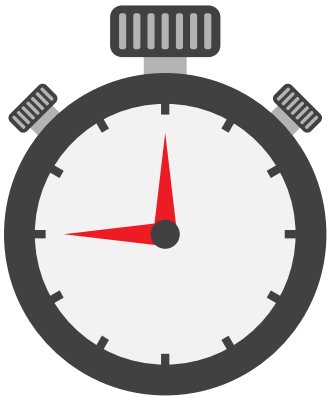


Direct action: the radiation hits the DNA molecule directly or via the ejected electron, disrupting the molecular structure leading to cell damage or cell death.

Indirect action: the radiation hits the water molecules, the major constituent of the cell, and other organic molecules in the cell, whereby **free radicals** such as hydroxyl are produced.Free radicals are very reactive.

Sterilization by Irradiation

Critical Parameters for Effective Radiation Treatment



Time !

Essentially a 1-step process – controlled by amount of time in the radiation field

Temperature typically not a factor – considered “cold sterilization” process. Typically 25-40 °C, but can be controlled!

Irradiation can take place under refrigerated or frozen conditions if necessary

Sterilization by Irradiation

Irradiation process monitoring:

Dosimeter

Device having a reproducible, measurable response to radiation, which can be used to measure the obsorbed dose in a given system.

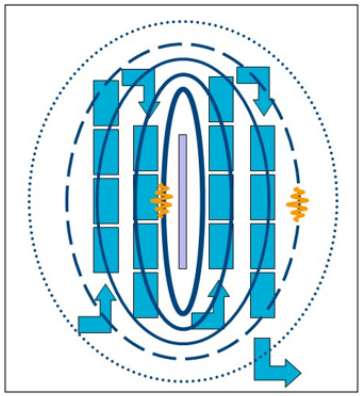
0 kGy 12 kGy 25 kGy 50 kGy 0kGy

Sterilization by Irradiation

Type of radiation, generation and directionality of radiation field

^{60}Co Gamma

Photons
from
Radioactive decay

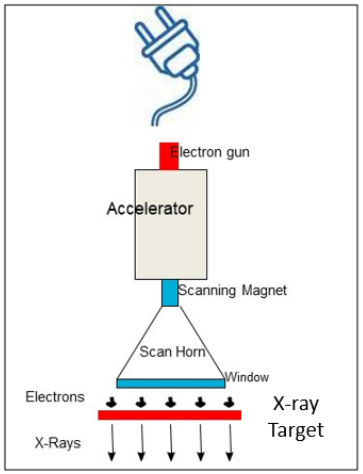


Isotropic radiation flux

Scale of decreasing intensity

X-ray

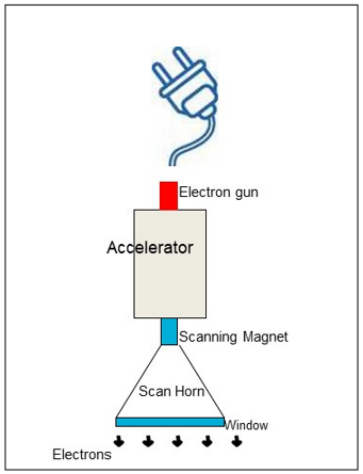
Photons
from
Particle accelerator
(by high energy electrons
hitting material with high atomic number)



Directional radiation flux
can be tailored to product needs

Electron Beam

10 MeV Electrons
from
Particle accelerator

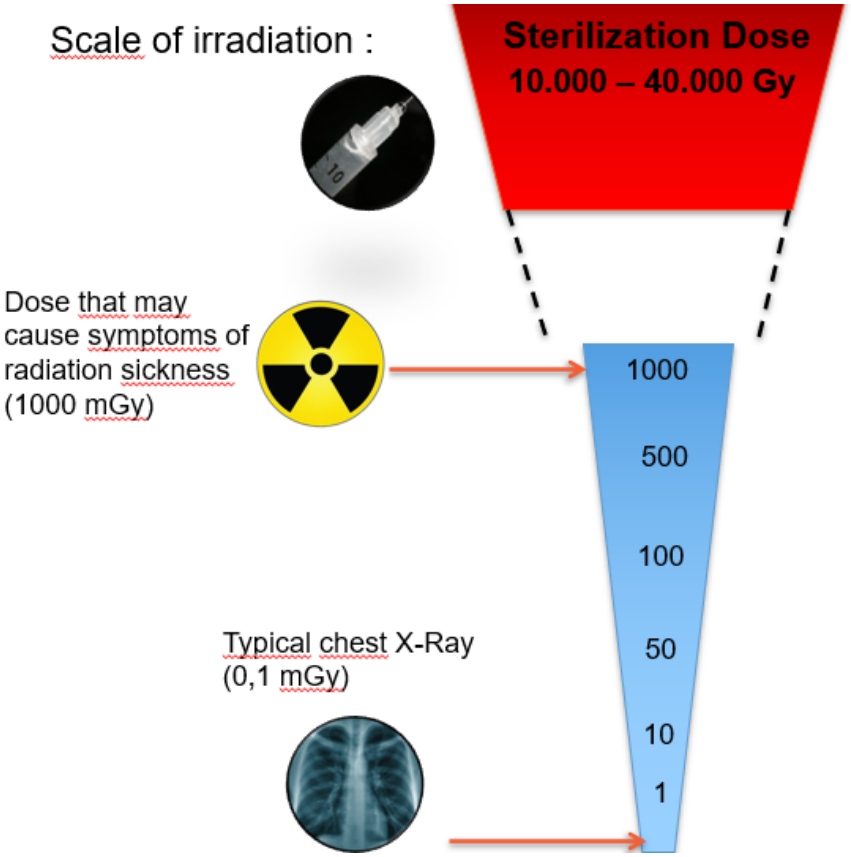


Directional radiation flux
can be tailored to product needs

Sterilization by Irradiation

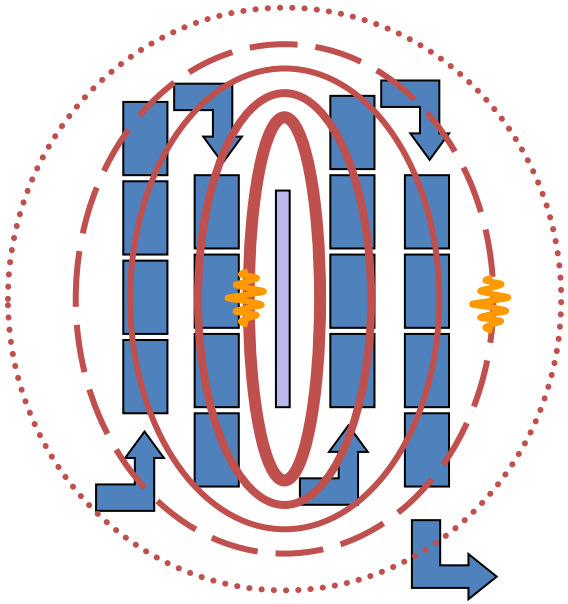
Gamma Irradiation

Sterilization by Gamma



Sterilization by Gamma

Source: ^{60}Co (mostly)
Decay rate: 12% per year (Half life 5,3 years)
Source Activity: Several Million Ci

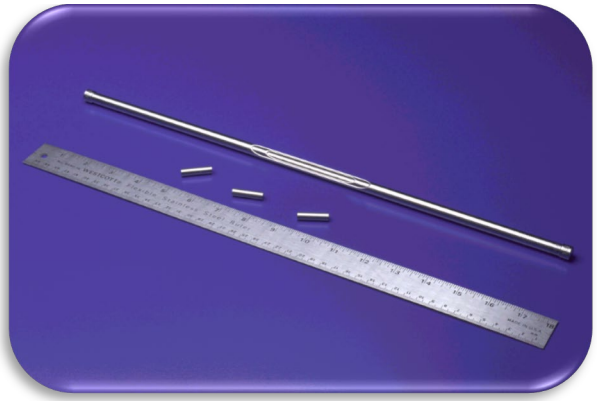


Isotropic radiation flux

Sterilization by Gamma

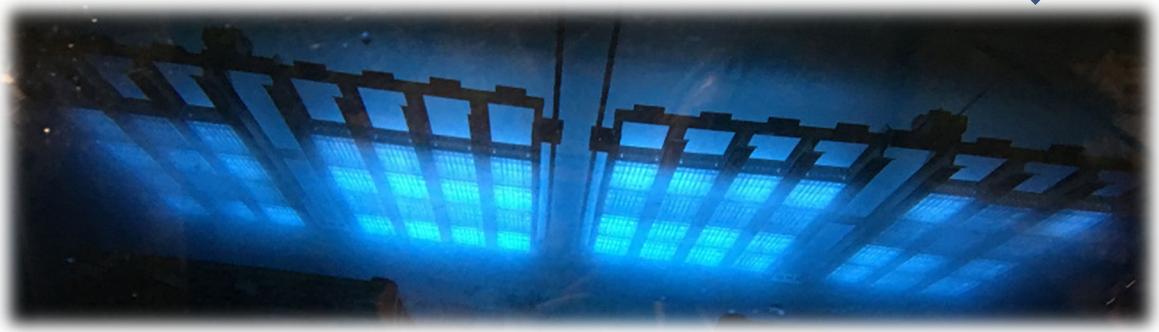
Source Rack

Cobalt-slugs in a source pencil



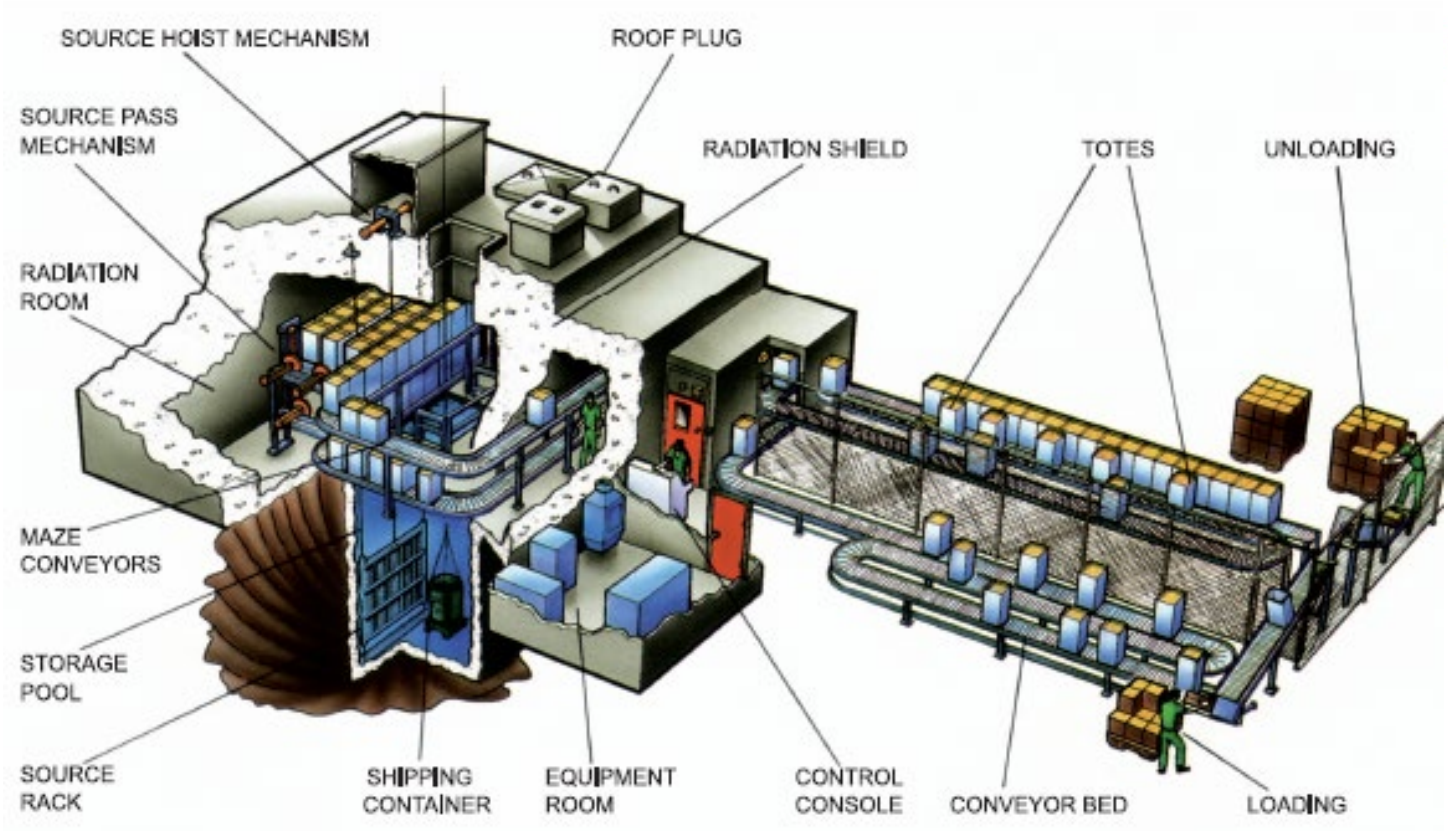
Source module

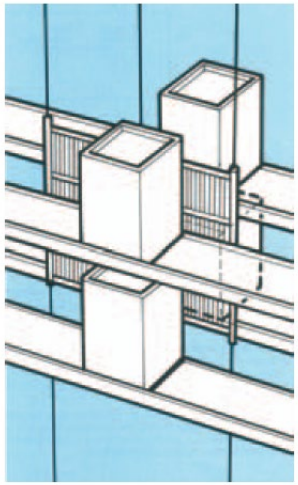
Source rack



Sterilization by Gamma

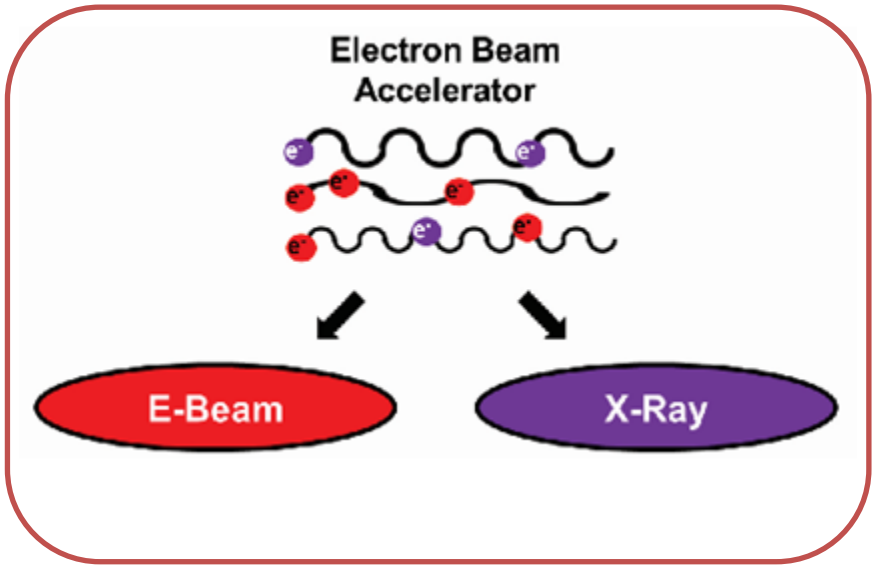
Layout Gamma facility





Product overlap

Sterilization by E-Beam



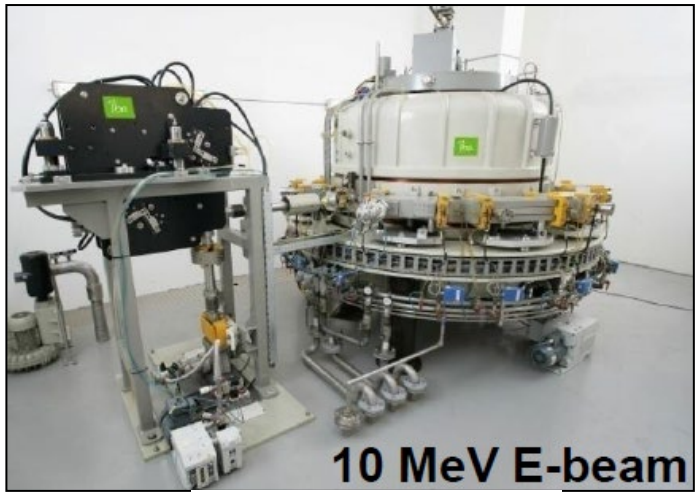
Sterilization by E-Beam

Electron Beam

Directed stream of electrons (B radiation) produced by a particle accelerator

Beam energy

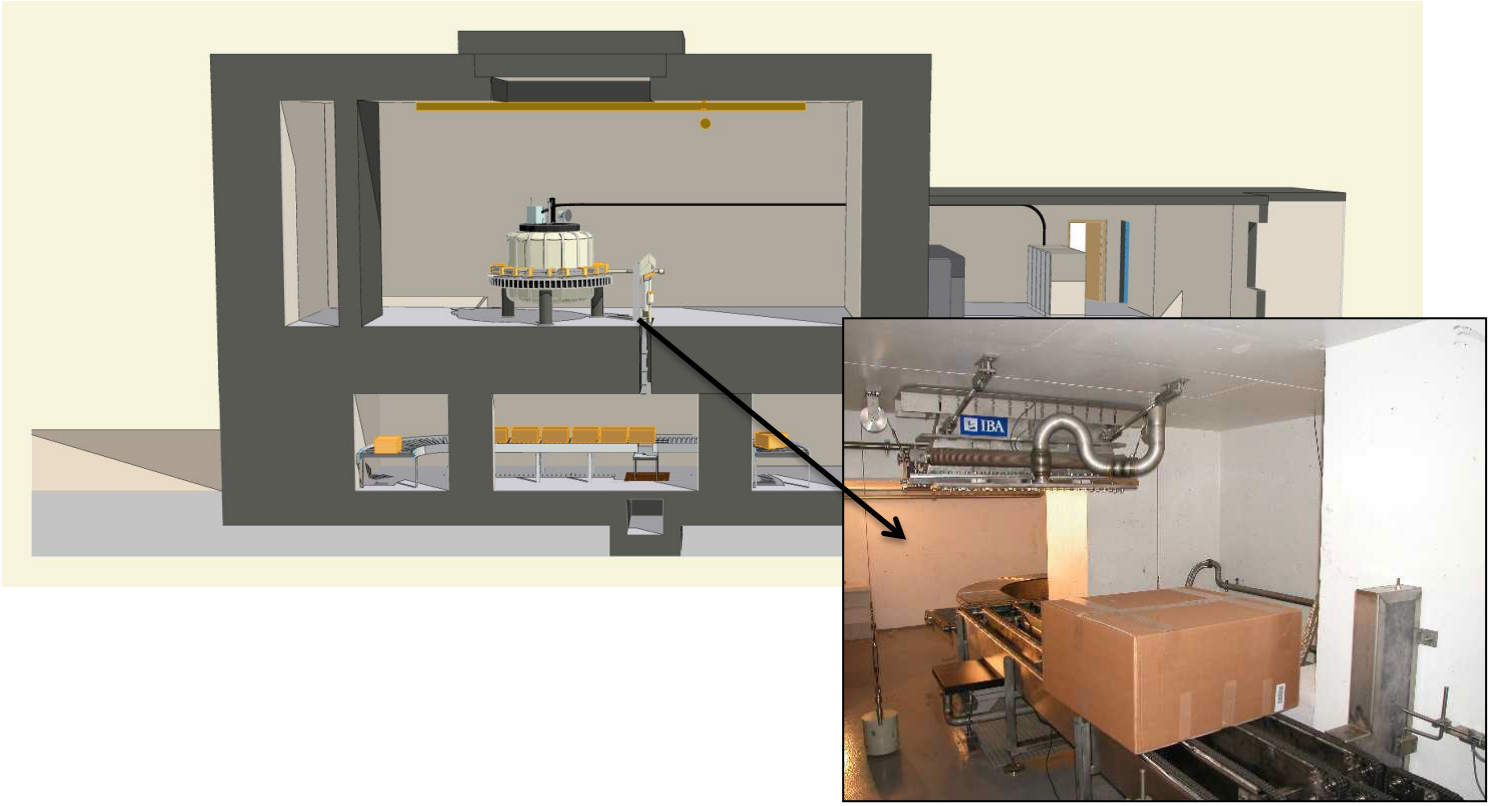
Speed of the electrons. Parameter related to depth of penetration
Limited to 10 MeV for medical device sterilisation (ISO 11137-1) to avoid radioactivity induced in product



IBA Rhodotron

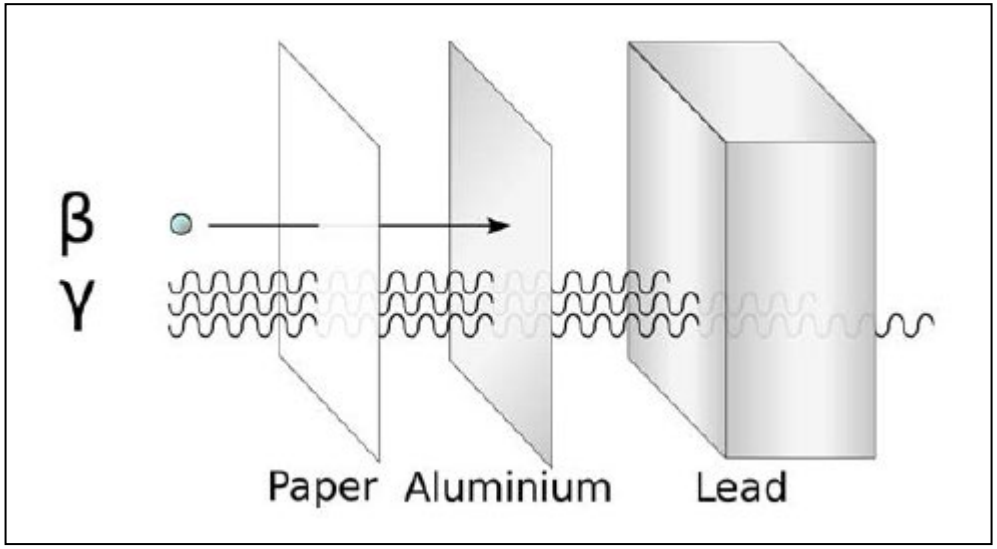
Sterilization by E-Beam

Layout E-Beam facility



Sterilization by E-Beam

Electron Beam & Gamma, Penetration



Sterilization by irradiation

Comparison

Parameter	Gamma	E-Beam
Irradiation parameter	Cycle Time Density	Conveyor speed Density Scan width Beam energy
Radiation Field	Isotroptic	Highly directional
Geometry of material and heterogeneity of Product	Important to consider	Critical

Sterilization by Irradiation

Parameter	Gamma	E-Beam
Product Treatment	Pallet/Tote	Boxes
Dose Rate (Dmin 25KGy)	Hours	Seconds
Dose uniformity ration (DUR)	Low sensitivity to product thickness	sensitivite to product thickness
On/Off Technology	No	Yes
Flexible Target Dose	No	Yes
Process validation	Straightforward	Potentially complicated

Sterilization by E-Beam

Validation principles

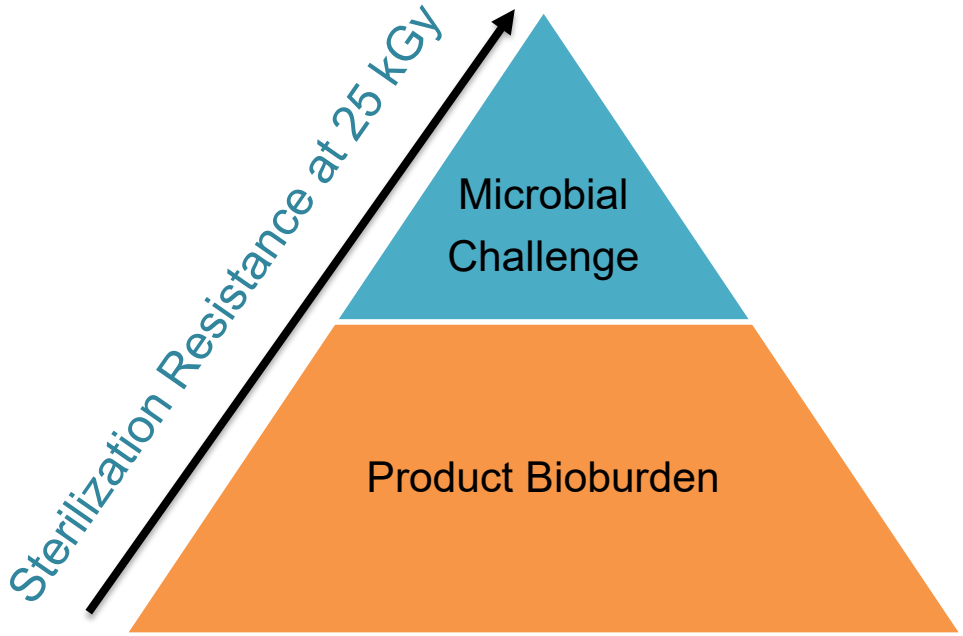
Relevant Standards:

ISO 11137-1:2015	ISO 11137-2: 2015	GMP – Annex 12
Sterilization of health care products – Radiation – Part 1: Requirements for development, validation, and routine control of a sterilization process for medical devices	Sterilization of health care products – Radiation – Part 2: Establishing the sterilization dose	Use of ionising radiation in the manufacture of medicinal products

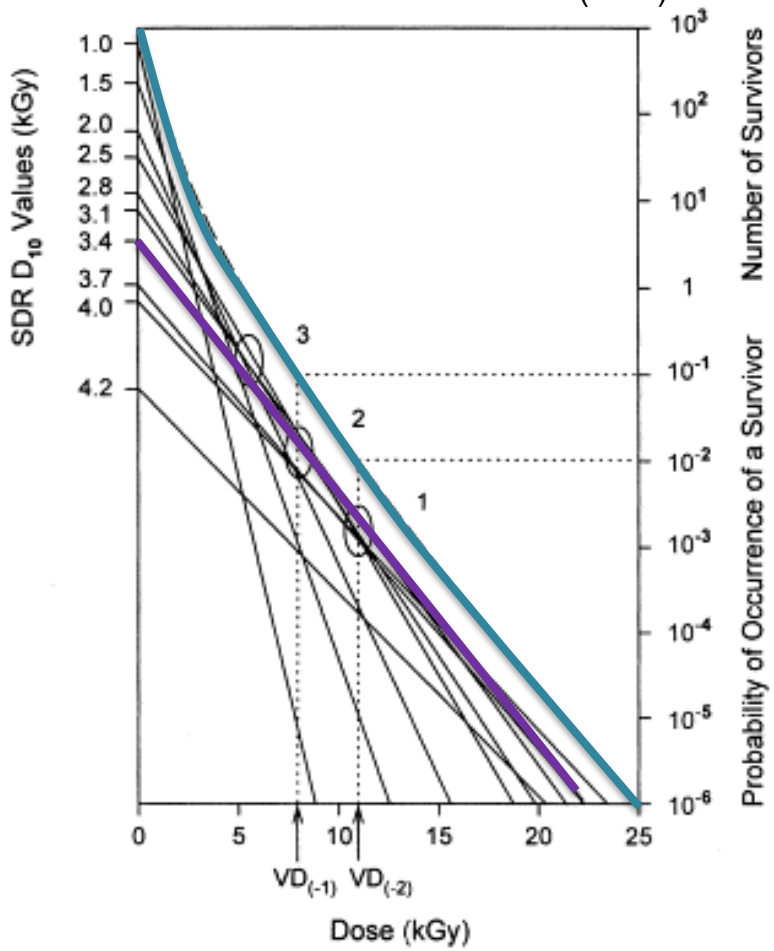
Sterilization by E-Beam

Validation principles

Method VD_{max}

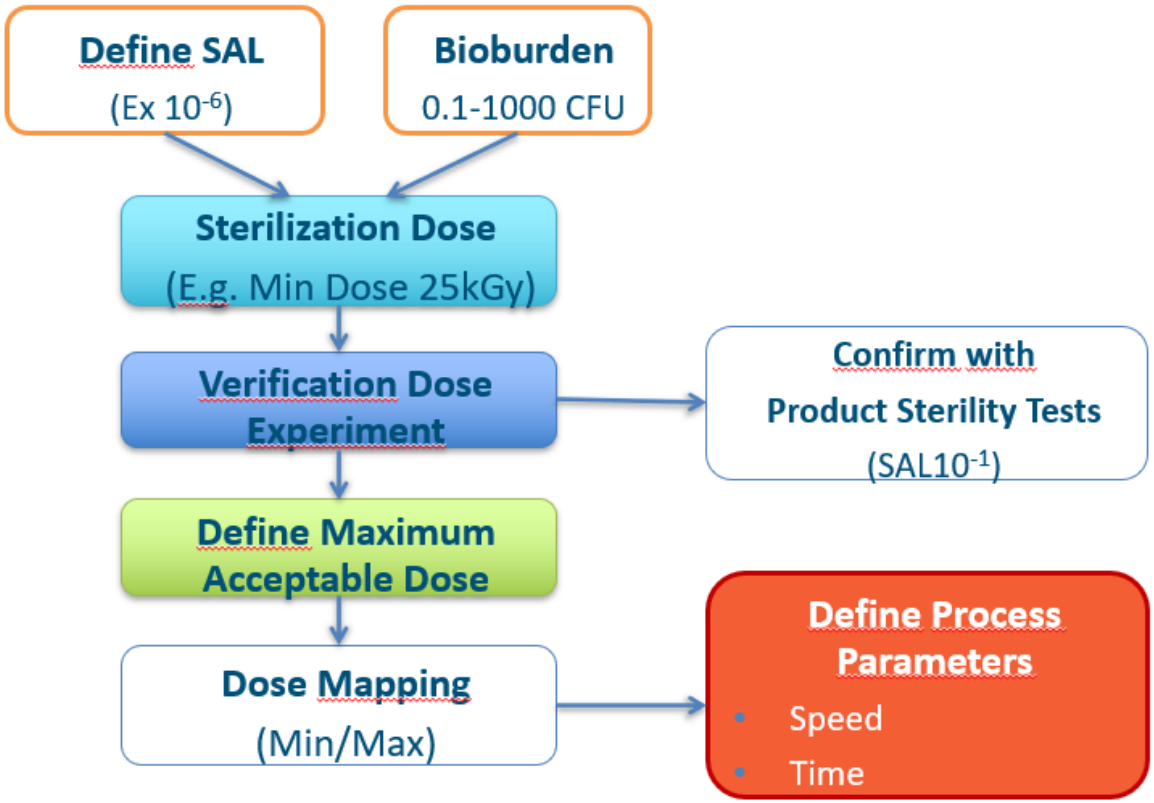


Standard Distribution of resistances (SDR)



Sterilization by E-Beam

Validation principles



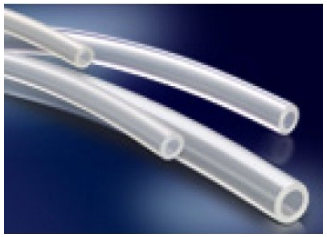
Sterilization by Irradiation

Bioburden is critical parameter in Irradiation technology

Sample Item Portion (SIP) is frequently used for bioburden evaluation .
Basis for SIP can be:

Length

- Consistent diameter tubing



Mass

- Powders
- Gowns
- Absorbable implants

Volume

- Fluid

Surface Area

- Non-absorbable implants
- Variable

Sterilization by Radiation

Validation principles

Select Sterilization Dose

Method VD_{max}

Bioburden Range	Dose (kGy)
≤ 0.1 to 1.5	15.0
≤ 0.1 to 9.0	17.5
≤ 0.1 to 45	20.0
≤ 0.1 to 220	22.5
≤ 0.1 to 1000	25.0
≤ 1.0 to 5000	27.5
≤ 1.0 to 23,000	30.0
≤ 1.0 to 100,000	32.5
≤ 1.0 to 440,000	35.0

Example minimum Dose to apply related to bioburden

Sterilization by Radiation

Validation principles

- Select Verification Dose: VD_{max}[25]

Bioburden	Verification Dose (kGy
40	8.6
45	8.7
50	8.8
55	8.9

Verification is conducted at an SAL of 10−1 with 10 product items irradiated.

Sterilization by Radiation

Validation principles

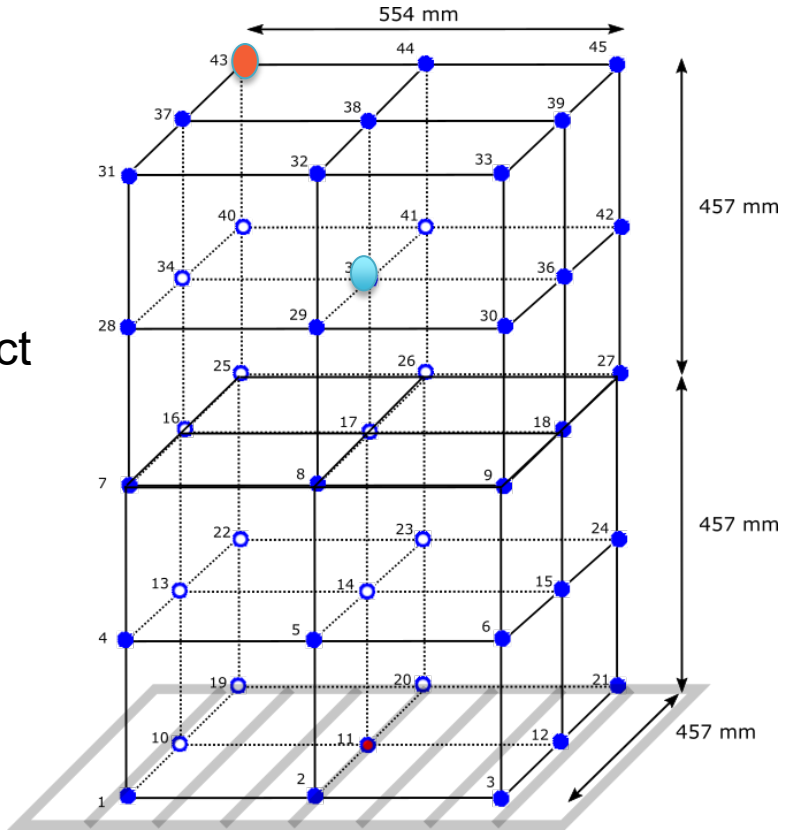
Dose Mapping

Establish the distribution of absorbed dose within the irradiation container when packed with product in a defined configuration

- Min and Max limits of absorbed Dose
- Define cycle time
- Establish monitoring points

Min Dose = 28KGy

Max Dose = 37KGy



Sterilization by Radiation
Validation principles

Quarterly Dose Audit (QDA)

Check bioburden

Can vary due to

- Season
- Environment …

Verification Dose

(Often In a research irradiator)

Ex: 8,7KGy

Sterility Test

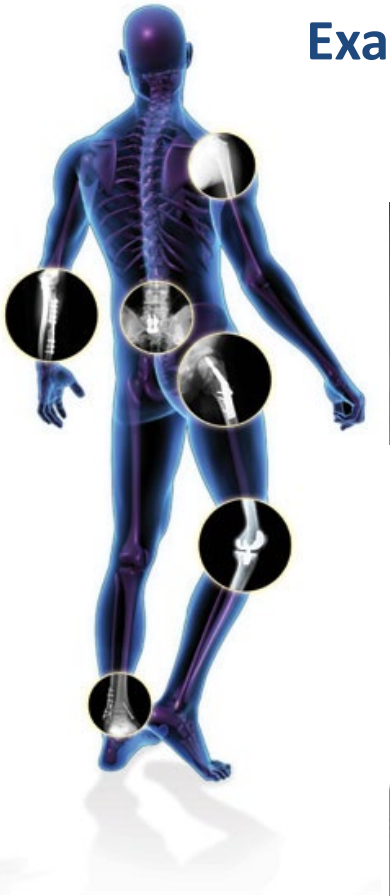
SAL 10^{-1}

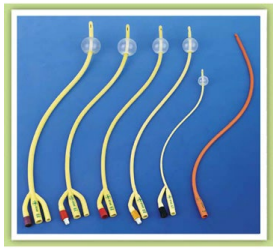
Confirm Product
SAL 10^{-6}
With Routine Dose

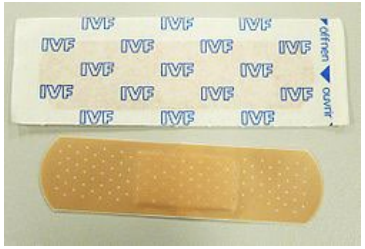
Ex:25KGy

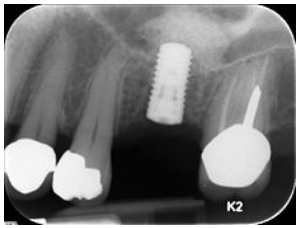
Sterilization by Radiation

Examples



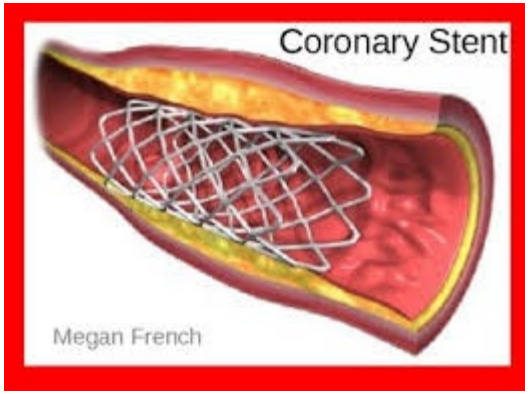




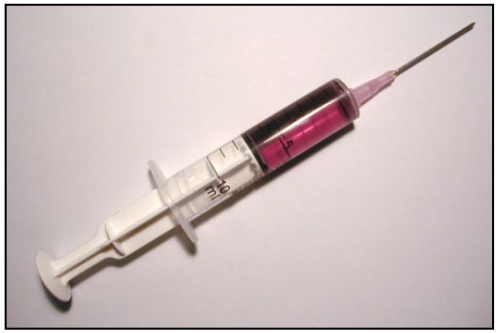


Sterilization by Radiation

… But also



Grafts



API

Sterilization by Radiation

Summary

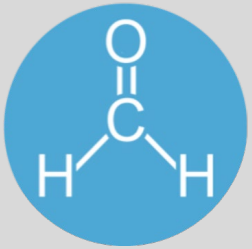
Minium & Maximum dose to product shall be defined

Methods 1, 2, VDmax, “equivalent method”

Based on natural product bioburden

Routine process monitored with dosimeters

Quarterly Dose Audit (QDA) required

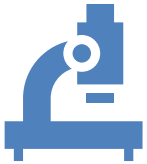


Ethylene Oxide Sterilization

Introduction

Sterilization by Ethylene Oxide

History



Ethylene Oxide discovered

Charles Wurz

1859

First production of Ethylene Oxide

Union Carbide Chemicals

1925

Patent for sterilization of spices

Lloyd Hall

1938

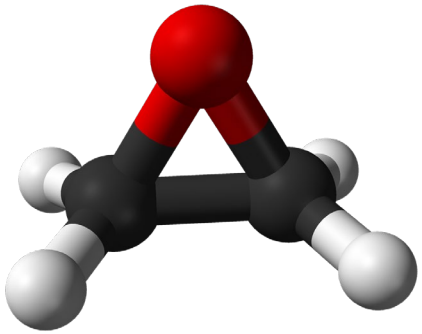
Use in sterilization of materials

1940

Sterilization by Ethylene Oxide

Mode of Action

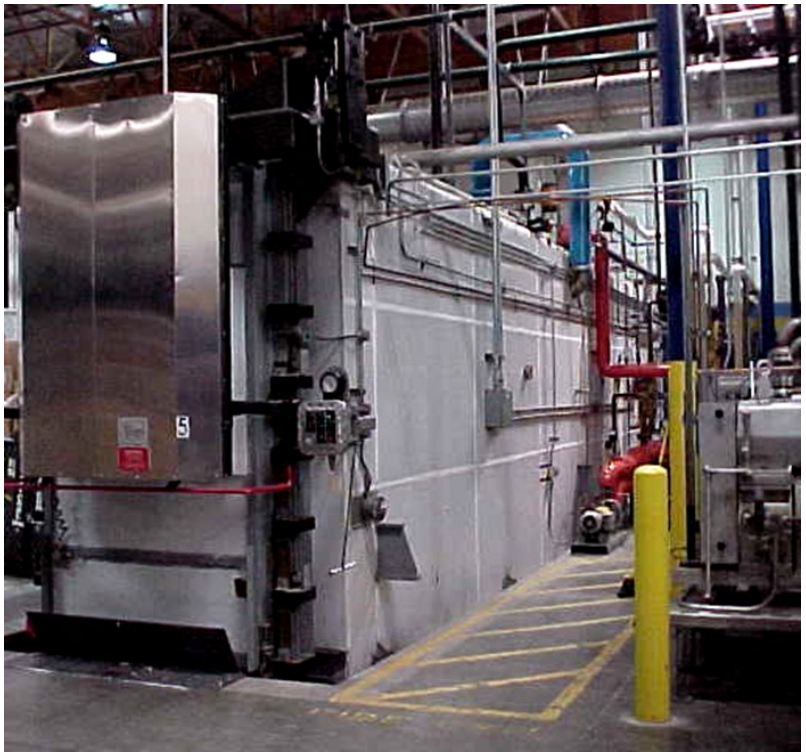
- Extremely reactive
- Irreversible reaction with DNA and proteins (alkylation)
  - The molecule is loses function
  - Replication stops
  - The cell dies



Sterilization by Ethylene Oxide

Mainly used to sterilize:

- Heat-sensitive material
- Material sensitive to ionizing radiation
- High Volumes
- Packs with multiple components



Sterilization by Ethylene Oxide

Device/packaging must be permeable to the gas

- No aqueous substances
- No protein-type materials
- Powders, batteries, electronic circuits have to be assessed (risk of explosion)
- Vacuum/heat can have adverse impact on some packaging (bubble wrap packaging, polystyrene)

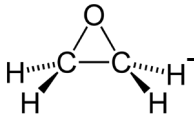
Sterilization by Ethylene Oxide

Customer Needs To Define

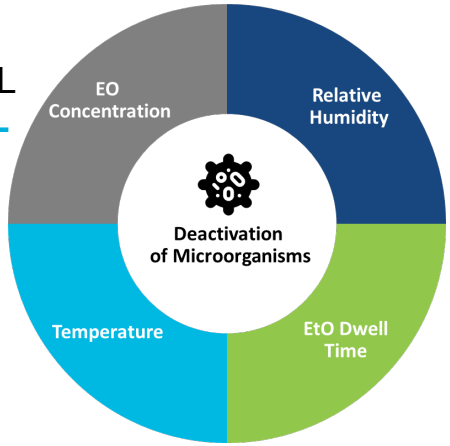
- Product Families/Processing Categories
- Finalize Packaging
- Load Configuration
- Bioburden
- Internal PCD

Sterilization by Ethylene Oxide

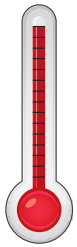
Key Parameters



Typical range 400-700 mg/L
3Rs Target : **200-400 mg/L**



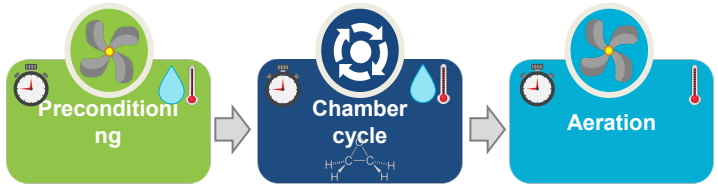
Necessary for **alkylation reacti**
EO is most effective at **RH > 30%**



Industrial sterilization
performed in 104-140 °F
(40–60°C) temperature range

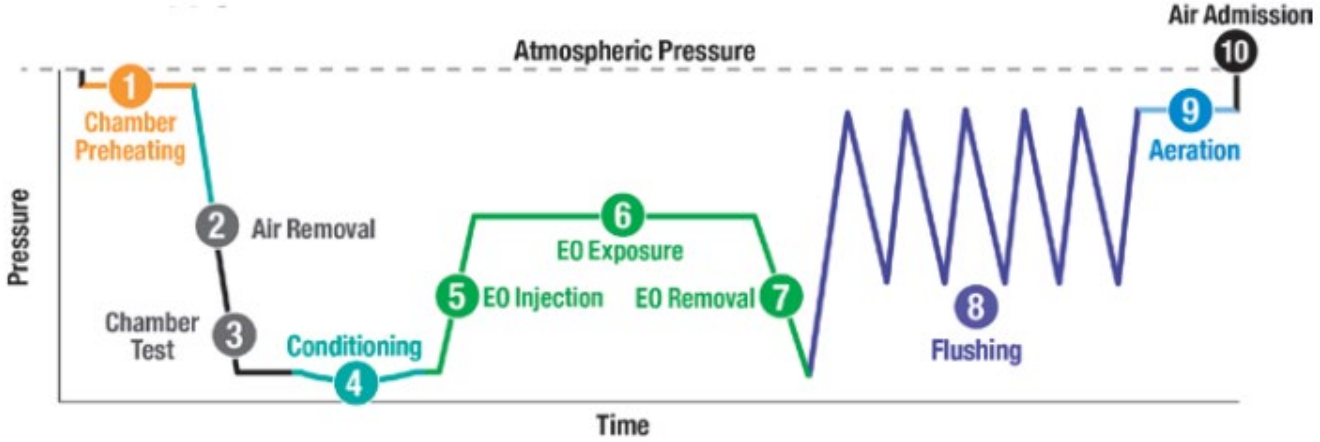
Microbiological deactivation
is more effective with longer gas dwell phase (**Industry cycles** typically 3-4 hours)

3-Step Process



Sterilization by Ethylene Oxide

Typical EO Cycle Design



The 3Rs of EO Sterilization

REDUCE
REUSE
RECLAIM™

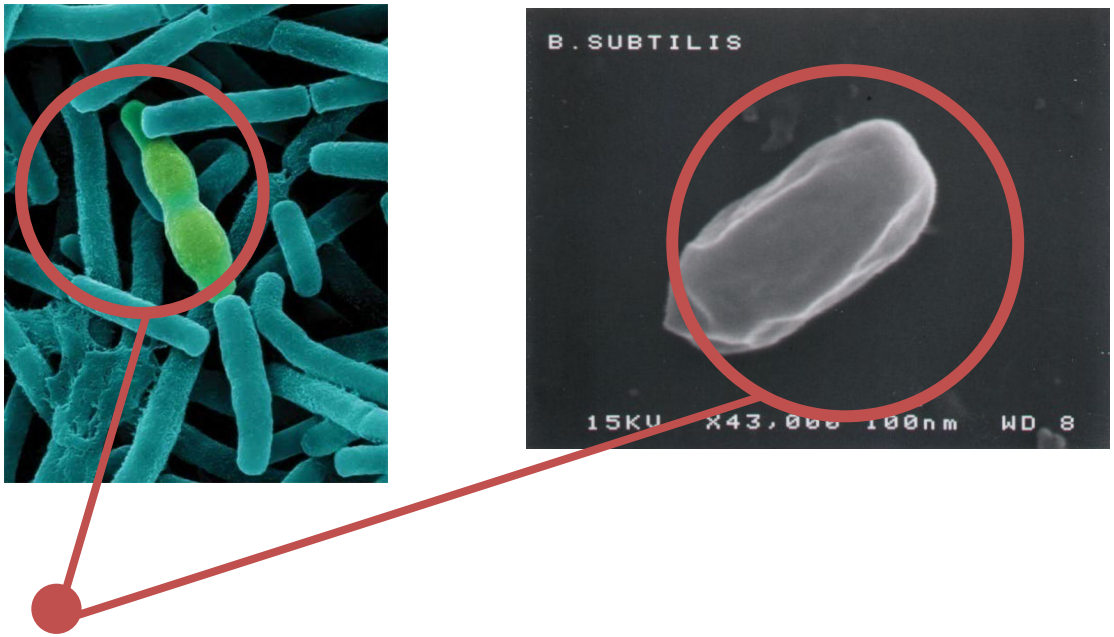
✓Optimize the EO sterilization process
✓Enhance the safe and sustainable use of EO

We have set a goal to reduce the amount of EO by ↓50%

Sterilization by Ethylene Oxide

Monitoring EO Sterilization - Biological Indicators

- Usually, the BI contains at least a million spores (>10Exp6) of an organism that is highly-resistant to the EO process (*Bacillus atrophaeus)*
- Growth is very characteristic (orange ring)

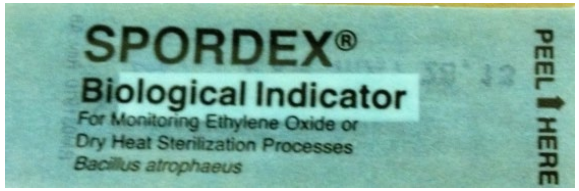


Sterilization by Ethylene Oxide

Process Challenge Device (PCD)

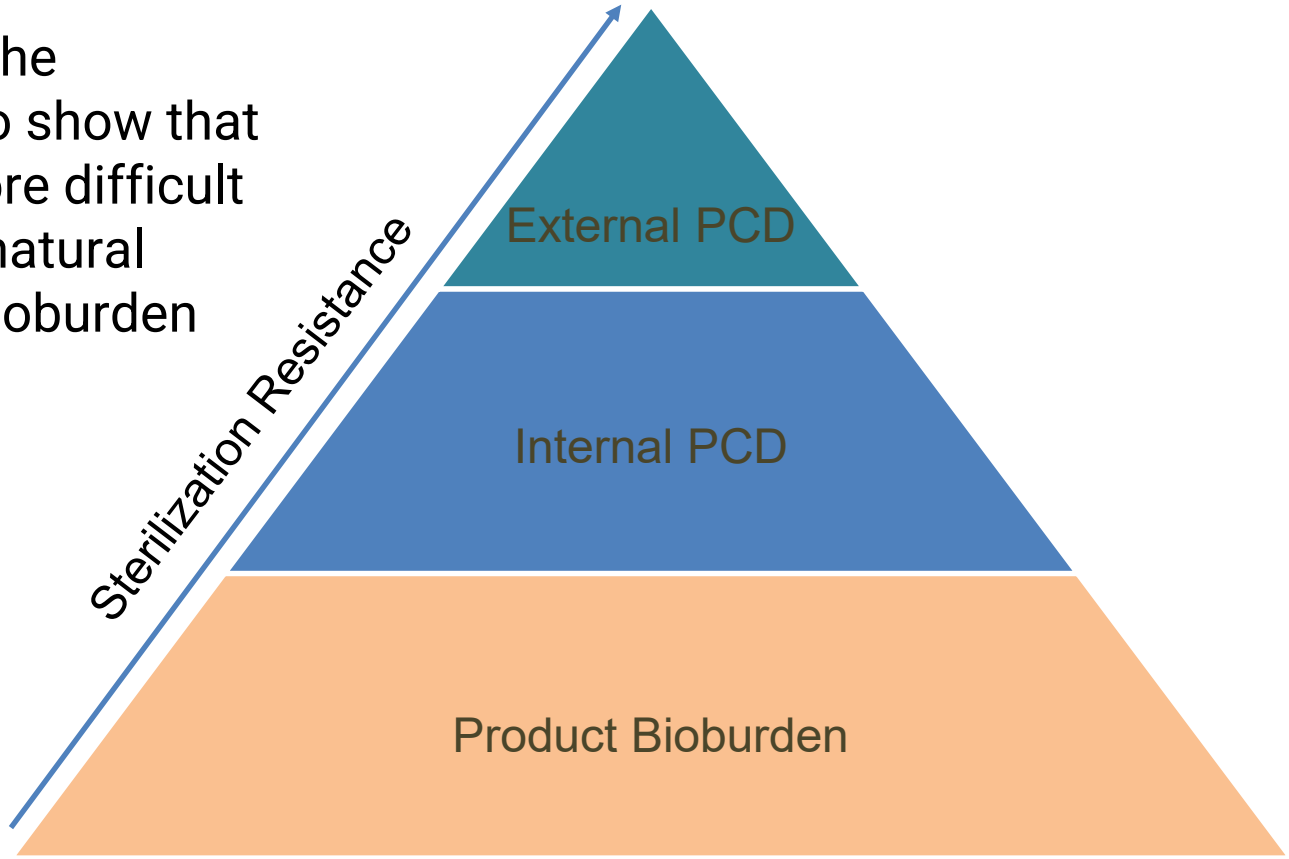
Item designed to constitute a defined resistance to the sterilization process and used to assess performance of the process

- Internal PCD (IPCD)
- External PCD (EPCD)



Sterilization by Ethylene Oxide

We design the validation to show that the **BI** is more difficult to kill than natural occurring bioburden



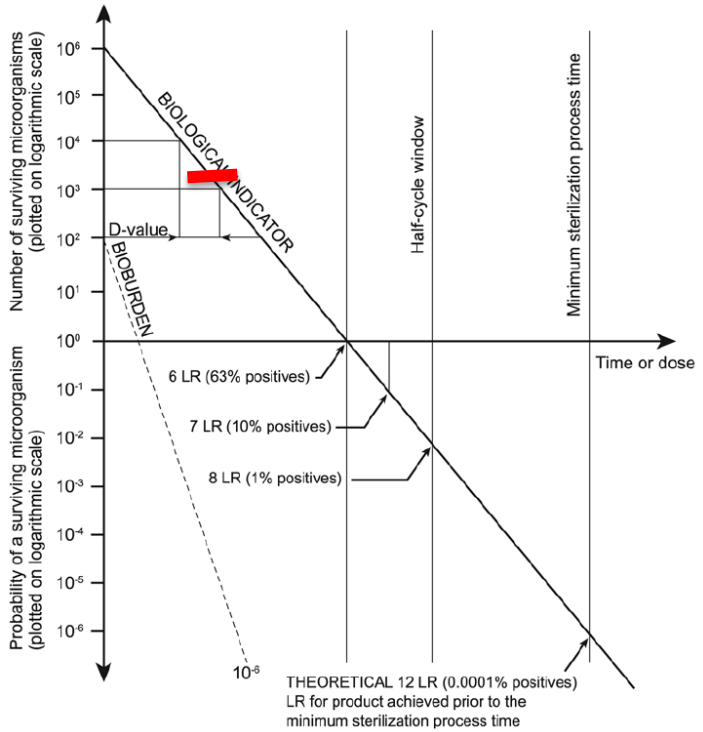
Sterilization by Ethylene Oxide

D Value

The Time needed to deactivate 90% of population of microorganisms (or 1 Log Reduction)

SAL $\leq 10^{-6}$

*The sterilization cycle is **validated** to predict achievement of an SAL equal to or less than a specified value (≥12LR)*



Sterilization by Ethylene Oxide

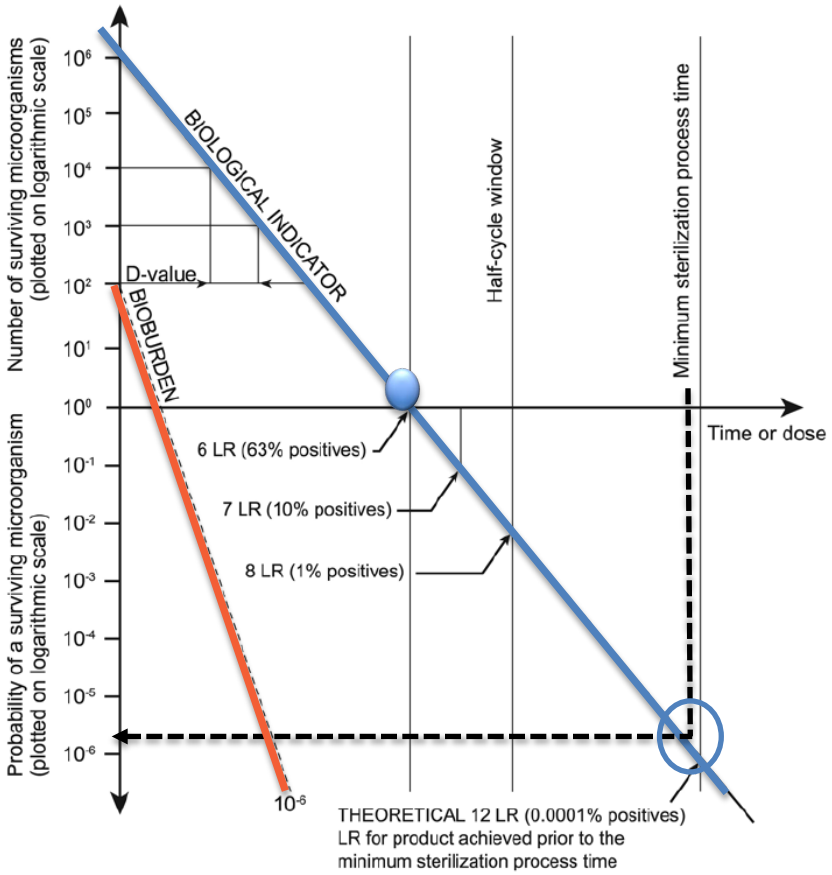
Validation principle

Level of Sterility Assurance

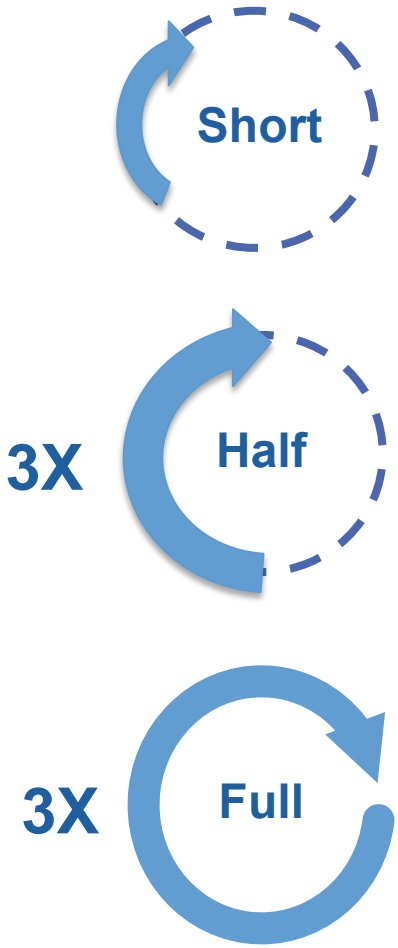
Example:

D_{value} IPCD = 15min = 1LR

6 LR = 90 min (Half cycle)
12 LR =180 min (Full cycle)



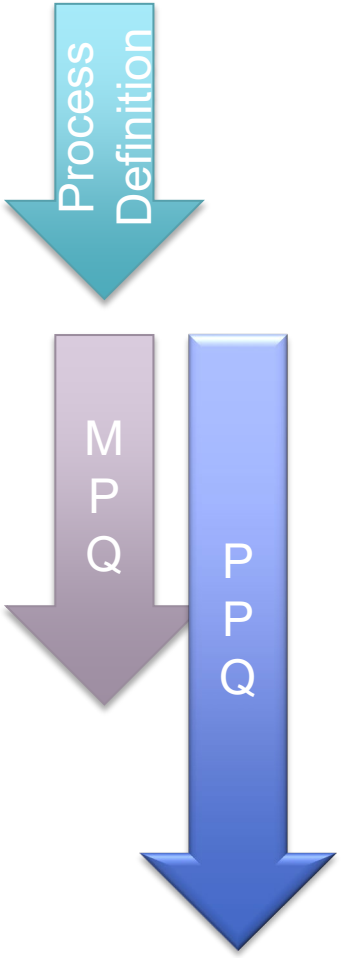
Sterilization by Ethylene Oxide



- **Establish Product/IPCD D_{Value}**
- Product Natural bioburden killed
- Define Challenges (IPCD -EPCD)

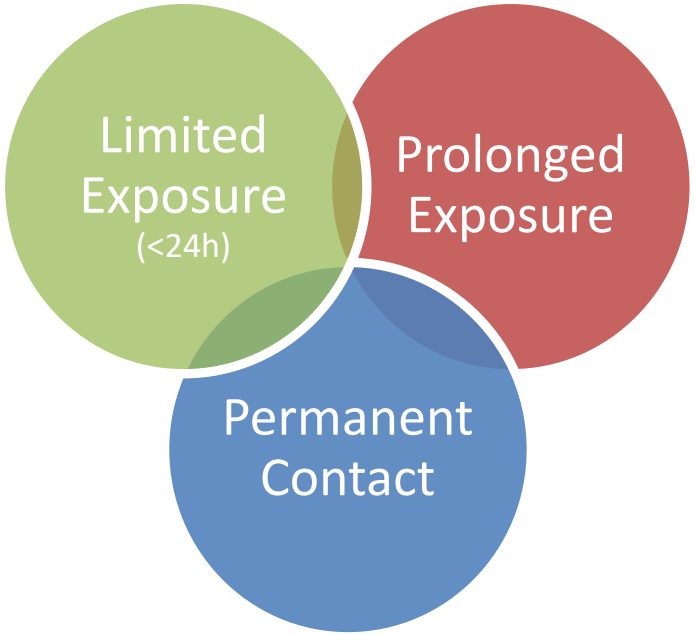
- **Confirm IPCD selection (SAL $\leq 10^{-1}$)**
- Confirm External Challenge (EPCD)

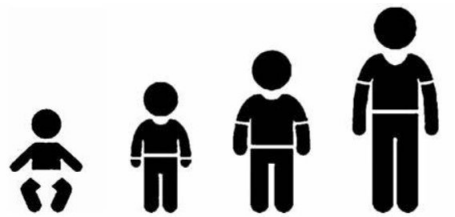
- **SAL $\leq 10^{-6}$**
- Aeration validation - Residue Tests



Sterilization by Ethylene Oxide

Residues



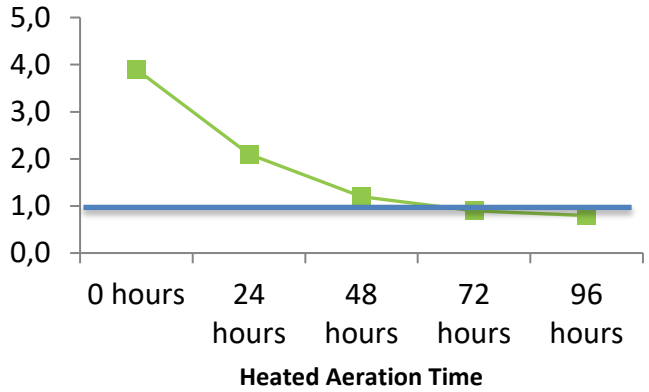


Body mass to consider (Amd1:2019)

Compounds that remain on product after EO sterilization:

- Ethylene Oxide (EO)
- Ethylene Chlorohydrin (ECH) = EO + HCL
- Ethylene Glycol (EG) = EO + H2O

Reference : **ISO 10993-7:2008** "Biological Evaluation Of Medical Devices-Part 7: Ethylene Oxide Sterilization Residuals"



Sterilization by Ethylene Oxide

Residue Limits for Pharma

Raw materials /Finished product

- Ethylene oxide: 1 µg/g
- Ethylene chlorohydrin (or any other halogenated ethylenehydrine): 50 µg/g.

If the residual ethylene oxide originates from its use in the raw starting material, its content must be limited in the raw starting material.

Containers

Specification (based on simulated use):

- Ethylene oxide: 1 µg/ml (container volume)
- Ethylene chlorohydrin (or any other halogenated ethylenehydrine): 50 µg/ml (container volume).

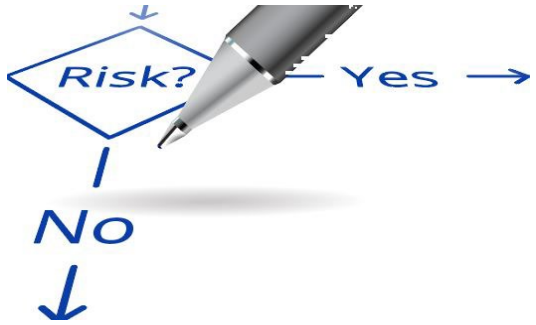
Reference : EMEA/CVMP/271/01 Note for guidance on limitations to the use of ethylene oxide in the manufacture of medicinal products

Sterilization by Ethylene Oxide

Residue Limits for Pharma

Other limits can be established based on

- Risk analysis
- Toxicological data
- Product intended use



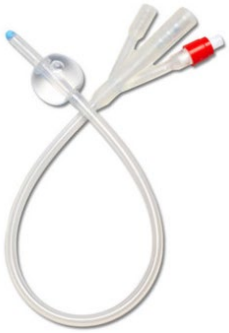
Note : In a prefilled syringe, the syringe is both the injector device and the primary packaging !

Reference : ICH guideline M7(R1) on assessment and control of DNA reactive (mutagenic) impurities in pharmaceuticals to limit potential carcinogenic risk

Sterilization by Ethylene Oxide

Medical Devices

Surgery packs



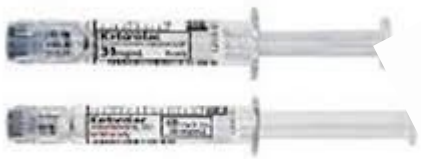
Catheters

vials

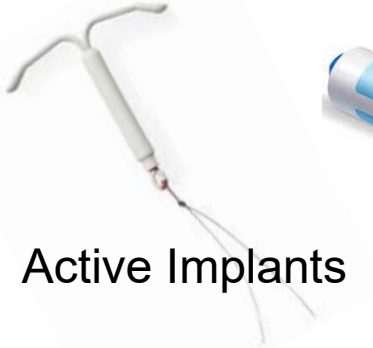
Bandages

Drug products

API



Prefilled syringes (external)



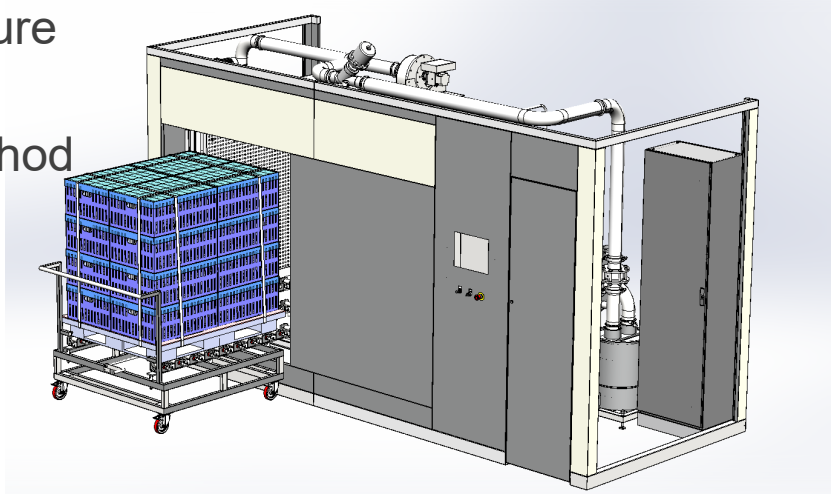
Active Implants

Auto-Injector (external)

NO_2 Sterilization

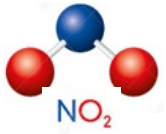
FDA Innovation Challenge 2

- **Surface sterilization** (Drug-delivery devices, Orthopaedic implants, implantable sensors)
- **Short** process time (2-4hours).
- **Safe** and simple to use: non-flammable, non-explosive and non-carcinogenic
- Wide variety of **compatible materials** (if not cellulose based)
- Allows processing of moisture/temperature **sensitive materials**
- Validation with the NO_2 Sterilization method follows **ISO 14937**
- **Low residuals**
- Small volume – Scale up ?

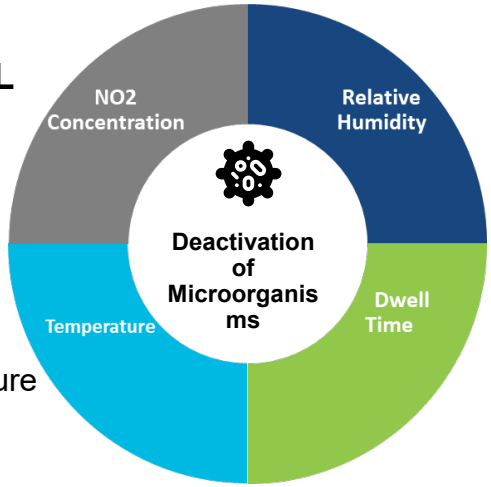


NO_2 Sterilization

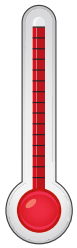
Key Parameters



Typical range **6-15 mg/L**



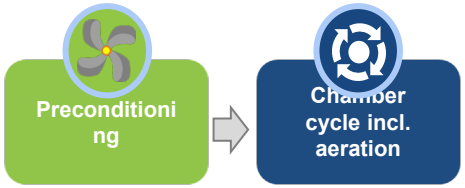
Necessary for **oxidation reaction** effective at **60-80 RH %**



Industrial sterilization performed in 20-25°C temperature range

Microbiological deactivation is more effective with longer gas dwell phase (**Total Cycle time = 4-8h**)

2-Step Process



Comparaison

Radiation and Gas sterilization

Parameter	Gamma or X-Ray	E-Beam	EO	NO2
Process	Individual product, box, tote, pallet	Boxes	Pallets – High Volume	Plastic Tote 1 pallet
Material compatibility	Not compatible with some type of polymers (PTFE and PVC affected)	Wider polymer compatibility compared to Gamma	Very good No liquid/proteins Low Temperature (40-55°C)	Good No Cellulose (paper/carton) No liquid/proteins Very Low Temperature (25°C)
Validation	Straightforward	Straightforward	Complicated	Complicated
Validation principle	Based on bioburden	Based on bioburden	Based on Bio Indicators or bioburden	Based on Bio Indicators
Requalification	Every 3 months (QDA)	Every 3 months (QDA)	Every 2 years (1 cycle)	Every 2 years (1 cycle)
SAL	<10exp6	<10exp6	<10exp6	<10exp6
Residues	None	None	ETO,ECH,(EG)	NO2,NO3

Selection of the method

Ideas to allow Terminal sterilization:

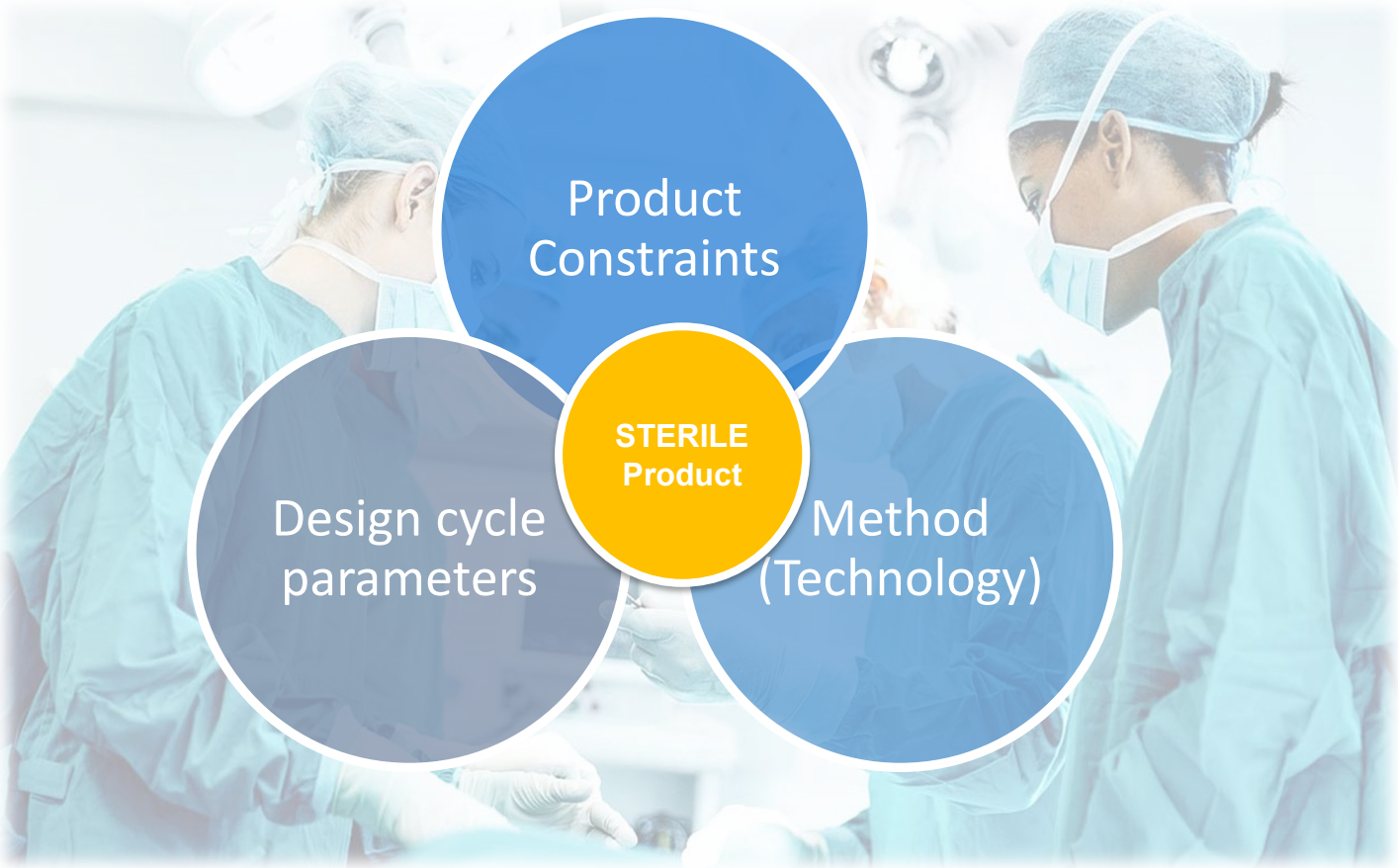
From:

- Steam sterilization ≥121 °C, ≥15 min / Dry heat ≥160 °C, ≥ 2 hours
- High sterilisation doses and wide specs (e.g. 25 kGy – 50 kGy)
- “Overkill” approach for EO

To:

- Lower sterilisation doses/exposure based on bioburden
- Steam : F0 ≥8 minutes
- Irradiation under Inert atmosphere
- Irradiation in cryotainers with dry ice
- shallow vacuum cycle in EO
- Higher SAL (10-4)
- New sterilization technology (NO2)?

Conclusions



Conclusions

Selecting the Right Technology is Key !

There are multiple Terminal Sterilization possibilities

Key is to select the most appropriate technology to **YOUR product** !

Thank you

agillet@eu.sterigenics.com

Reference Slide

- *ISO 11135:2014* Sterilization of medical devices – Requirements for the development; validation and routine Control of a Sterilization Process for Medical Devices – Ethylene Oxide
- *ISO 10993-7:2008 Amd1 (2019)* Biological evaluation of medical devices - Part 7: Ethylene oxide sterilization residuals
- *ISO 11137-1* Sterilization of health care products – Radiation – Part 1: Requirements for development, validation, and routine control of a sterilization process for medical devices
- ISO 11137-2 Sterilization of health care products – Radiation – Part 2: Establishing the sterilization dose
- *ISO 11737-1:2018* Sterilization of medical devices (Microbiological methods) Part 1: Determination of a population of microorganisms on products
- *ISO 11737-2:2009 (R) 2014*
- Sterilization of medical devices (Microbiological methods) Part 2: Tests of sterility performed in the definition, validation and maintenance of a sterilization process
- *ISO 11138-1:2017*
- Sterilization of health care products (Biological indicators) Part 1: General requirements
- *ISO 11138-2:2017*
- Sterilization of health care products (Biological indicators)Part 2: Biological indicators for ethylene oxide sterilization processes
- *ISO 14161: 2009 (R) 2014*
- Biological indicators. Guidance for the selection, use and interpretation of results

Reference Slide

- *ISO 11737-2:2009 (R) 2014*
  Sterilization of medical devices (Microbiological methods) Part 2: Tests of sterility performed in the definition, validation and maintenance of a sterilization process
- *ISO TS 19930:2017 Guidance on aspects of a risk-based approach to assuring sterility of a terminally-sterilized, single use health care product unable to withstand processing to achieve maximally a sterility assurance level of 10-6*
- *AAMI TIR 33* Sterilization of health care products—Radiation—Substantiation of a selected sterilization dose — Method Vdmax
- *United States Pharmacopeia* (USP) Chapter <71> Sterility Tests
- *Eudralex Volume 4* – GMP Annex 1
- *Eudralex Volume 4* – GMP Annex 12
- *European Pharmacopeia* (EP) Chapter 2.6.1 Sterility
- The *Aseptic and Sterile Processing: Control, Compliance and Future Trends* - Edited by Tim Sandle, Edward Tidswell PDA – 2017
- *PDA Survey*: 2017 PDA Aseptic Processing
- A comparison of Gamma, E-beam, X-Ray and ETO technologies for the indsutrial Sterilization of MD and Health care products – GIPA, IIA – 31 Aug 2017