Medical Device Sterilization:
Past, Present, and Future
September 20-21, 2023

In-house e-Beam Sterilization

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User Group

Current Participants

- Abbott, Bayer, BD, Boston Scientific, J&J, Medtronic, Pfizer, Terumo

Vision:

We strive to see distributed small scale in-house sterilization capability that supports automated assembly lines for disposable medical devices. These sterilization tools will be compatible with the products, safe for employees, easy to deploy and validate.
They will minimize production lead time, energy consumption and environmental footprint.

Mission:

We will encourage small-scale in-line or end-of-line eBeam sterilizer development by defining our common technical requirements and leveraging this commonality to attract new equipment suppliers and designers to support our needs. We will support industry knowledge development for materials and processes to facilitate incorporation of distributed eBeam sterilization in our product and process designs.

Desired Benefits of in-line or end-of line eBeam vs EtO

- Lower business continuity risk in the USA for eBeam vs EtO. Both for incoming materials and emissions.
- Fit with large volume automatic assembly:
  - Possibility to build self-contained plant anywhere
  - Output 50-350 kgs of product per hour at typical 25 kGy average absorbed dose
  - Reduced production time by 4 days, reduced release time by up to 14 days vs EtO (dosimetric, no bioindicators)
- Low Capital Cost
  - Easy permitting. Easy grid connection (<100 kVA). Direct costs target ($0.50/kg), below EtO
  - Need for “standard” designs that cover most med device permutations (i.e. 1 MeV * 1 kW; 3 MeV x 3 kW; 10 MeV x 8 kW) and can be “customized” with product-specific material handling for single or double sided irradiation
- Energy Benefits vs large centralized sterilization
  - Boxes are not sterilized ➔ cheaper cardboard or taller pallet → reduced transport costs
  - Typical energy consumption per lb sterile device in EtO is 5 times higher than in eBeam
  - Reduced carbon footprint resulting from less transportation, less emissions control
- Main eBeam Concerns
  - Equipment availability, dose uniformity/penetration, materials degradation under radiation

per lb product	EtO**	eBeam*	EtO/eB
kWh electric	0.22	0.13	2
000 Btu gas	1.4	0.01	190
Btu equivalent	2.1	0.42	5
EtO, lbs/ton product	10	0	n/a

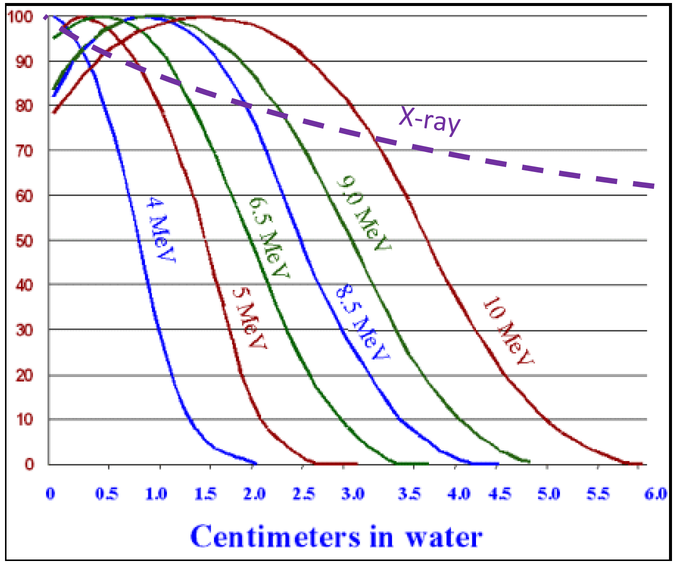
*eBeam accelerator, handling, excl building

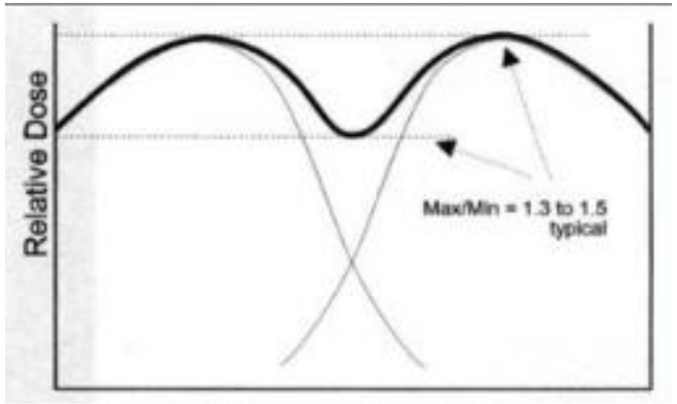
** EtO chambers, aeration, handling, building

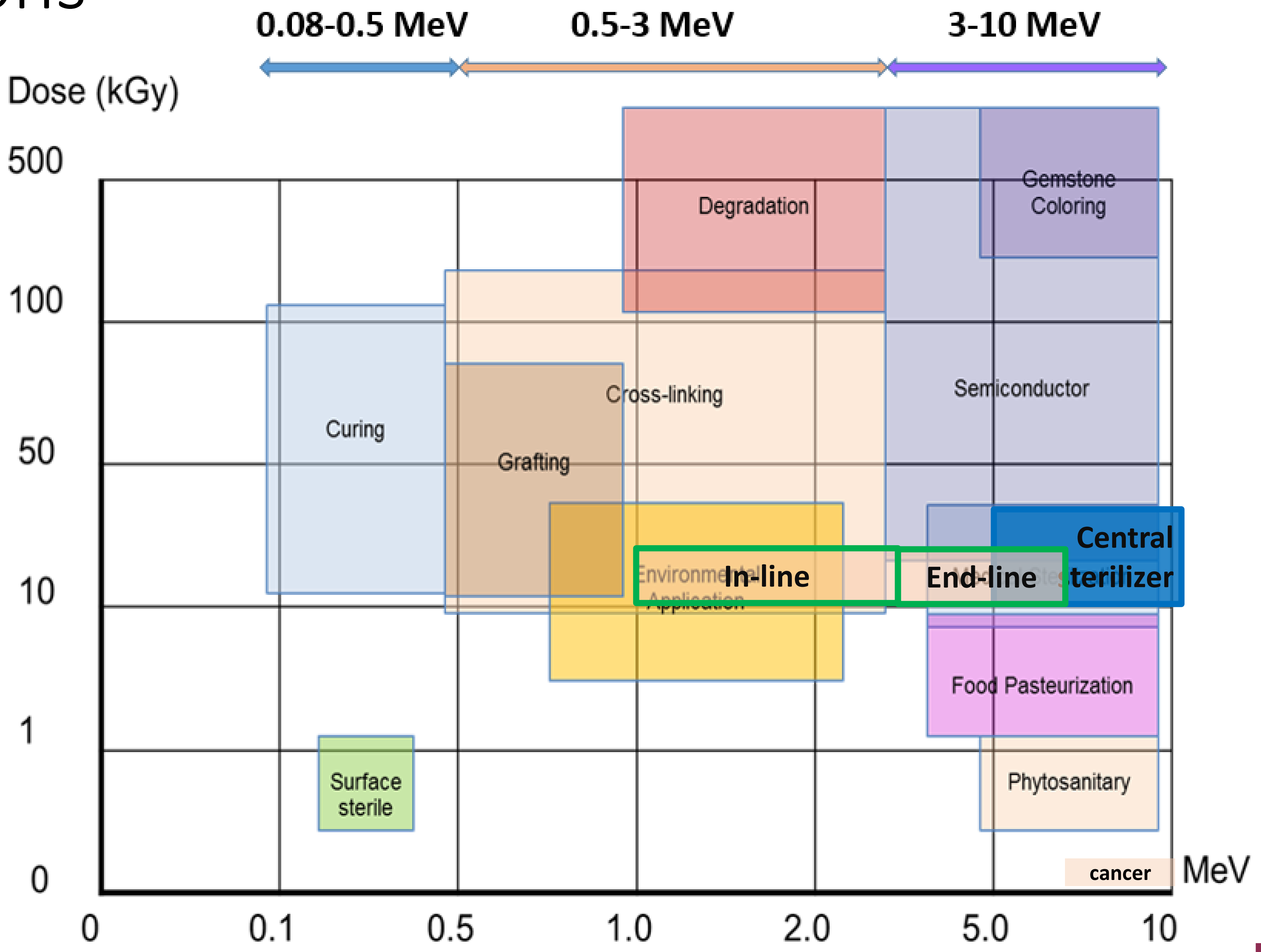
Applicability of Radiation Methods to a Terumo Tubing Set

	Gamma	X-Ray 7 MeV	Central eBeam	In-line eBeam	End-of-line eBeam
Energy	Mean 1.25 MeV	mean 1.4 MeV	10 MeV	2.5 - 4 MeV	6 - 9 MeV
Installation power	30-40 kW equivalent	200 – 500 kW	15 – 150 kW	6-8 kW	6-10 kW
Energy usage kWh/kg	TBD	High	Medium	Low	Low
Penetration (**water**)	>100 mm	>150 mm	50 mm	9 mm (1 sided) 20 mm (2 sided)	14 mm (1 sided) 34 mm (2 sided)
Absorbed dose rate	1-8 kGy/h	10-100 kGy/h	1000-3000 kGy/hr	1500 kGy/hr	1500 kGy/hr
Material compatibility	except: PVC, PTFE, Acetal, PP	Less degradation than gamma	Least damage, but may affect polyurethane, PP, PE, hard PVC, ABS		
Process unit	Pallet or box	Pallet	Box	Kit	Box
Process	Continuous/ batch	Semi continuous	Semi continuous	Continuous	Continuous
Consistency	Changes from box to box	Consistent	Consistent	Consistent	Consistent
Process time	Hours	Hours	10 - 40 s per box	2 s per Rika set	60 s per box
Footprint, sq. meters	Building	Building 1500 m^2	Building 1000 m^2	Warehouse – 100 m^2	Warehouse 150 m^2
Shield	Concrete	Concrete	Concrete	Lead, Self shielding	Lead, Self shielding
Release	←====================================Dosimetric, one parameter====================================→				
Dose Uniformity	Good	Best (penetration, backscatter)	Good (backscatter)	Medium	Good (backscatter)
Technology status	Mature	Developed	Developed	Needs development	Needs customization
Min site invest, $mln	?	?	?	$10 million per line	$10 million per line

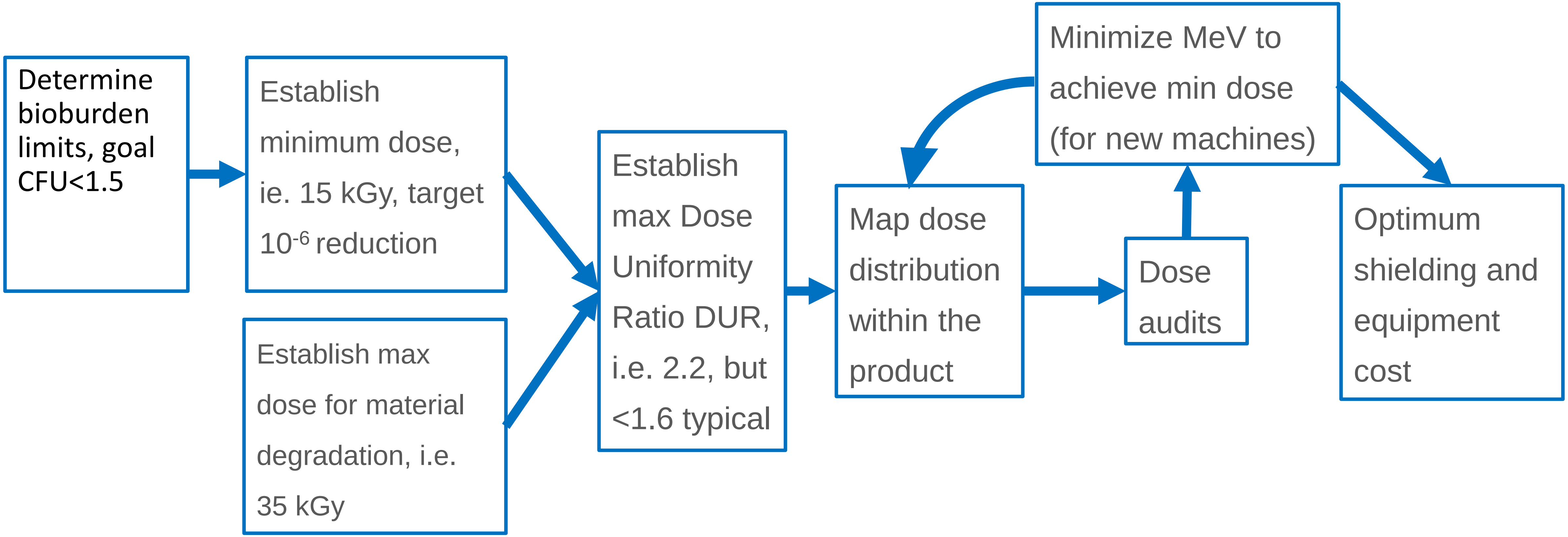
E-Beam Applications





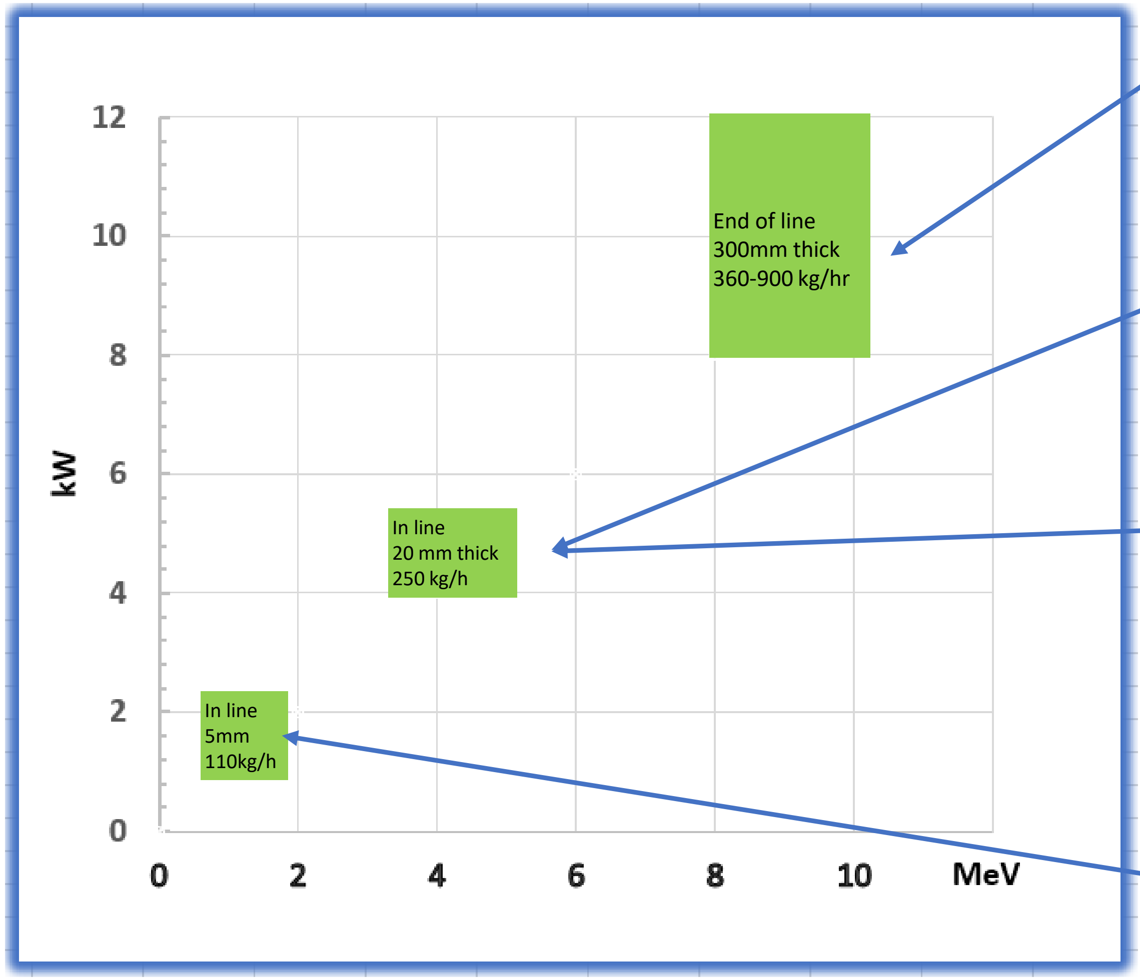


eBeam Sterilization Process Development and Validation



Sample products

Total power (total for 2 accelerators per machine)



Bayer syringes

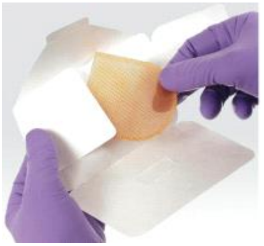
Terumo tubing sets

Abbott guidewire, delivery systems

Medtronic, Pfizer

Sutures

Mesh



Vials

Materials Degradation

BEAM DIRECTION

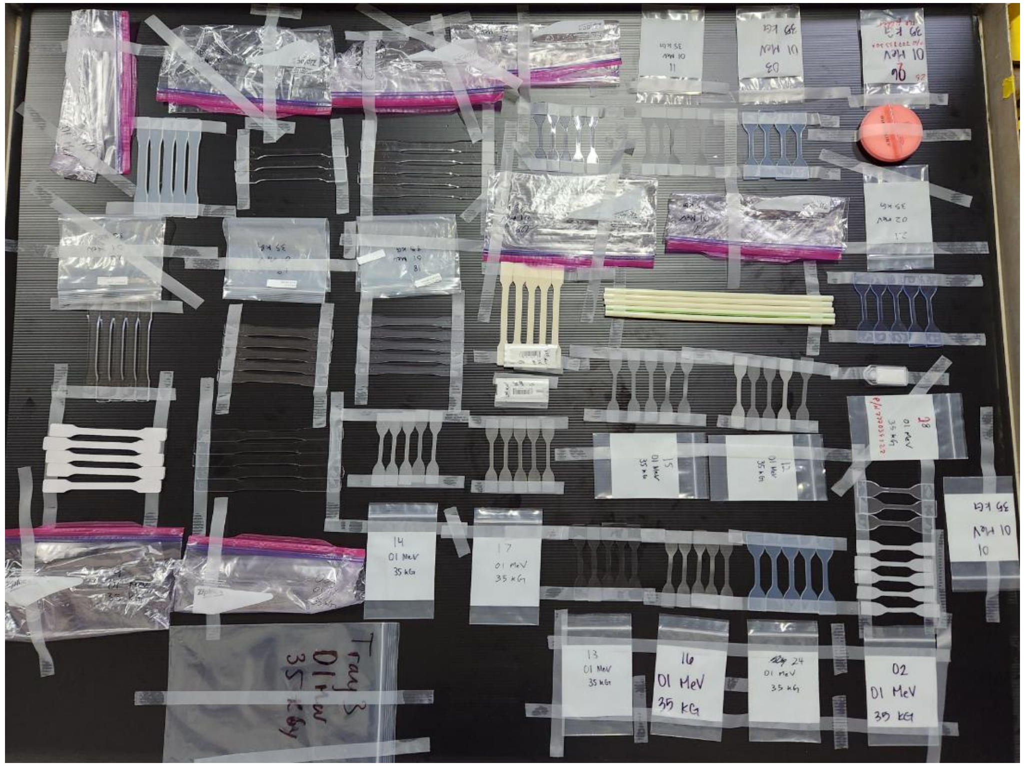
TOP VIEW

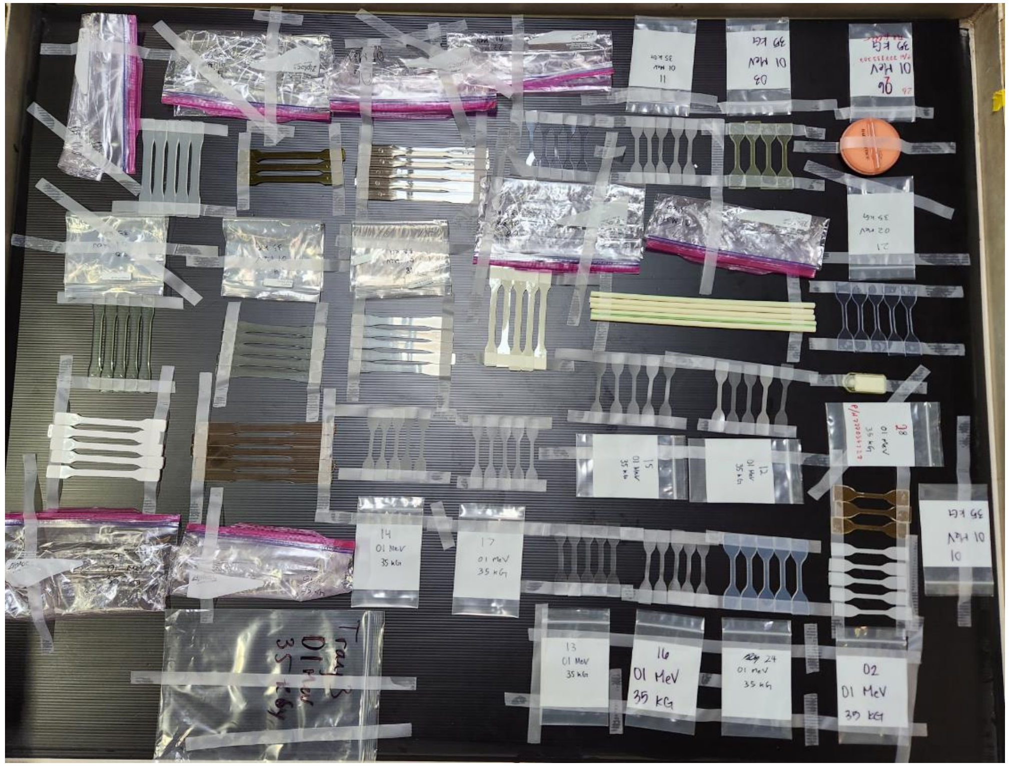
eBeam effect on mechanical properties

24 materials irradiated at 15, 25, 35, 45, 60 kGy, tested at PNNL

- Complete testing at PNNL ➔ industry database
- Define max degradation, discoloration

ABS
EVA
P-Ester
PETG
PMMA
Polycarb
Polyester
Propylene
PVC hard
PVC soft
Silicone





Materials Degradation after 15, 25, 35 kGy – PNNL Test Results

Material	Matl	Matl Type	Dose effect	eBeam energy effect
Material 01	1	PVC (Hard)	Increased YI	Decreased EAB
Material 02	2	Polyester	No	No
Material 03	3	PVC (Hard)	Increased YI	No
Material 04	4	PC	Increased YI	10% decrease TS
Material 05	5	PETG	No	Decreased EAB
Material 06	6	PETG	No	No
Material 08	7	Polyester	No	**10% increase EAB, TS**
Material 09	8	ABS	Increased YI	No
Material 10	9	PP	No	No
Material 11	10	PVC (Soft)	Increased YI	Decreased CI
Material 12	11	PVC (Soft)	Increased YI	Decreased CI
Material 13	12	PVC (Soft)	Increased YI	No
Material 14	13	PVC (Soft)	Increased YI	No
Material 15	14	EVA	**15% increase TS**	No
Material 16	15	PVC (Soft)	Increased YI	No
Material 17	16	PVC (Soft)	Increased YI	No
Material 18	17	PMMA	Increased YI	No
Material 19	18	PMMA	Increased YI	No
Material 20	19	PMMA	Increased YI	No
Material 21	20	PVC (Hard)	Increased YI	No
Material 22	21	PVC (Soft)	Increased YI	No
Material 24	22	Silicone	**5% increase M, H**	No

Measurements:

- Mechanic: modulus, hardness, tensile strength, elongation to break
- carbonyl index - CI - conversion of C-C or C-H bonds to carbonyl (C=O) bonds due to oxidation
- Yellowness

Observations:

- Most polymers turn yellow
- More yellow after 45, 60kGy (not mechanically tested)
- No surface oxidation (no CI change)
- Small effect on mechanicals
- Silicone hardens slightly but no effect on ABS valve

Conclusion:

- No material red flags for Rika
- Customers may accept yellowness as proof of eBeam
- Keeping DUR <2.2 is important – by box design and MeV selection

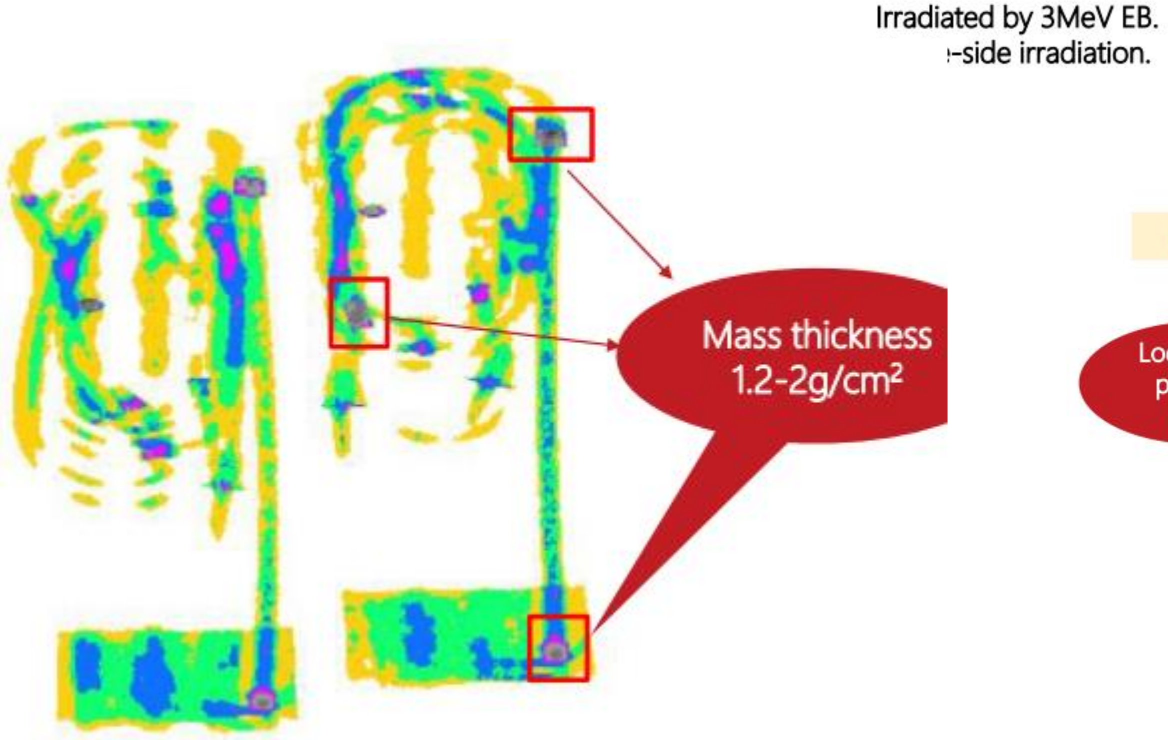
Materials:

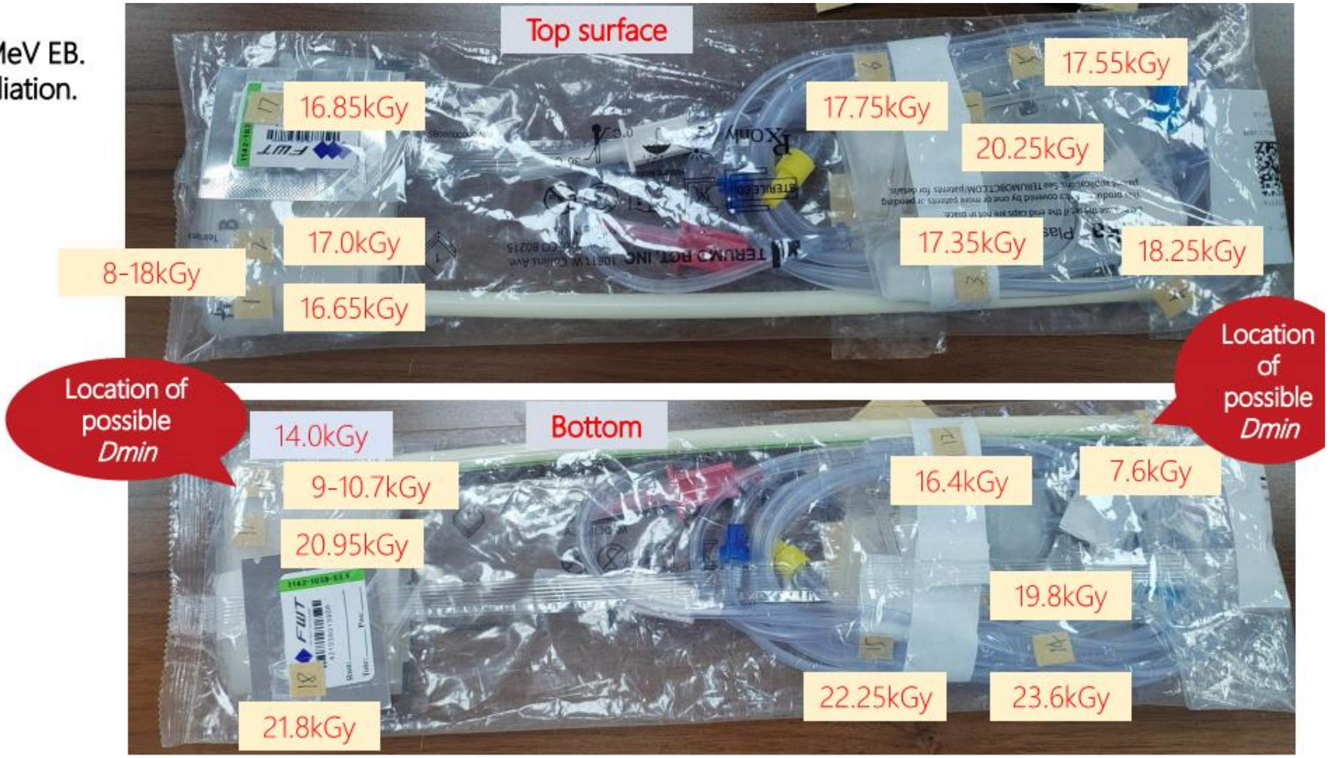
PVC = polyvinyl chloride; PC = polycarbonate; PP = polypropylene;
ABS = acrylonitrile butadiene styrene; PMMA = polymethyl methacrylate;
EVA = ethylene-vinyl acetate; PETG = polyethylene terephthalate

This testing was supported by the U.S. Department of Energy National Nuclear Security Administration Office of Radiological Security. The Pacific Northwest National Laboratory

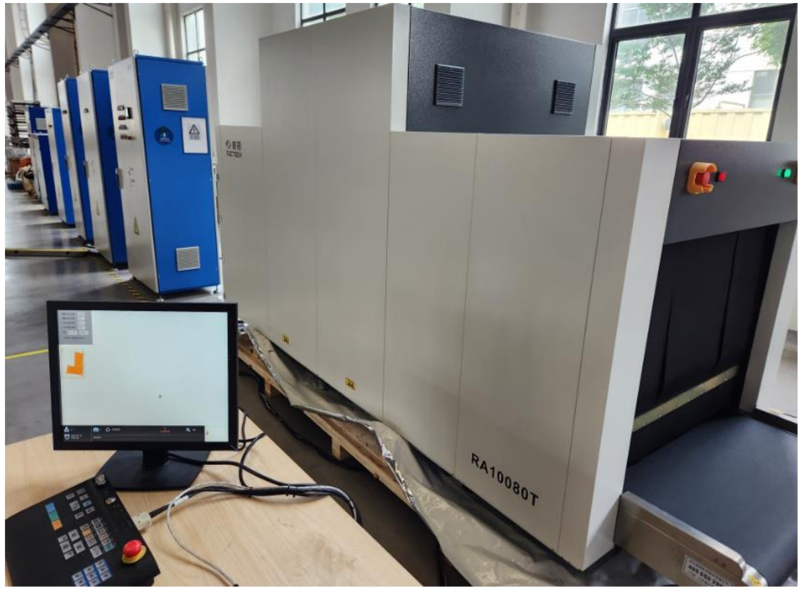
Nuctech (China) – Dose Mapping and MeV optimization

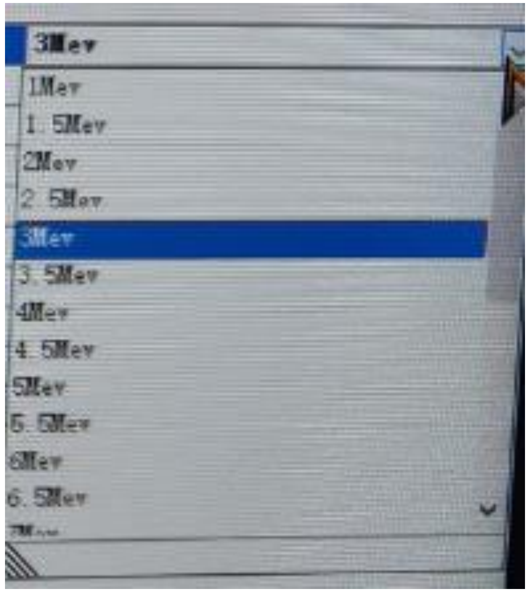
- Experiments at eBeam Services at 1.7–4.5 MeV,
- At Texas A&M and Nuctech Changzhou at 10 MeV
- Terumo Kofu at 10 MeV, pending; Photon Japan at 6 MeV - pending

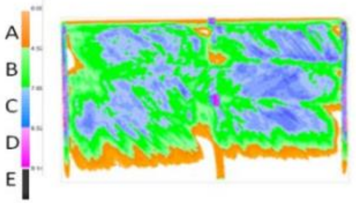


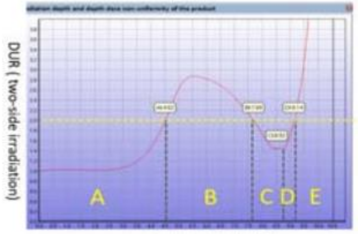


Nuctech (China) – MeV optimization







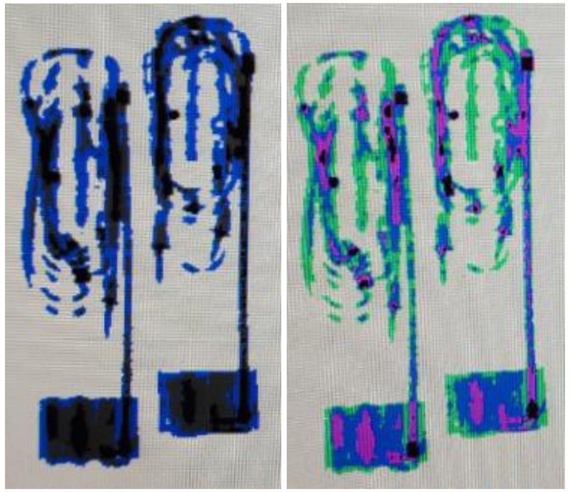


Dose distribution is predicted by simulation with the precise mass thickness for a certain energy EB, including the Max and Min dose, DUR and dose distribution ratio of the whole product in both numeric and visual formats.

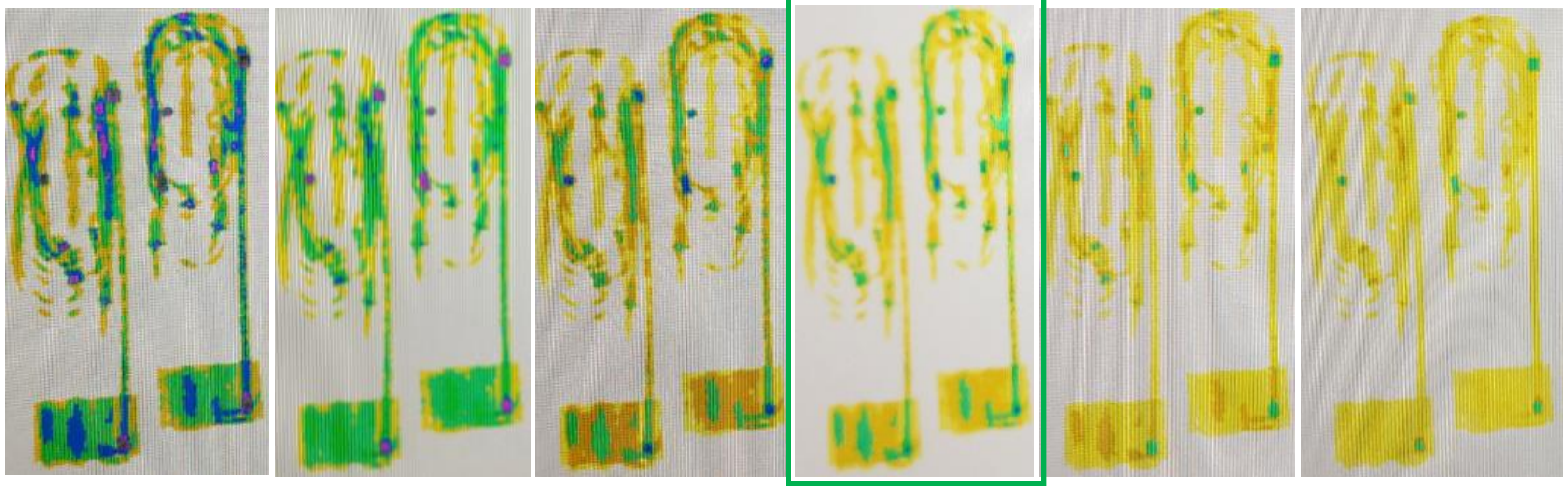
170 keV X-ray source. Resolution: 1 mm^2

Nuctech (China) – MeV optimization

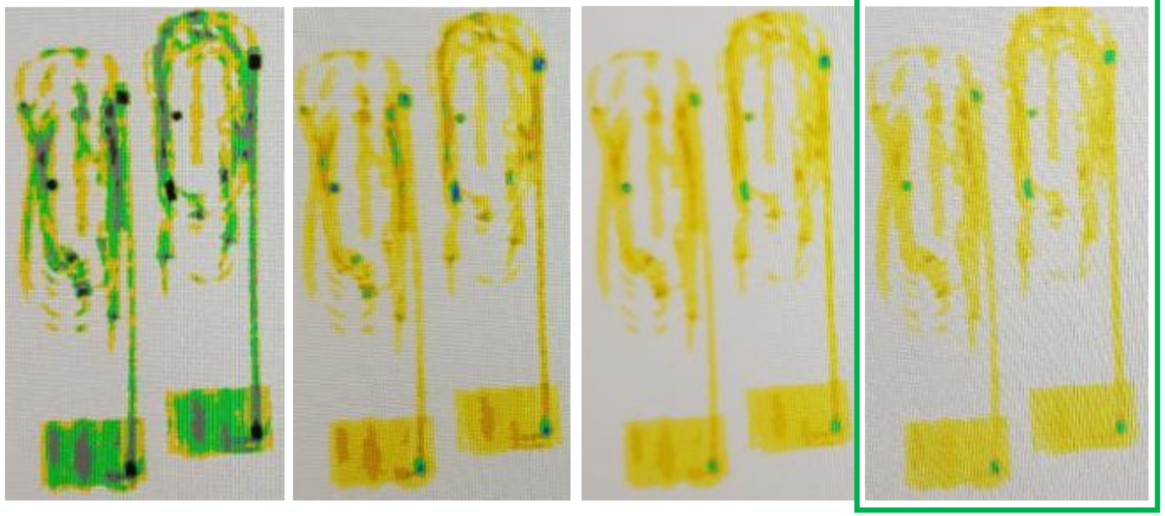
1MeV, DUR31000 | 2MeV, DUR6000



3MeV, DUR2400 | 4MeV, DUR200 | 5MeV, DUR3.0 | 6MeV, DUR1.7 | 8MeV, DUR1.5 | 10MeV, DUR1.4

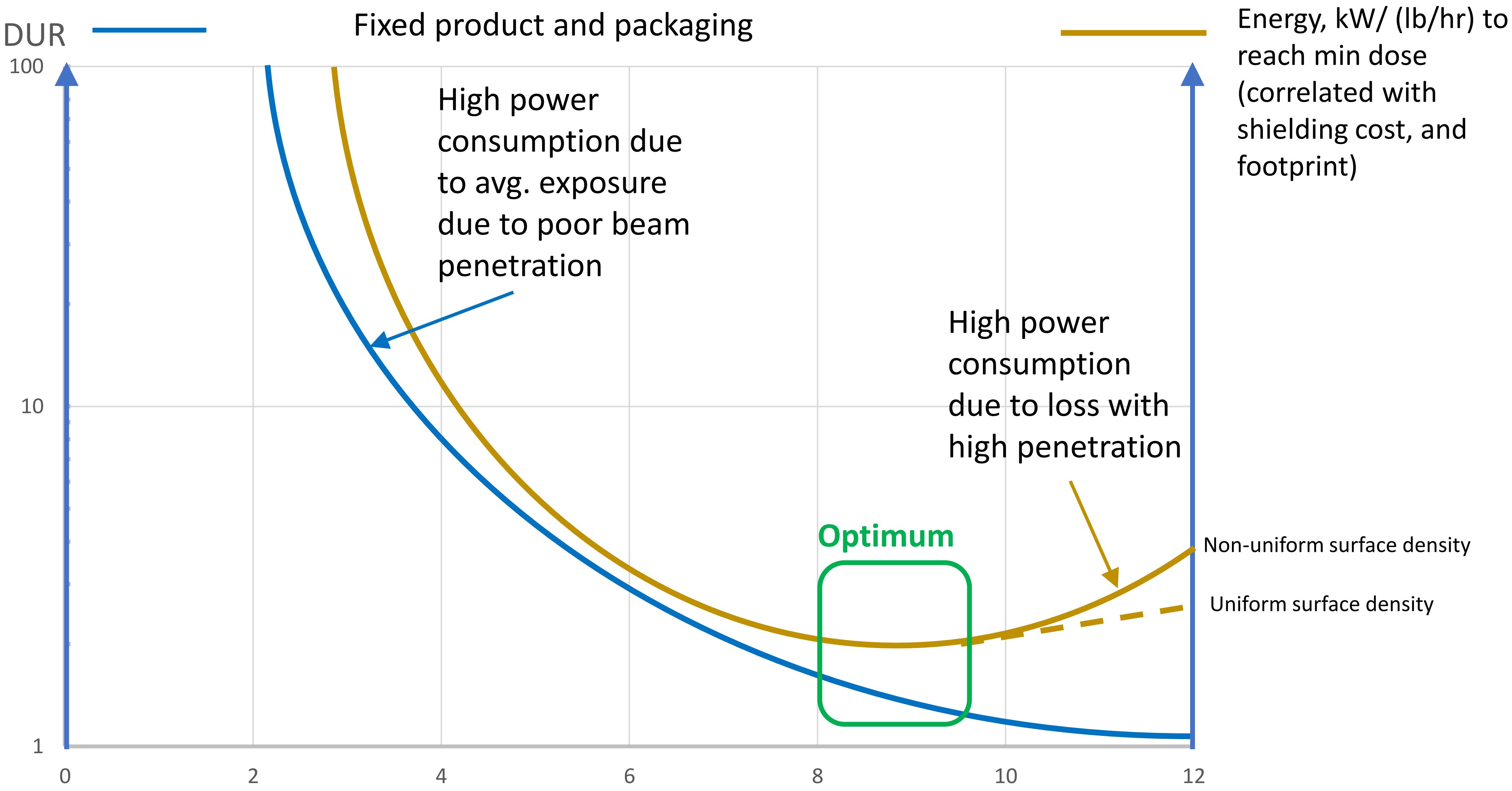


1MeV, DUR9500 | 2MeV, DUR1400 | 2.5MeV, DUR 3 | 3MeV, DUR 1.9



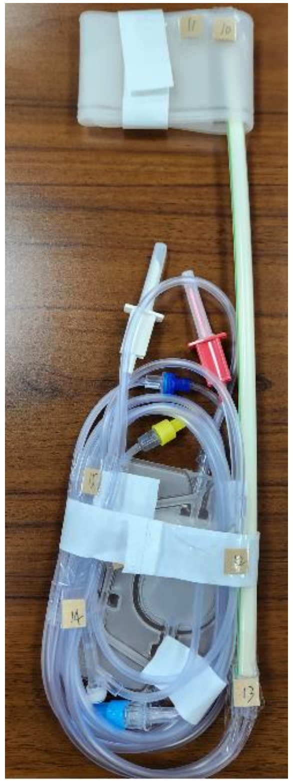
10MeV, DUR 1.1

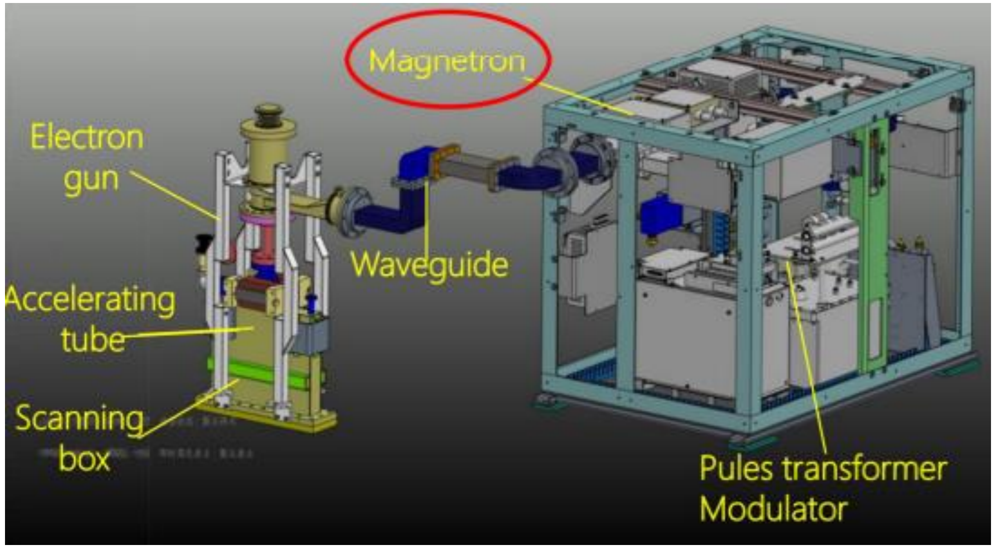
Optimum MeV for eBeam efficiency and cost for one

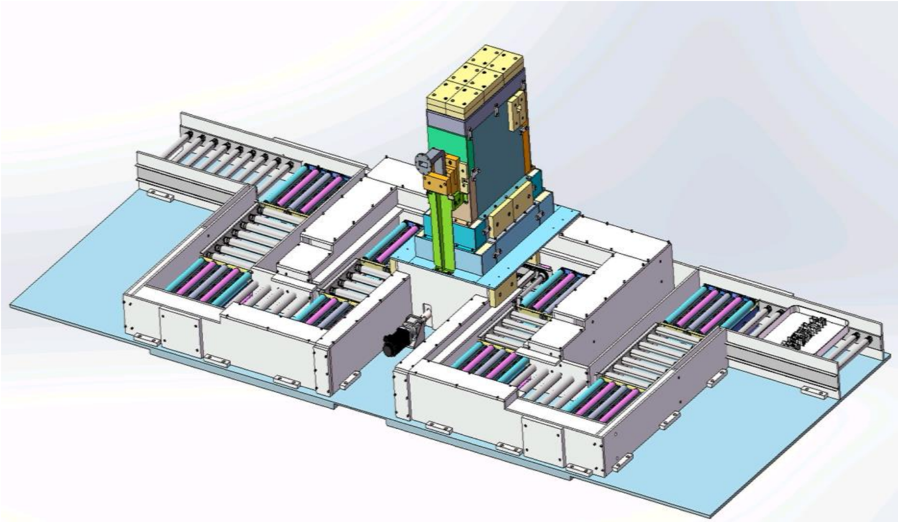


Nuctech (China) – compact sterilizer

3 MeV, 2 kW, 8’ x 8’ x 20’; Scanning uniformity +-5%







Need for a compact footprint

Sample 24 kW contract eBeam sterilizer

- Store, load, transport to sterilizer
- Unloading dock
- Incoming Warehouse
- Pallet break
- Pallet conveyance system
- Destacking robot
- Box conveyance system
- Human access bunker (8’ wide)
- Stacking robot
- Pallet wrap
- FG Warehouse
- Loading dock

Total 40,000 sq ft for 4000 t/y

= 10 sq ft floor space per ton per year

Target end of line 10 kW eBeam

- ~~Store, load, transport~~
- ~~Unloading dock~~
- ~~Incoming Warehouse~~
- ~~Pallet break~~
- ~~Pallet conveyance system~~
- ~~Destacking robot~~
- Box conveyance system
- Box-wide (2’) access
- ~~Stacking robot~~
- ~~Pallet wrap~~
- ~~FG Warehouse~~
- ~~Loading dock~~

Total 1,200 sq ft for 2000 t/y

= 0.6 sq ft floor space per ton per year

Industry Ask

For ourselves (med device manufacturers):

- Target eBeam-compatibility in new product development
- Standardize needs in few MeV*kW sweet spots

For National Labs:

- Publish materials behaviour database
- Perform energy efficiency and environmental benefit assessment eBeam vs chemical methods
- Make dose modeling service commercially available
- Facilitate shielding modeling

For Standards Organizations:

- Industry Standard for parametric release for accelerator – based systems

For DOE

- Fund development of “standard” machines
- Demonstration project at a manufacturer
- Fund a blind study of energy efficiency for various sterilization methods
- Promote environmental and energy benefits of eBeam (if it proves to be better)
- Development of dosimetry in 1-10 MeV range

For FDA

- For sterilization modality change, allow a limited biocompatibility testing. i.e a risk based testing
- Change SAL from 1.0×10^{-6} to 1.0×10^{-3}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