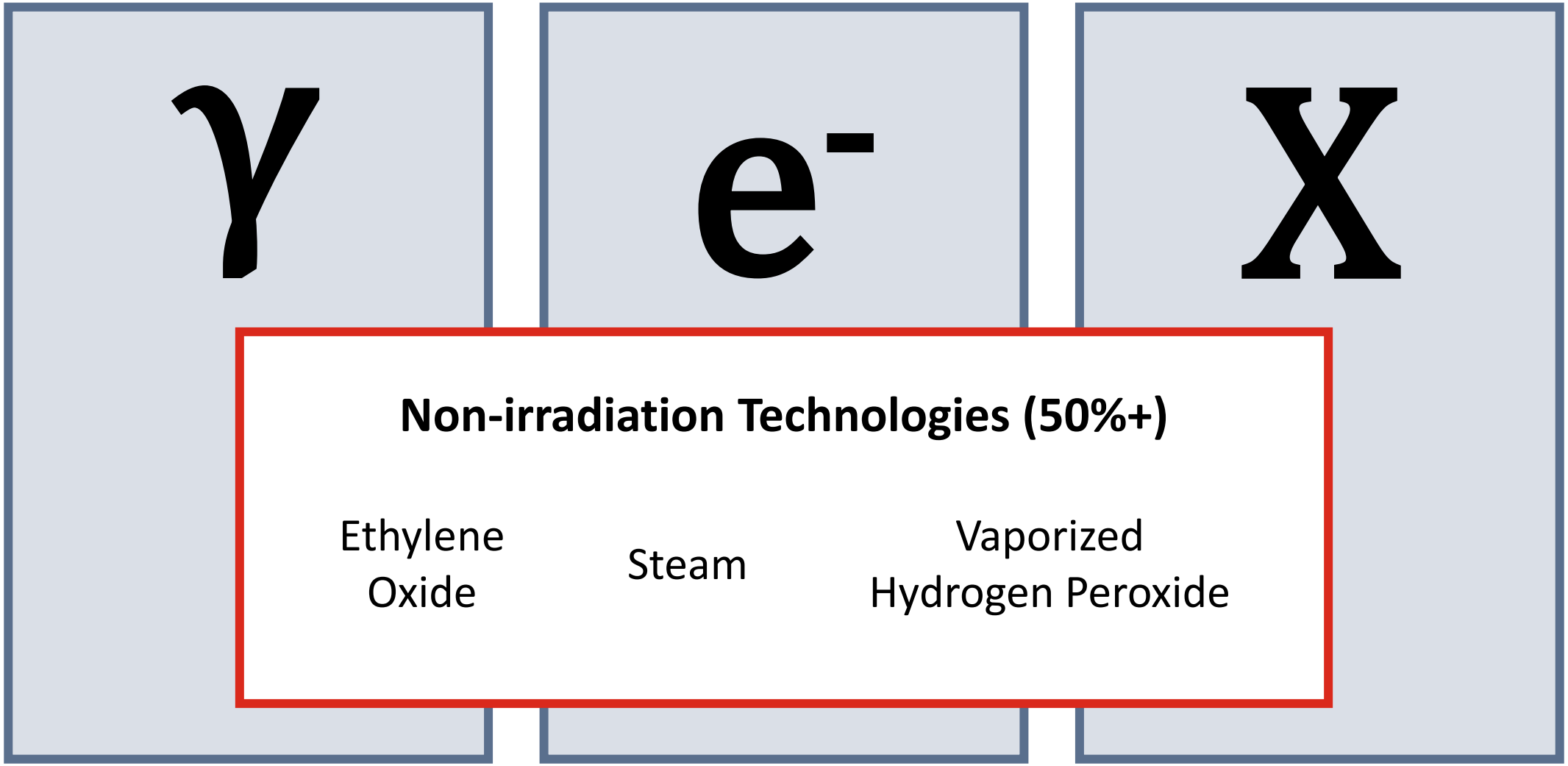
Low-energy X-ray (LEEX) is Expanding

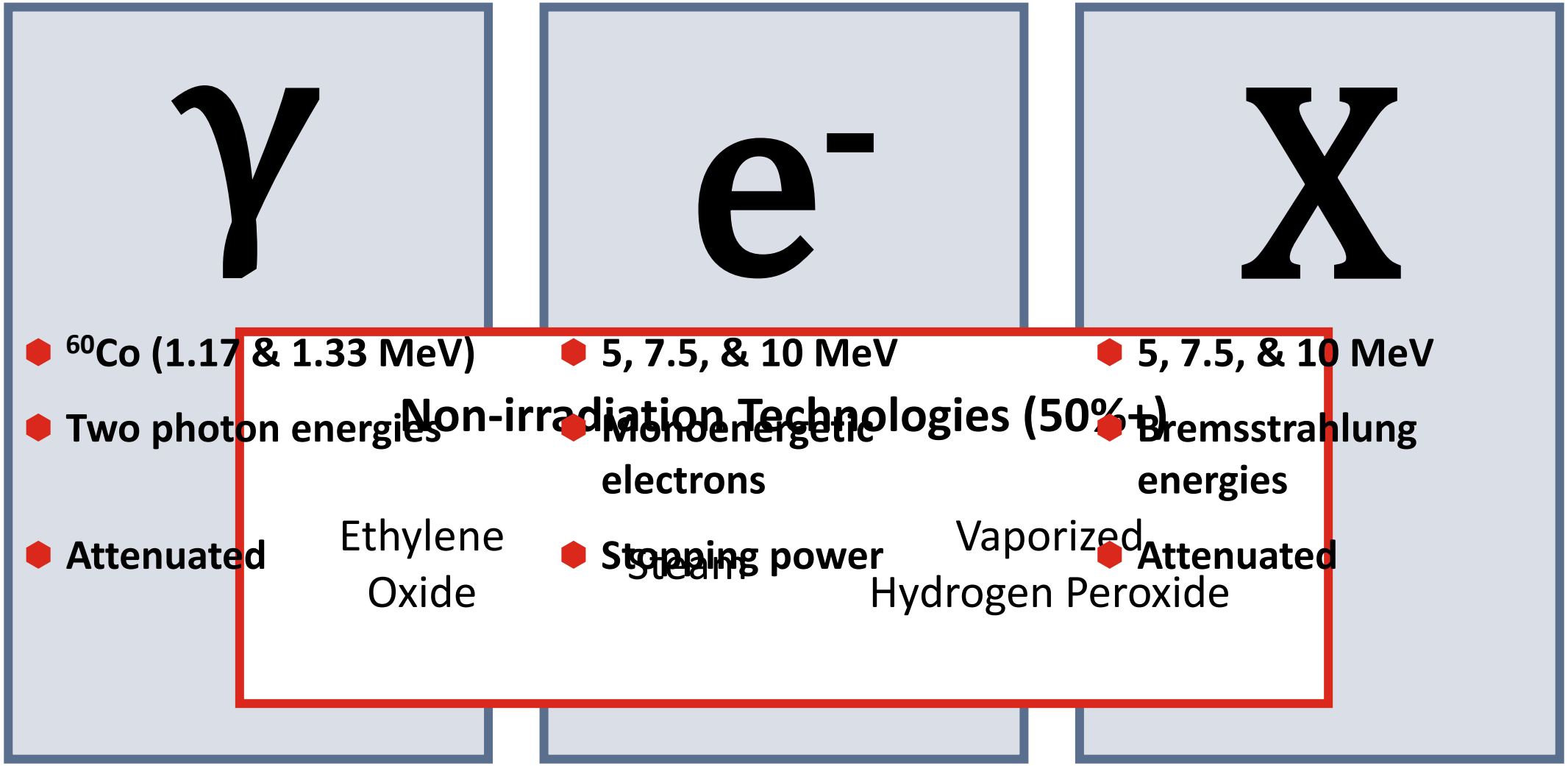
By P. Michael Fletcher, President, Ebeam Consulting
and Dr. Sage Schissel, Applications Specialist,
At PCT Ebeam and Integration

April 12, 2022

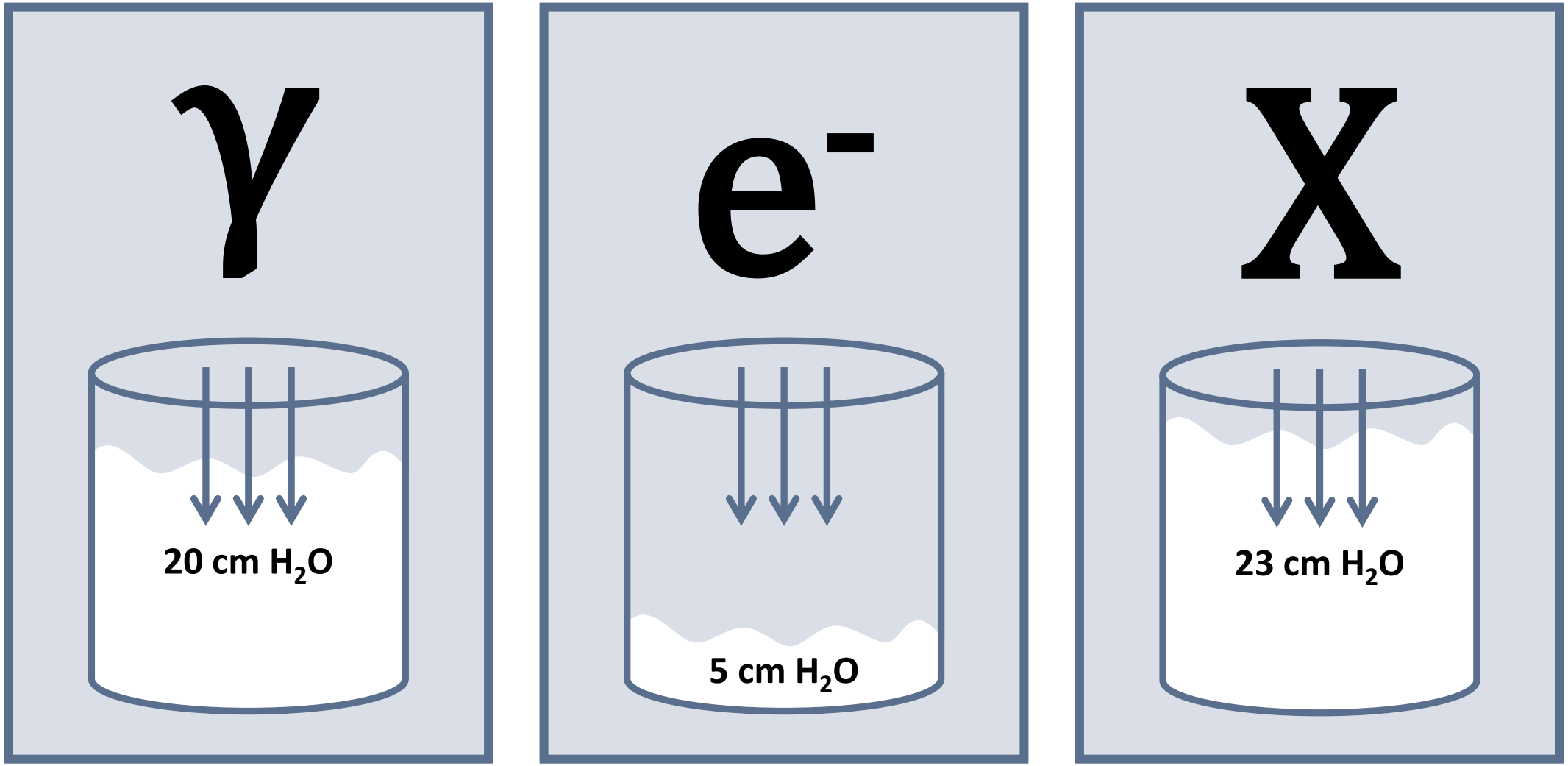
Irradiation, divided between 3 different modalities, represents ~45% of contract sterilization.



Irradiation, divided between 3 different modalities, represents ~45% of contract sterilization.



For material densities ~0.2 to 0.3 g/cm^3, these irradiation methods allow for the treatment of large totes or pallets.

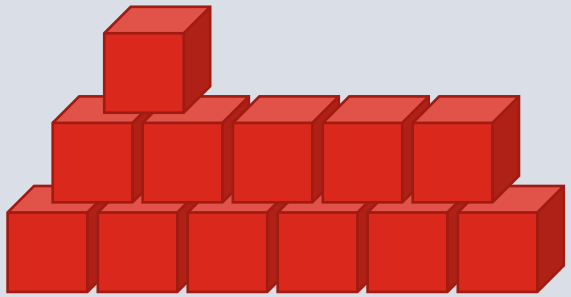


All 3 have high throughput capacities (>2000 tons/month) at a dose of 25 kGy.

**Note: Data on example capacities are from GIPA&iiA White Paper, 2017*

γ

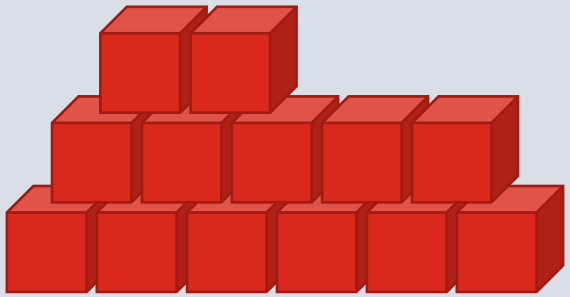
~ kGy/hr



2,400 tons/month

e^-

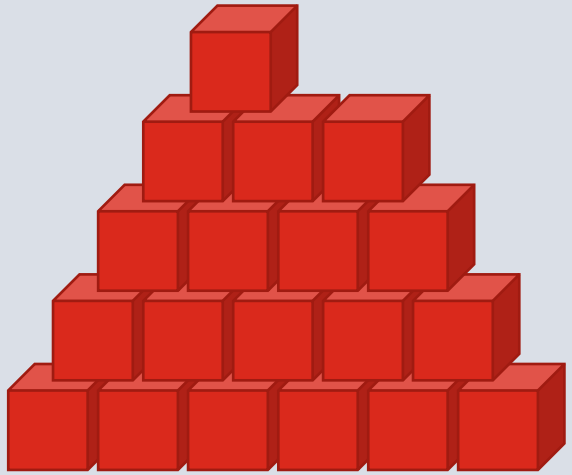
~ MGy/hr



2,600 tons/month

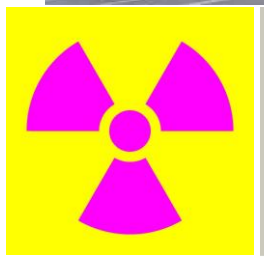
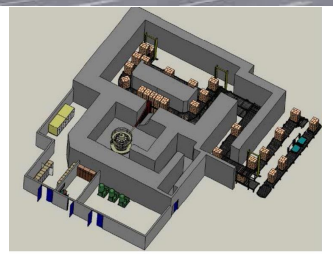
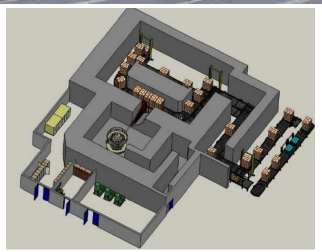
X

~ kGy/hr



3,700 tons/month

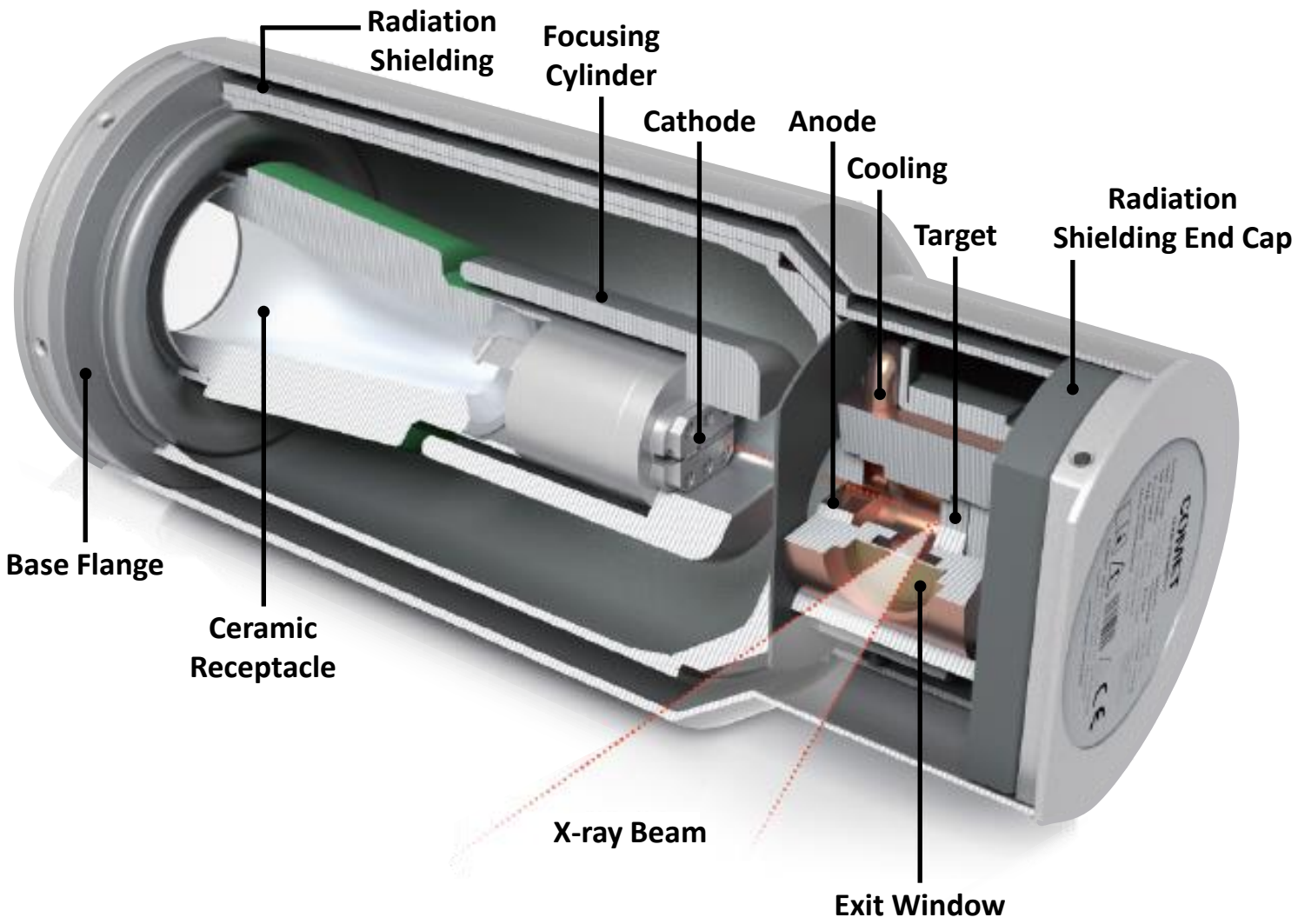
Currently, gamma represents the majority of the irradiation sterilization market, but there are pressures against new facilities.

γ	e^-	X
Pressures Against:		
		
		
		
X-Ray Facility Image Credit: IAEA	X-Ray Facility Image Credit: IAEA	X-Ray Facility Image Credit: IAEA

Wilhelm Conrad Roentgen discovered x-ray in 1895.

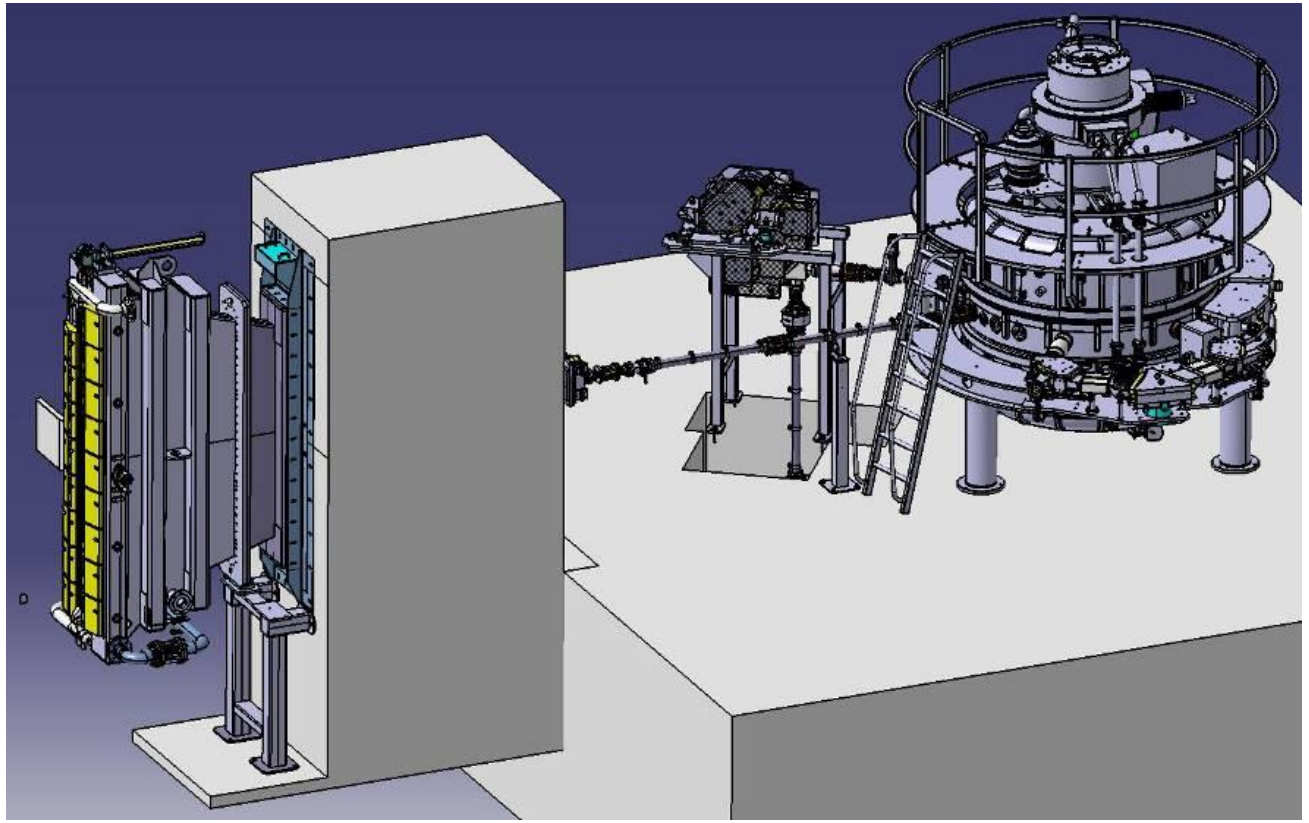
- Conducted experiments with a Crookes tube
- Used in cancer treatment within 10 years
- Multiple patents for use to kill microbes within 10 years
- Exposed his wife's hand for 15 min. to produce an image
- Awarded the very first Nobel Prize in Physics in 1901 for discovering the x-ray

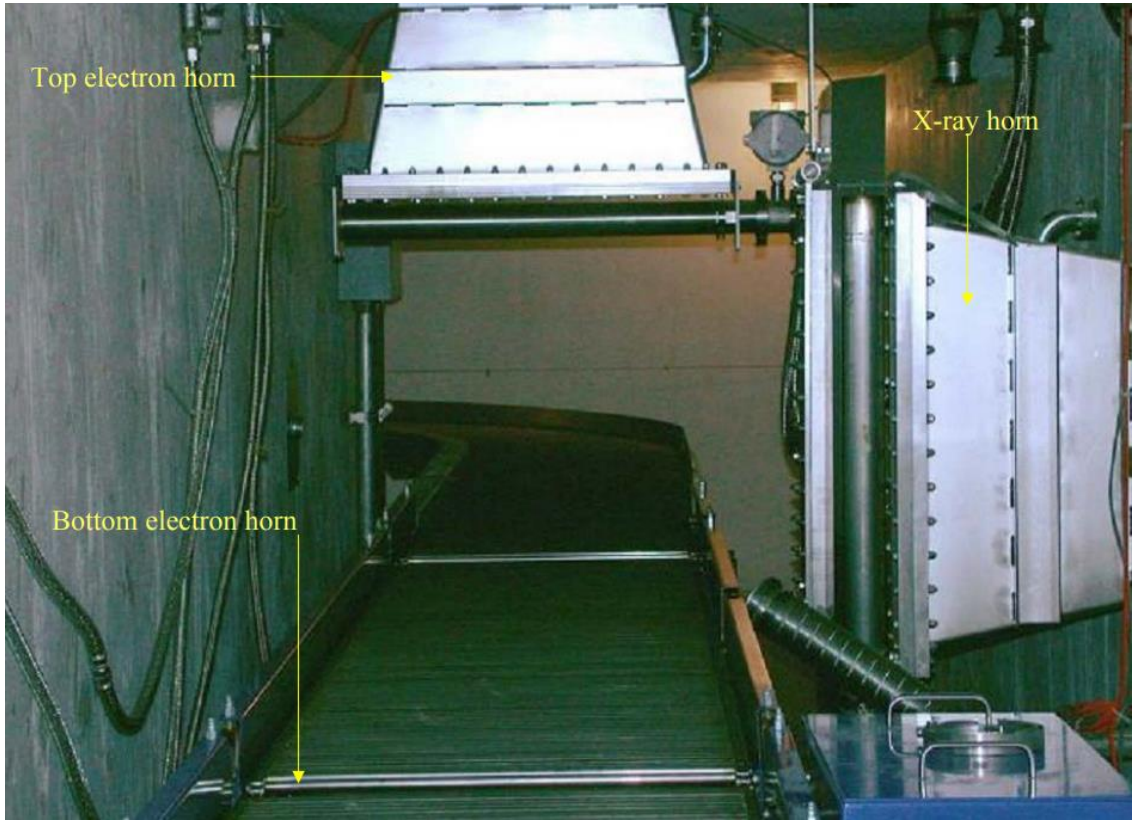
X-rays are produced when electrons are accelerated at a target.



Low-energy x-ray systems typically operate at 100-800 kV and < 5 kW, though some are capable of 10-15 kW.

High-energy x-ray systems typically operate at 3-7 MeV and can range up to 100's kW.

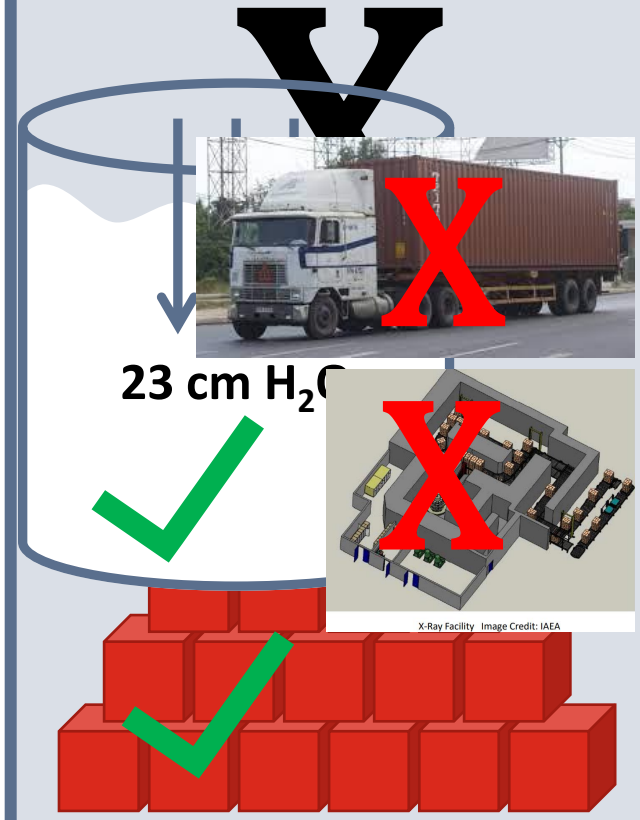




Treatment zone at Texas A&M (5 MeV, 15 kW)

High-energy x-ray systems----------Low Energy x-ray systems

High Energy High Power



3,700 tons/month

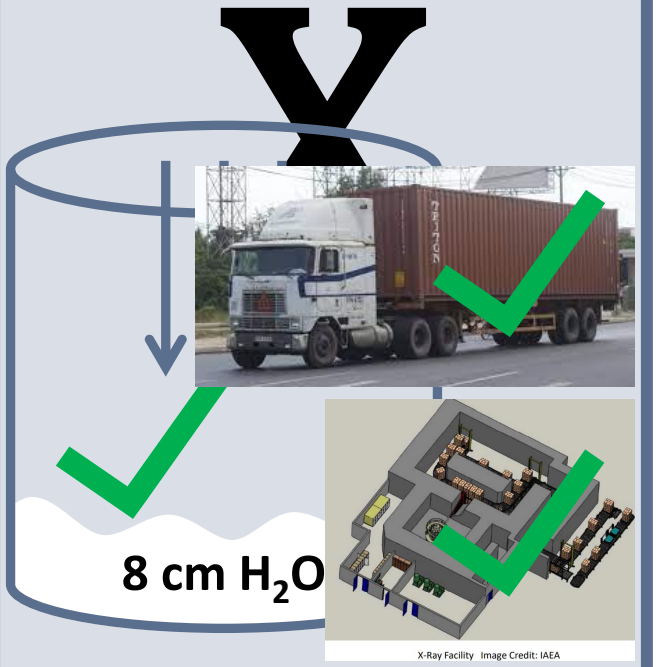
If *need:*

- **Medium Penetration**
- **In-house, in-line processing**
- **Small machine footprint**
- **Medium throughput**

As examples:

- **Some in-line med devices/drugs – for slight bioburden reduction**
- **In-line small packages – e.g. 12 inches or 30 cm deep; depends on density**
- **In-line meats – whole chickens**
- **Pet-food treats – boxes of treats**
- **Phytosanitary treatments - boxes of fruits or vegetables**

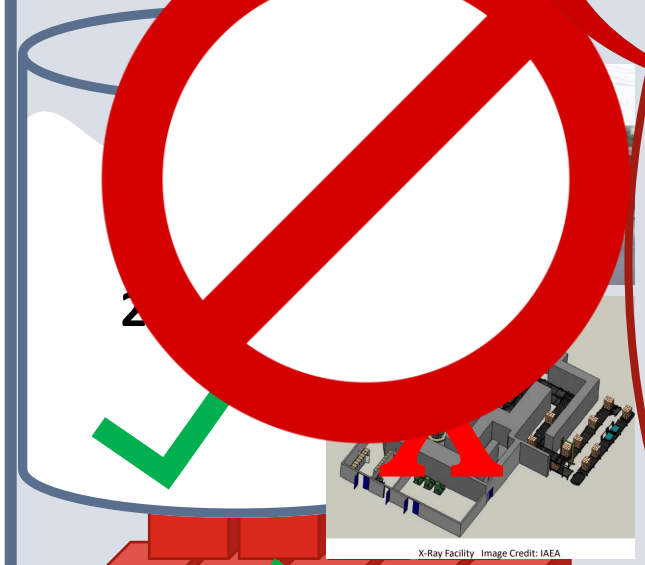
Low Energy Low Power



<1 ton/month

High-energy x-ray systems----------Low Energy x-ray systems

High Energy High Power



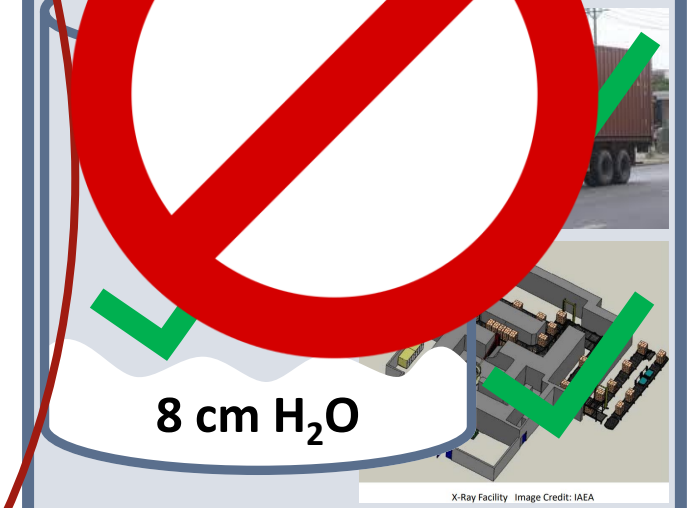
3,700 tons/month

Low Energy

High Power

X-ray Systems

Low Energy Low Power



8 cm H_2O

<1 ton/month

Low Energy High Power X-ray

- Energy: 300 keV X-ray source
- Power: 150 kW, 300 kW, 600 kW
- Treatment Zone: 4 ft^2 or 8 ft^2
- Maximum Dose Rate Averages:
  - 280 Gy/minute over top surface
  - 200 Gy/minute below 50 mm of water
  - Note: Actual dose to product depends on presentation, attenuation, and dwell time

Low Energy High Power X-ray

For a 600 kW eXede, the throughput is given below for two box sizes and two doses:

Box size (cm x cm x cm)	Density (g/cm^3)	DUR	Throughput at 1000 Gy (kg/hour)*	Throughput at 10 kGy (kg/hour)*
25 x 25 x 30	0.2	1.4	270	27
15 x 25 x 30	1.0	1.7	2140	214

Compare to:
4 kg/hr at 6 kW @1.0 kGy
(RadSource data)

*Mapping of x-ray output was done with a RadCal sensor (Model 2186). Simulations were made to estimate dose for moving products through the x-ray zone, and the simulation tool was then validated by using WinDose dosimeters. The simulated doses and actually received doses were compared and found to have excellent correlation.

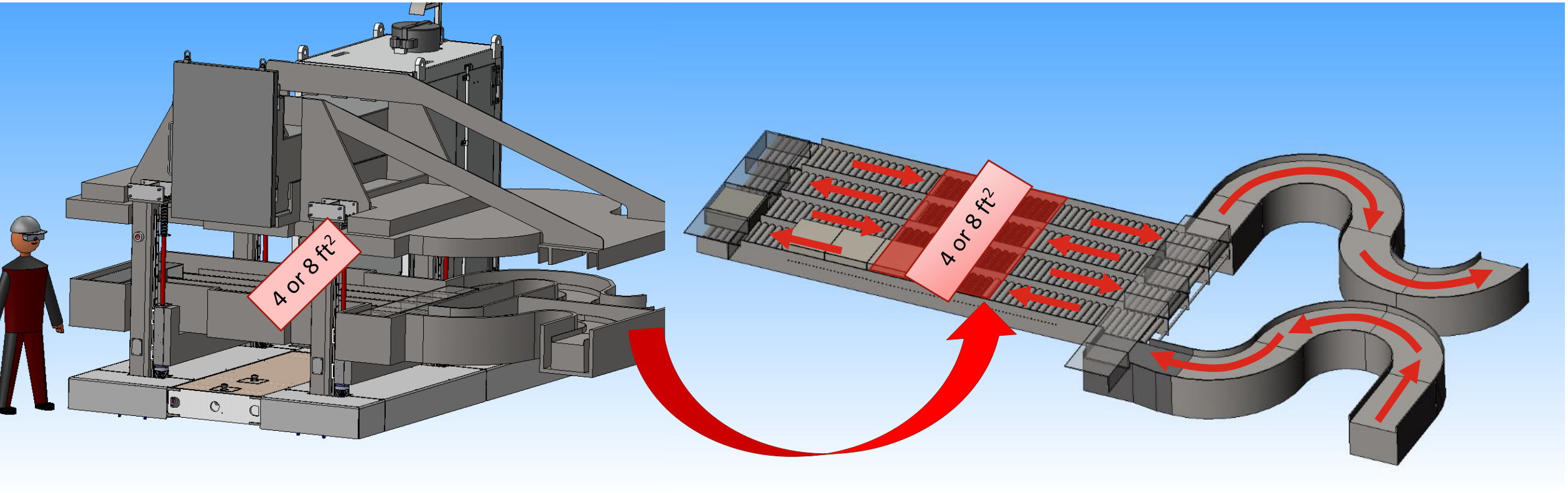
500x capacity

Low Energy High Power X-ray

- Energy: 300 keV X-ray source
- Power: 150 kW, 300 kW, 600 kW
- Zone treatable: 4 ft^2 or 8 ft^2
- Maximum Dose Rate Averages:
  - 280 Gy/minute over top surface
  - 200 Gy/minute below 50 mm of water
  - Note: Actual dose to product depends on presentation, attenuation, and dwell time

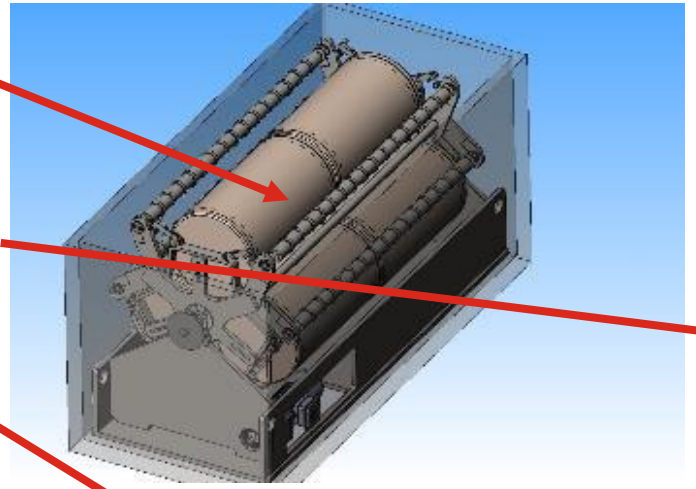
Low Energy High Power X-ray – *With Conveyor*

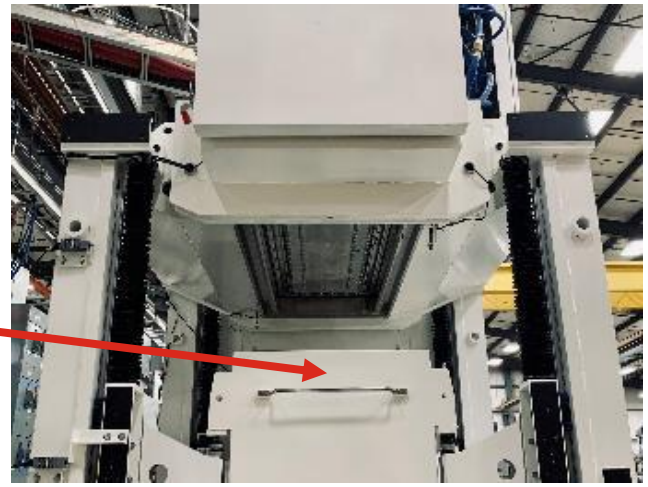
Conveyorized, to pass product through multiple lanes within shielding

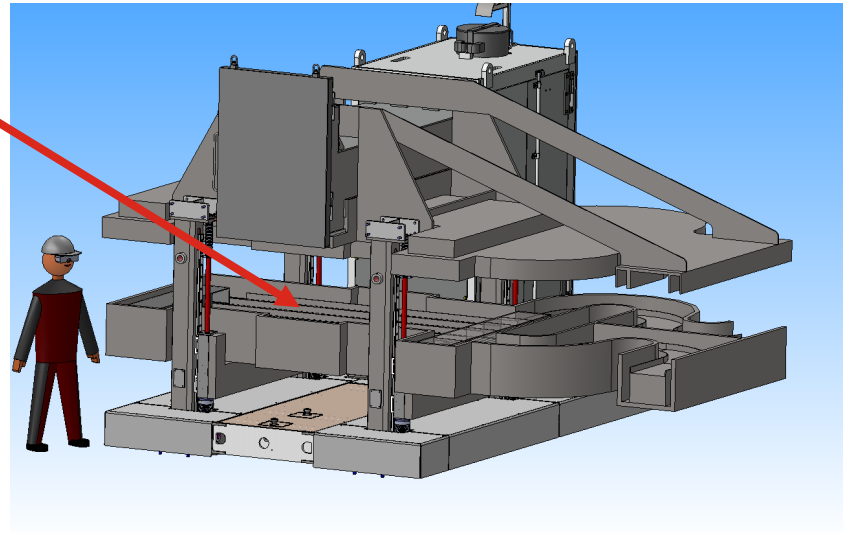


Low Energy High Power X-ray – *Material Handling Options*

- Cannisters for loose materials
- Pipes for liquids
- Batch tub for low volume parts
- Conveyors for boxes, bags, totes, or trays
- Beam delivery orientation: vertically up or down, sideways
- Controlled atmosphere possible

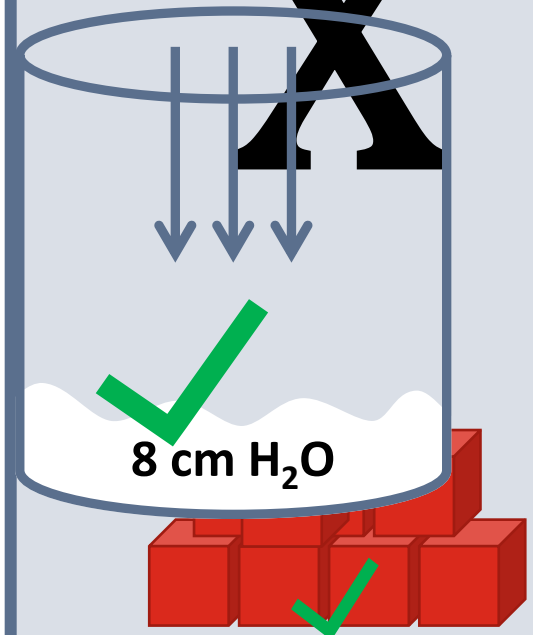






Low Energy High Power X-ray Systems' Benefits

High Power



34 tons/month, 25 kGy

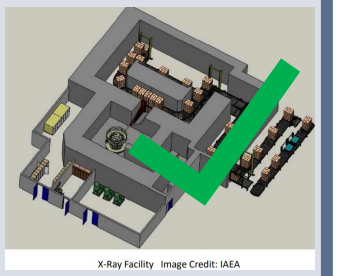
850 tons/month, 1 kGy

Low Energy

High Power

X-ray Systems

Low Energy

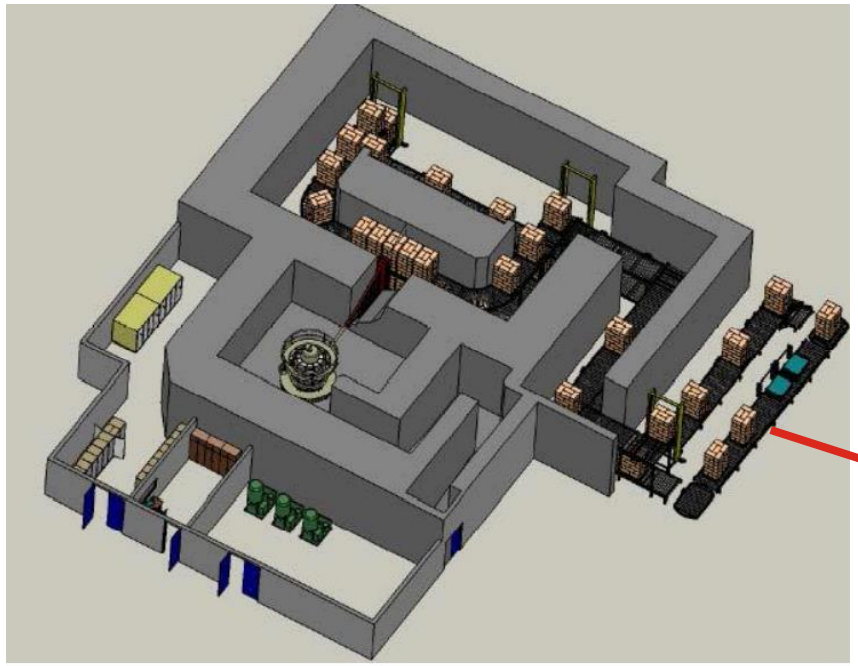


X-Ray Facility Image Credit: IAEA

Low Energy High Power X-ray – *Power Ratio*

40-100 x more power

Low Energy High Power X-ray – *Shield-Size Ratio*



X-Ray Facility Image Credit: IAEA

1/10th the size

Low Energy High Power X-ray – *Looking forward*

- Market need
  - In-line and in-house installations
- Further studies of LEEX
  - Comparison of bio-burden reduction, D_{10} value compared to Gamma
  - Projects such as: *IAEA CRP D61025 - Innovating Radiation Processing of Food with Low Energy Beams from Machine Sources*
- Isotope Impetus
  - Shifting Medical Devices from Gamma to X-ray
  - Electronic-radiation enabling broader food treatment in more countries

Low Energy High Power X-ray

- **Available for evaluation and product testing**

Low Energy High Power X-ray – *Throughput examples*

For Product with **ρ=0.2 g/cm^3** and requiring **1000 Gy** dose –

If pack 25 cm x 25 cm x 30 cm box –

At 300 kV:

- DUR from top to bottom of box: 2.46
- DUR from top to middle of box: 1.50
- DUR after four passes, with flipping and rotating: 1.29

Product Throughput Capacities (100% utilization)

- At 500 mA over 1.2 m x 0.25 m beam window: 270 kg/hr; 196 tonnes/month
- At 1000 mA over 1.2 m x 0.25 m beam window: 540 kg/hr; 390 tonnes/month
- At 2000 mA over 2.4 m x 0.25 m beam window: 1080 kg/hr; 780 tonnes/month

Low Energy High Power X-ray – *Throughput examples*

For Product with ***ρ=1.0 g/cm^3*** and requiring **1000 Gy** dose –

If pack ***15 cm*** x 25 cm x 30 cm box –

At 300 kV:

- DUR from top to bottom of box: 4.0
- DUR from top to middle of box: 2.3
- DUR after four passes, with flipping and rotating: 1.5

Product Throughput Capacities (100% utilization)

- At 500 mA over 1.2 m x 0.25 m beam window: 535 kg/hr; 385 tonnes/month
- At 1000 mA over 1.2 m x 0.25 m beam window: 1070 kg/hr; 770 tonnes/month
- At 2000 mA over 2.4 m x 0.25 m beam window: 2140 kg/hr; 1540 tonnes/month

Low Energy High Power X-ray – *Throughput examples*

For Product with **ρ=0.2 g/cm^3** and requiring **25 kGy** dose –

If pack 25 cm x 25 cm x 30 cm box –

At 300 kV:

- DUR from top to bottom of box: 4.0
- DUR from top to middle of box: 2.3
- DUR after four passes, with flipping and rotating: 1.5

Product Throughput Capacities (100% utilization)

- At 500 mA over 1.2 m x 0.25 m beam window: 10 kg/hr; 8 tonnes/month
- At 1000 mA over 1.2 m x 0.25 m beam window: 20 kg/hr; 15 tonnes/month
- At 2000 mA over 2.4 m x 0.25 m beam window: 40 kg/hr; 31 tonnes/month

Questions?

Michael Fletcher & Dr. Sage Schissel

Michael.fletcher@pctebi.com
Sage.Schissel@pctebi.com

PCT
EBEAM AND INTEGRATION