NIST Low-Energy Electron Facility

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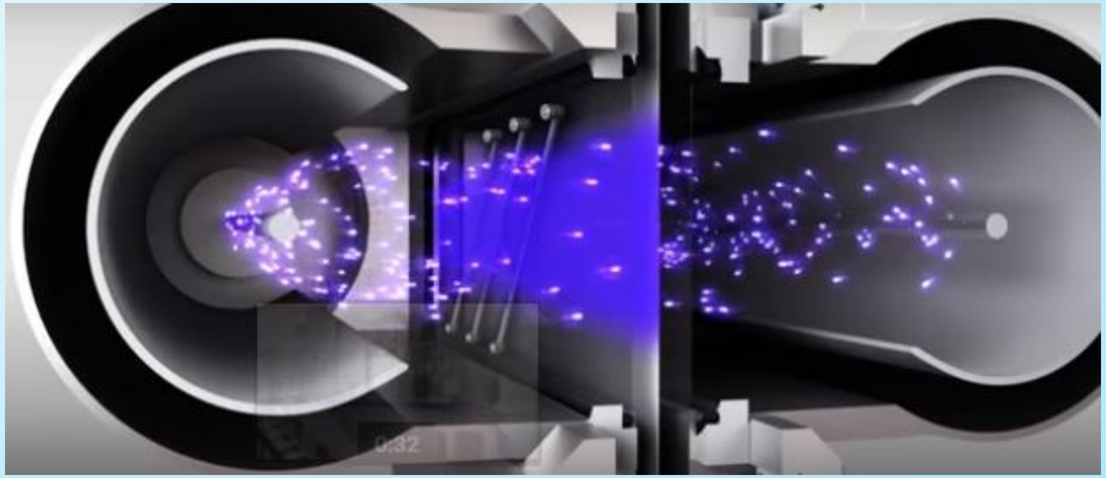

Low-Energy Radiation Processing Applications

- Sterilization
  - Surface sterilization of food and packaging materials
  - Gas purification (SO_2, NO_x)
- Food-safe packaging
  - Curing of inks, crosslinking
- Materials Modification
  - Crosslinking
  - Radiation grafting
  - Protective coating for metal coils
  - Pressure-sensitive adhesives
  - Advanced materials (nano-hydrogels, etc.)

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http://www.packworld.com

* Does not imply endorsement by NIST

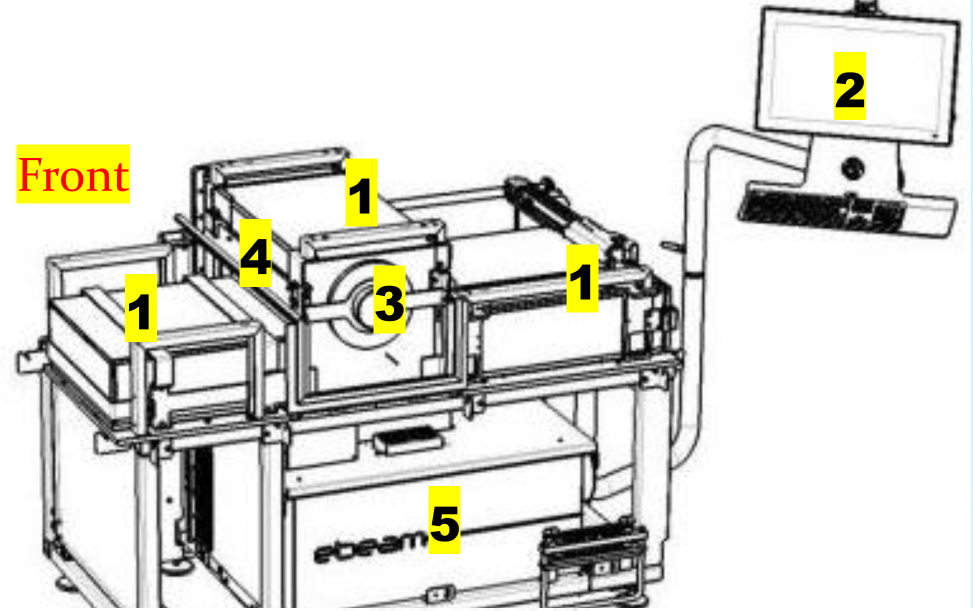
Comet EBLab-300 Laboratory Unit

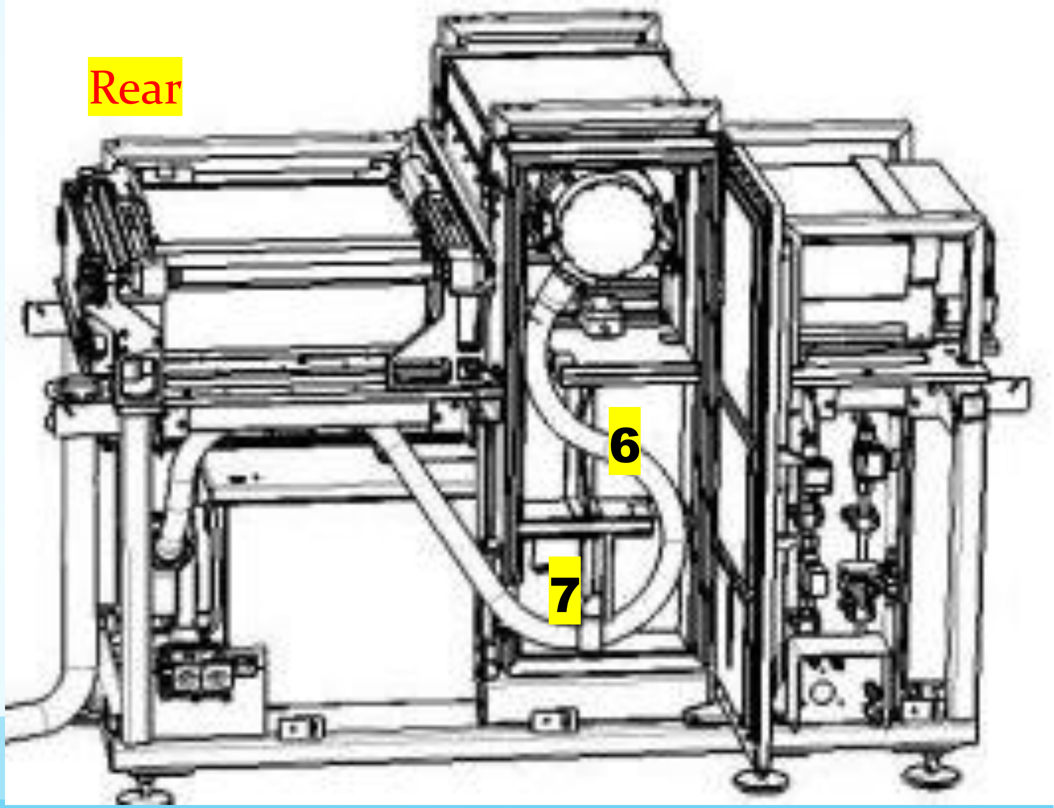
- Self-shielded, self-contained electron beam unit
- Semi-custom design features broad energy range from 80 keV to 300 keV
  - Covers most LEEB radiation processing applications
- Additional shielding, R&D required during design and development
  - Extensive factory testing procedures
- Installed in new laboratory facility (H-wing) in Radiation Physics Building
- Acceptance testing completed

How Does it Work?

Components and Systems

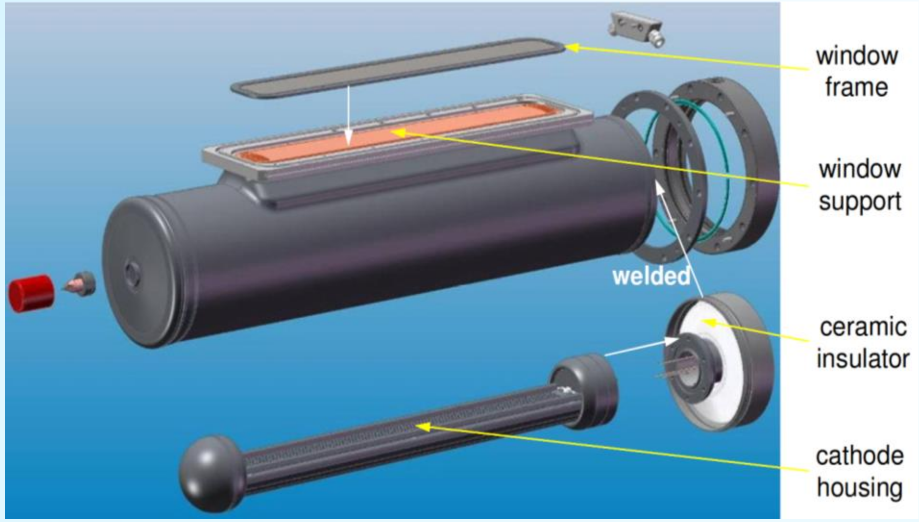
1. Sample tray and transport system
2. Process control interface
3. Electron beam lamp
4. Irradiation chamber
5. High voltage power supply
6. HV cable and labyrinth
7. Inerting gas, ozone extraction ports

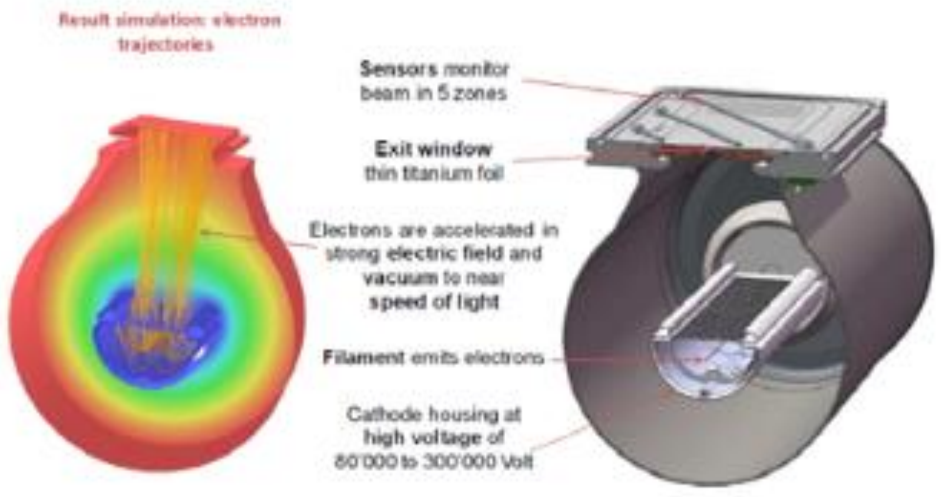




Comet ebeam Lamp

- Vacuum-sealed beam emitter
- Electron "shower"
- Grounded anode, cathode at high voltage
- Thin (10 micron) Ti (equivalent) exit window to maximize transmission



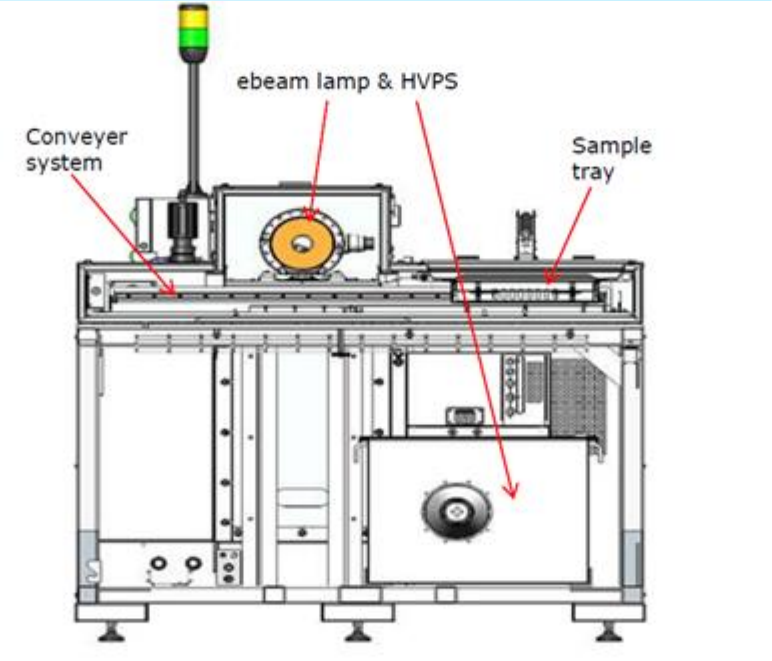


Under the Hood

ebeam Engine

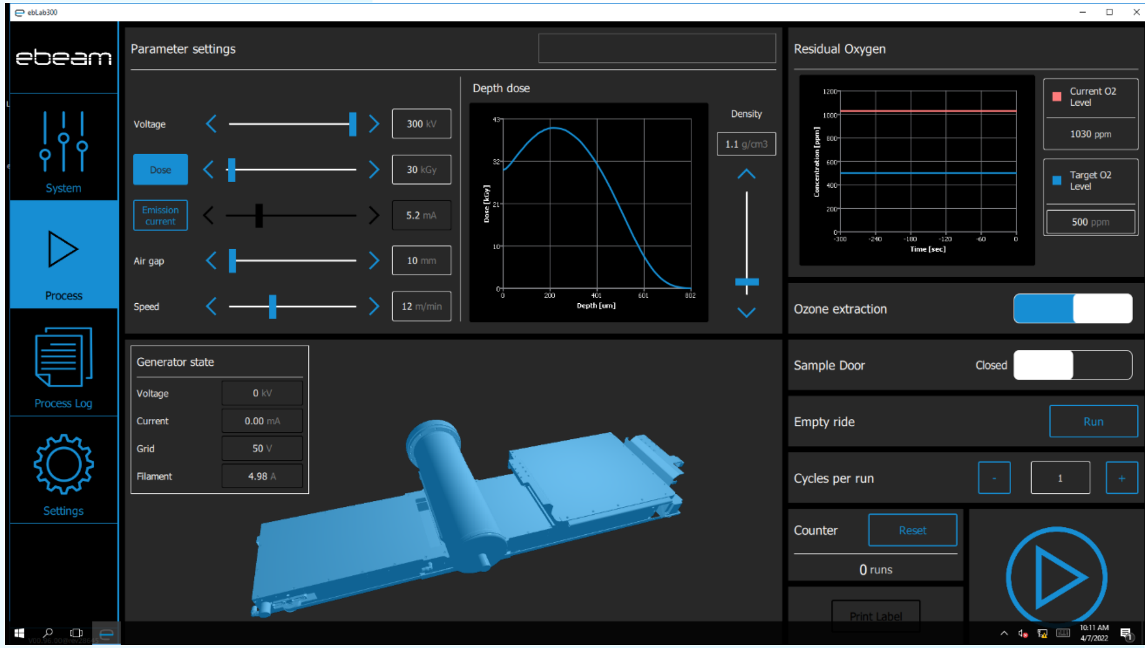
- Beam energies 80 keV to 300 keV
- Beam current adjustable up to 20 mA through user interface (4.5 kW power limit)
- Dose uniformity, +- 10% at 30 mm from window
- Field width 230 mm

Energy [keV]	Air Gap [mm]	Max. Surface Dose [kGy] (single pass)
300	10, 50	346, 380
125	10, 50	1023, 812
80	10, 50	674, 18



Sample Handling

- Sample tray can accommodate samples up to 21 cm x 30 cm, with air gaps from 10 mm to 50 mm
- Transport speeds variable from 3 m/min to 30 m/min

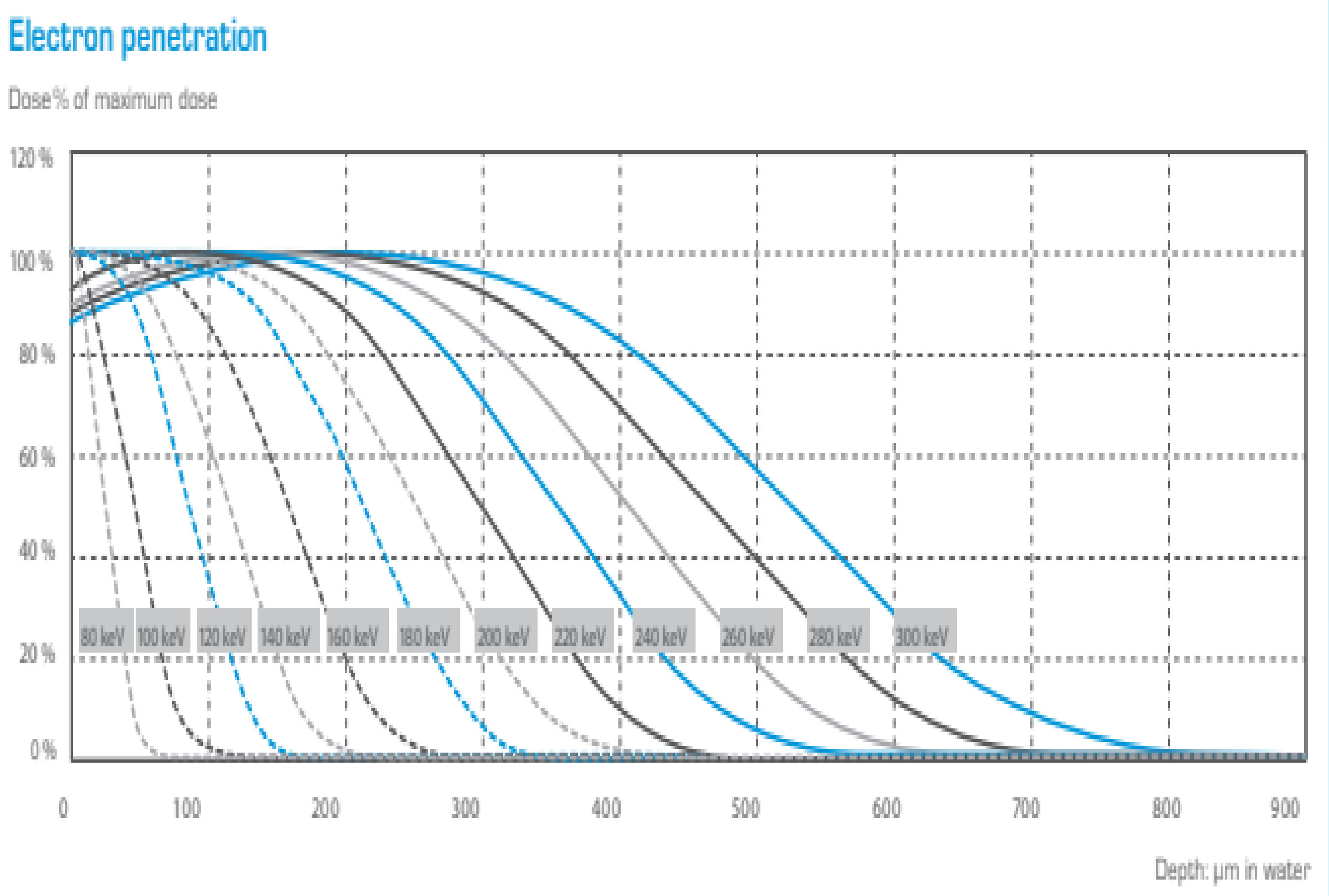


Low-energy e-beam advantages

- Simpler components
  - Maintenance free electron source
  - Ebeam emitter is vacuum-sealed, modular, customer replaceable
- Very high surface dose rates
- Minimal radiation shielding compared to higher energy accelerators or cobalt-60 irradiators

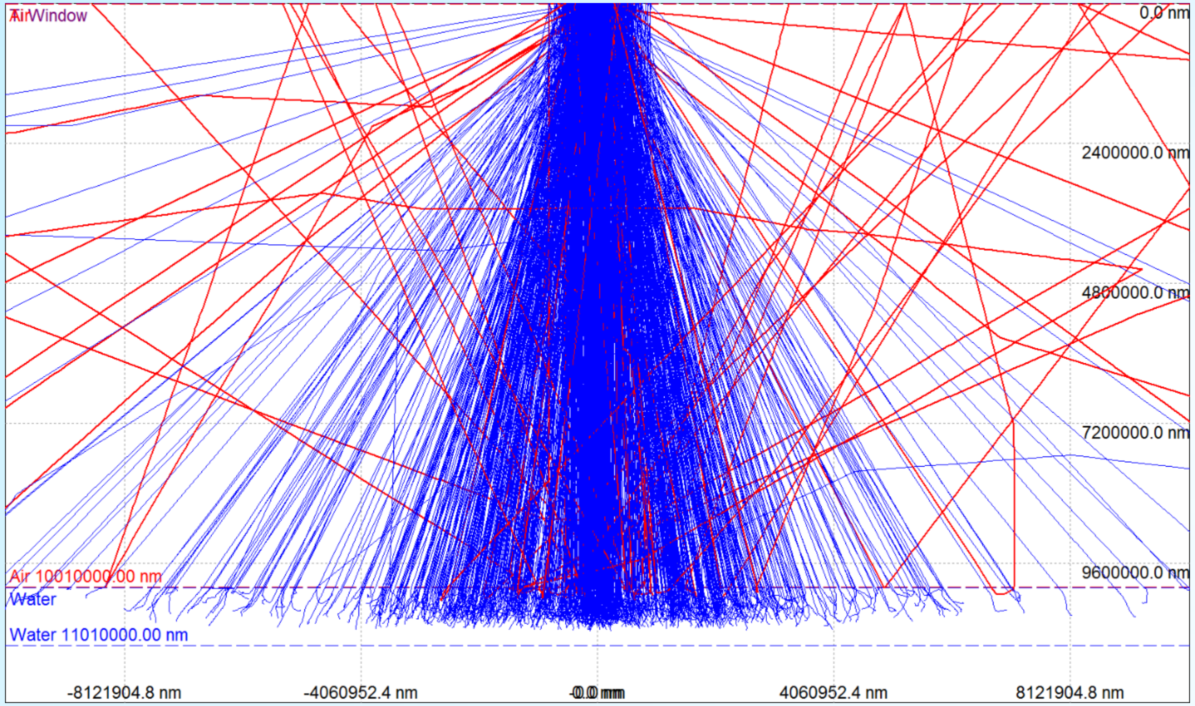
Low-Energy Electron Beam Penetration

- Low-energy electron beams have an extremely steep dose gradient
- Even at 300 keV, penetration depth in products and materials is less than 1 mm (unit density)
- This makes the quantification of dose extremely difficult, particularly at lowest energies
  - Dose gradient at 80 keV ~3 % per μm

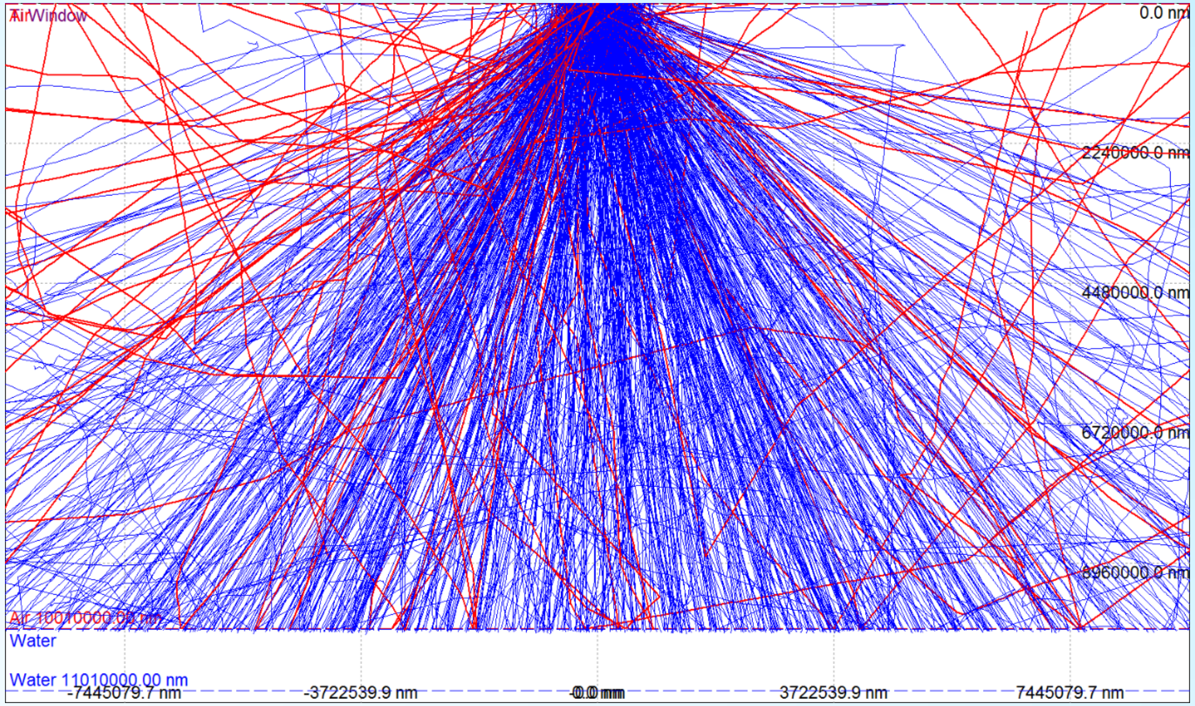


LEEB Dosimetry Challenges

Electron beam penetration into water—10 μm Ti window, 10 mm air, 1 mm water



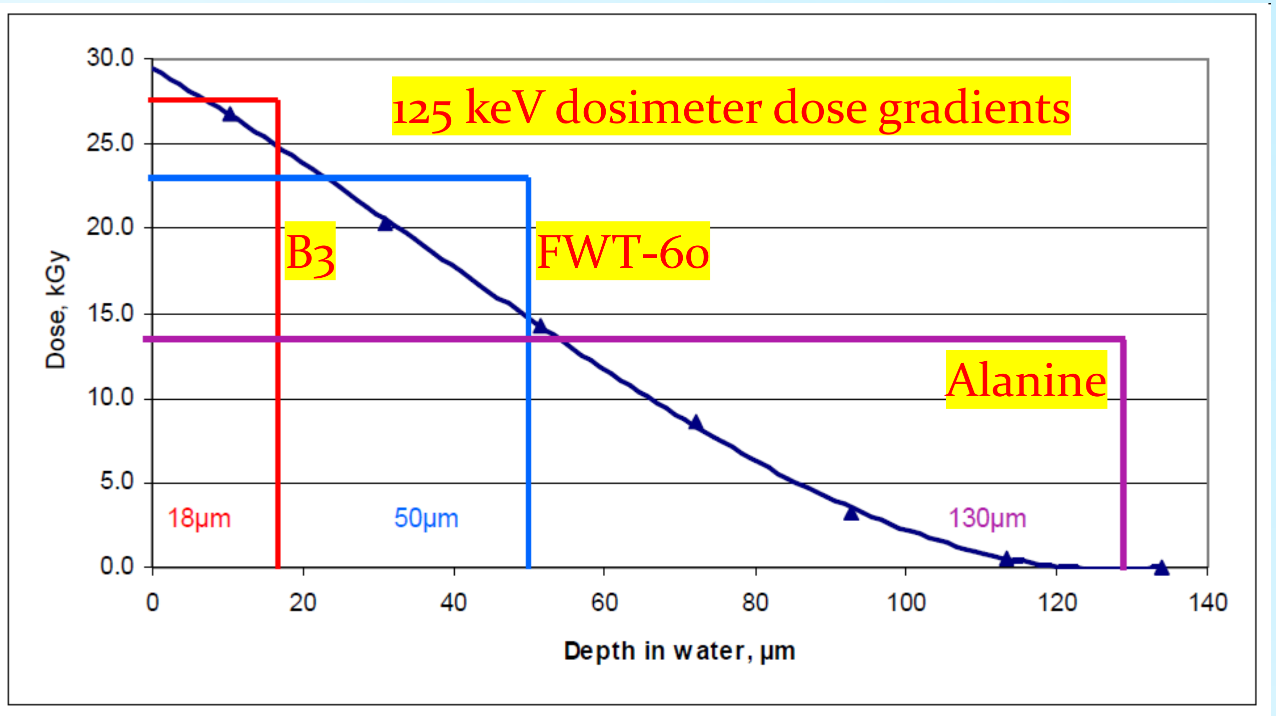
300 keV



100 keV

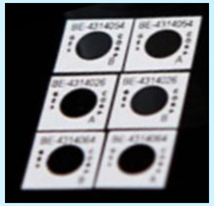
LEEB Dosimetry Challenges

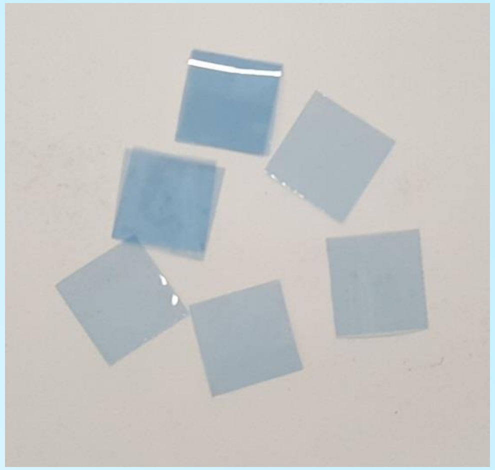
- Thermal effects
  - Significant heating of the exit window and the air surrounding the samples/dosimeter
    - This heat transfer can have a significant effect on the measurement of dose using calorimeters
    - Thermal shields can cause additional attenuation of the primary beam
  - The response of most thin film dosimeters can vary significantly with ambient temperature
- Dose gradient
  - Apparent (measured) dose depends strongly on dosimeter thickness
- Dose rate effects
  - Dosimeter response may vary with dose rate
- Radiation damage of components

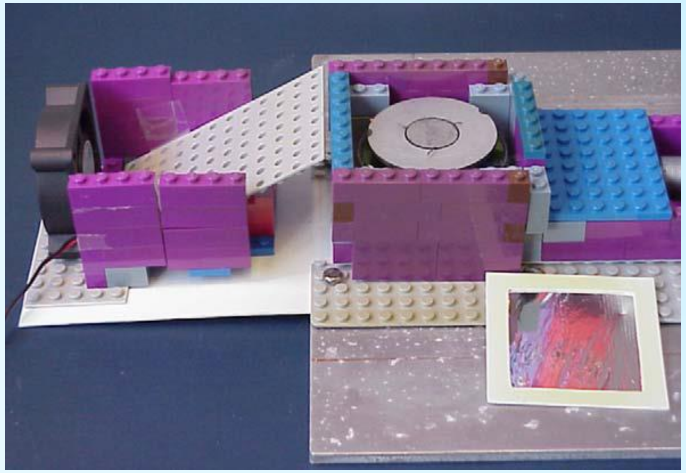


Approaches to Low-Energy dosimetry

- Thin film dosimeters
  - Radiochromic
    - Response dependent on temperature and humidity during irradiation
    - Dose rate dependence
    - Thickness variations
  - High-density polyethylene
    - Trans-vinylene absorbance peak measured with FTIR
    - Not affected by humidity or ambient light, very little temperature dependence
    - Limited to doses > ~25 kGy
- Alanine film dosimeter
  - Relatively insensitive to influence quantities
  - Large dose gradient due to thickness of coating
- Graphite calorimeters
  - Sensitive to environmental heating
  - Steep dose gradient
  - Totally absorbing





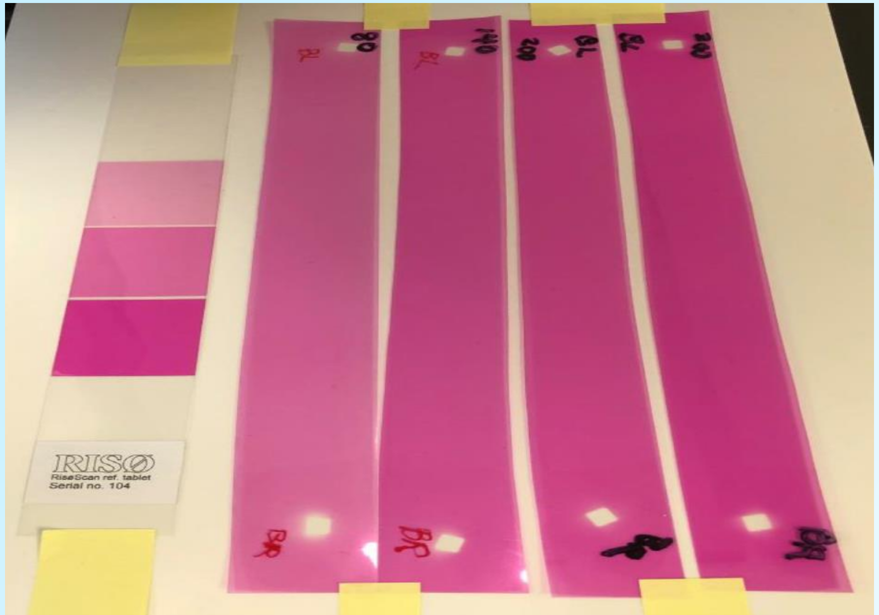


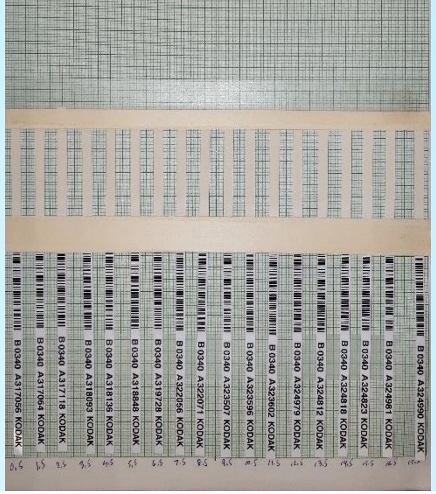
J. Helt-Hansen et al. / Radiation Physics and Chemistry 74 (2005)

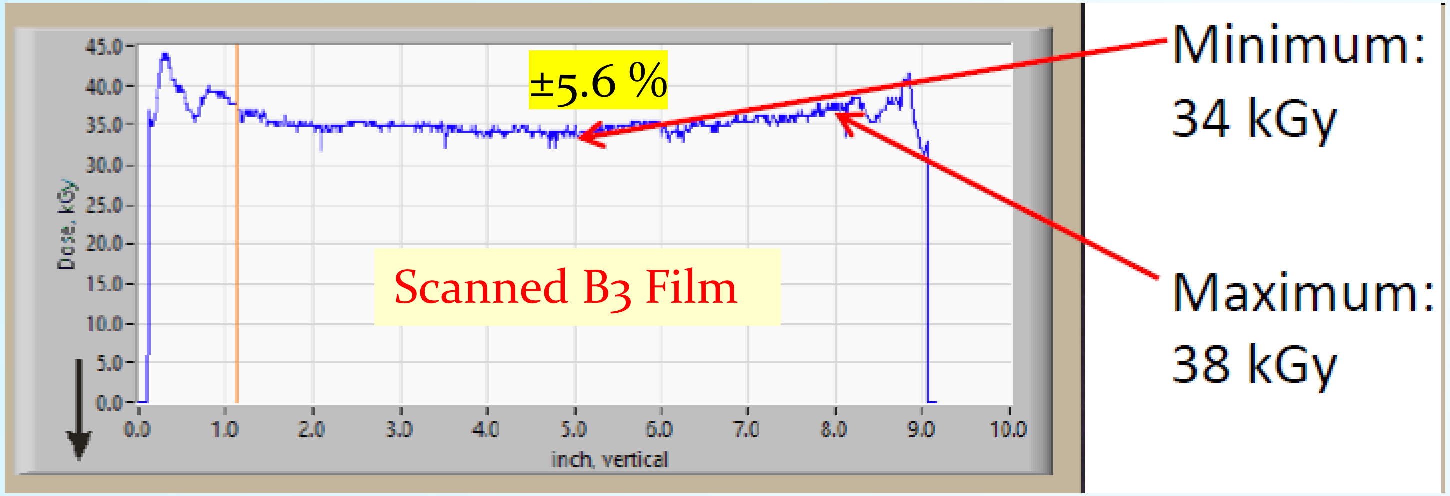
Acceptance Testing and Validation Studies

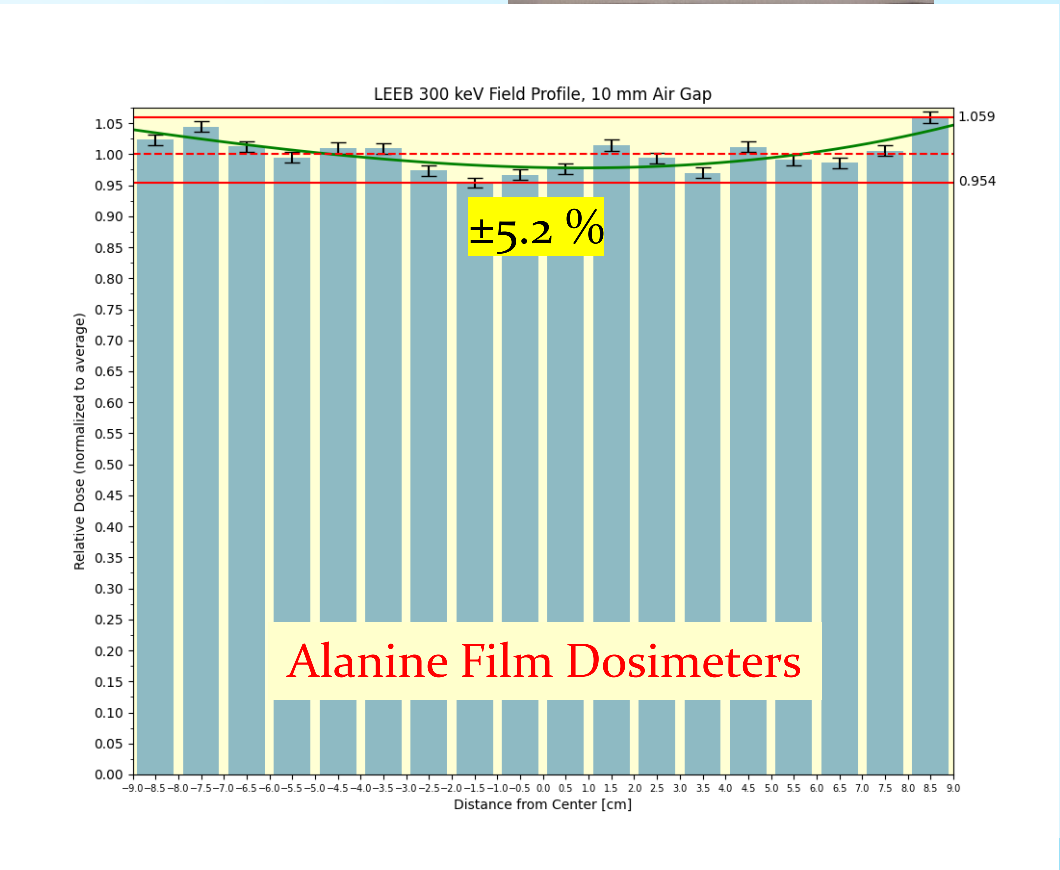
EBLab-300 Field Profiles

Specification is ±10 %



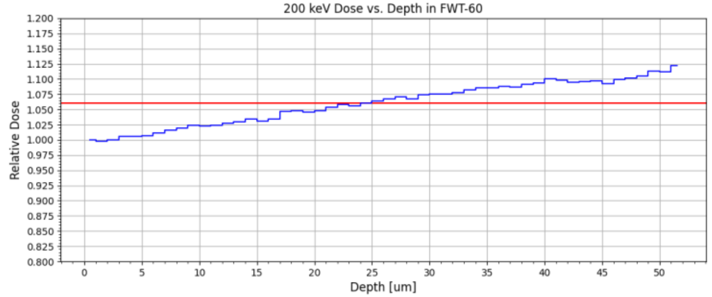


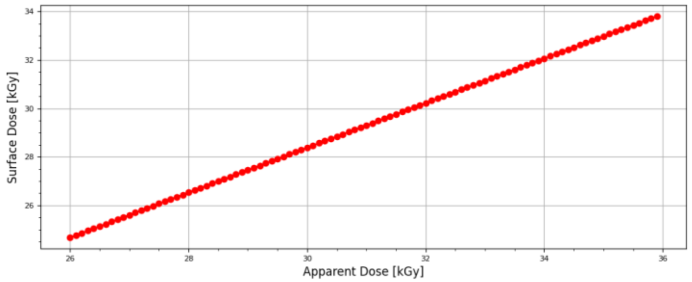


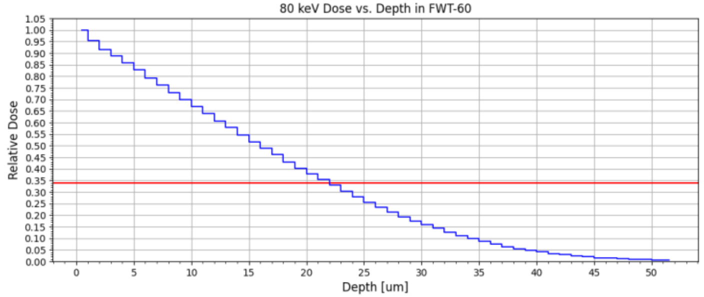


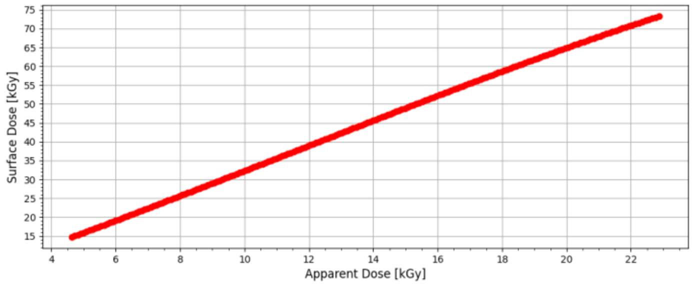
Dose Validation

- EBLab-300 target surface dose based on D_μ
- Dosimeter films (FWT and alanine) used for dose comparison
- D_μ protocol applied to compare apparent (measured) doses to target doses
- Target dose based on AVERAGE dose across the 18 cm field









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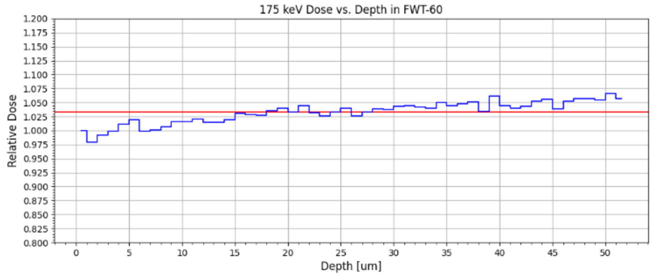
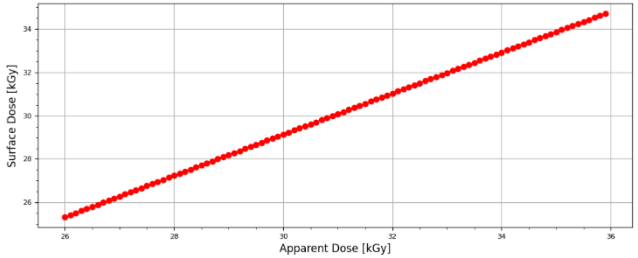
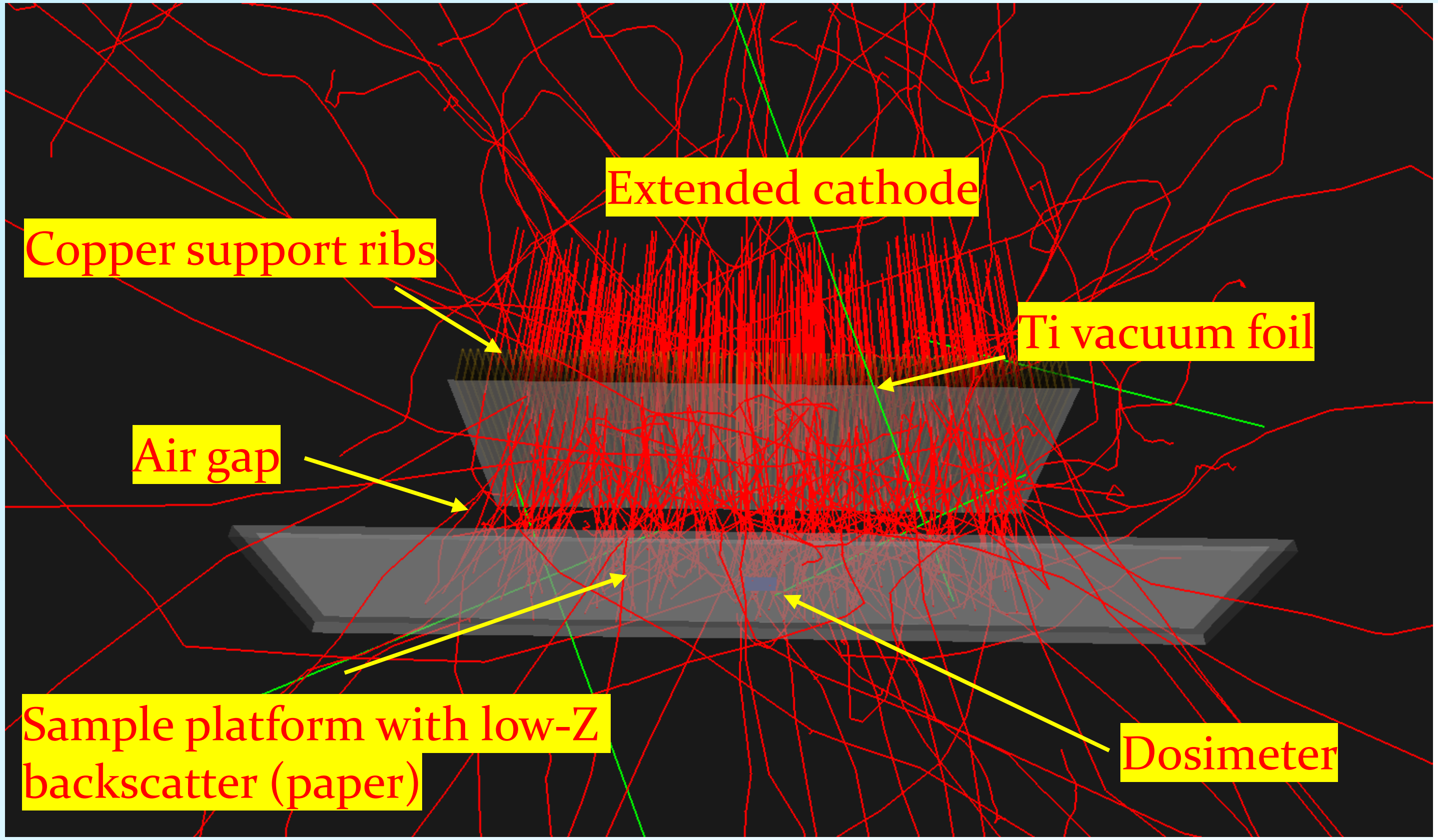
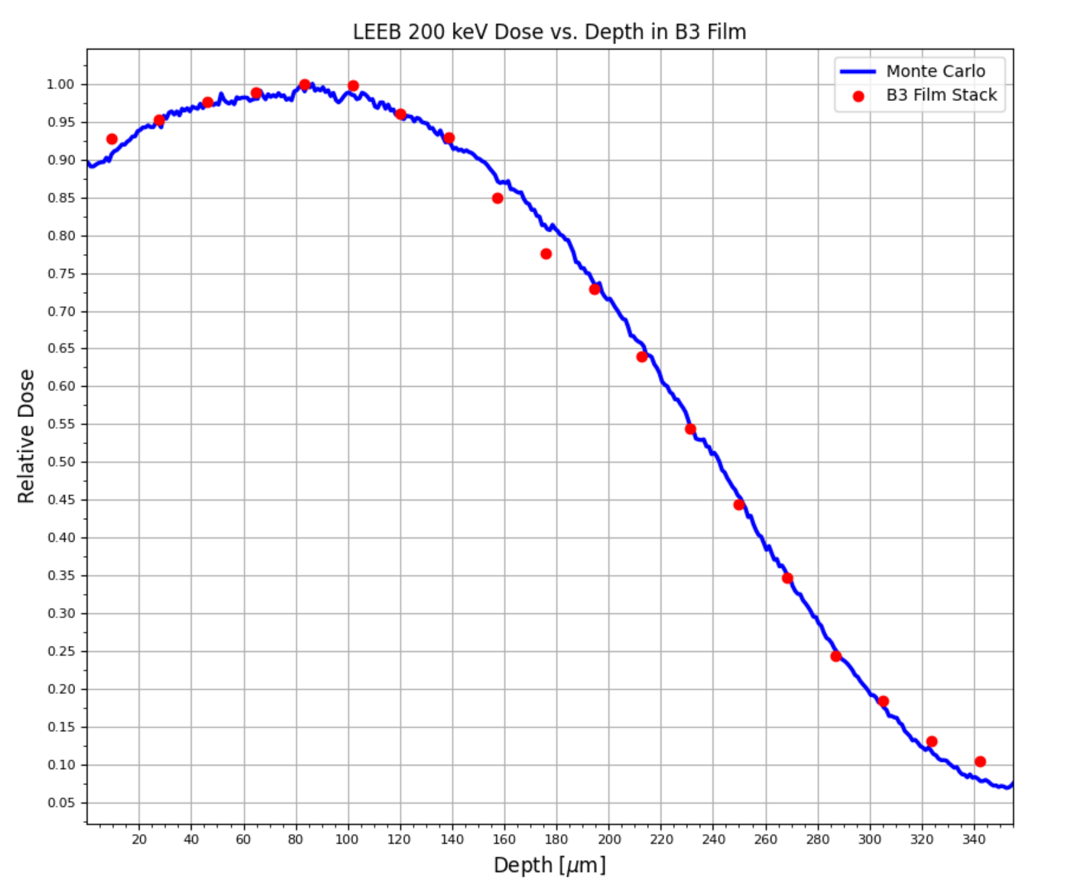




Energy [keV]	Dose Setting [kGy]	Dosimeter	Apparent Dose [kGy]	D_μ Dose [kGy]	% Difference
80	30	FWT-60	10.10 ± 3.2 %	32.61	8.3 %
175	30	FWT-60	31.39 ± 0.79 %	30.40	1.3 %
200	30	FWT-60	30.92 ± 1.23 %	29.10	3.0 %
300	20	Alanine Film	23.47 ± 1.82 %	24.66	5.1 %

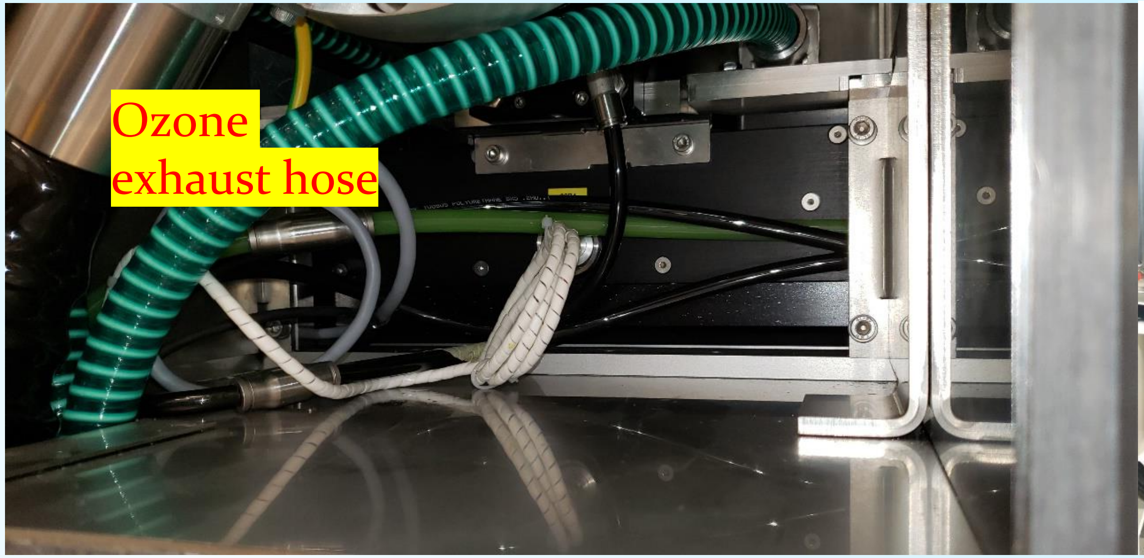
Monte Carlo Modeling

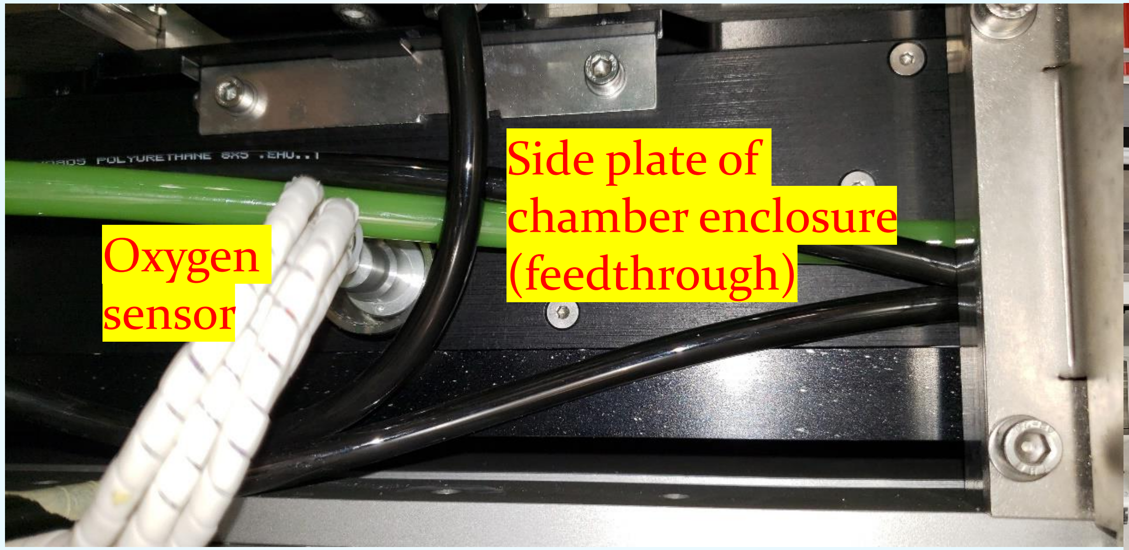


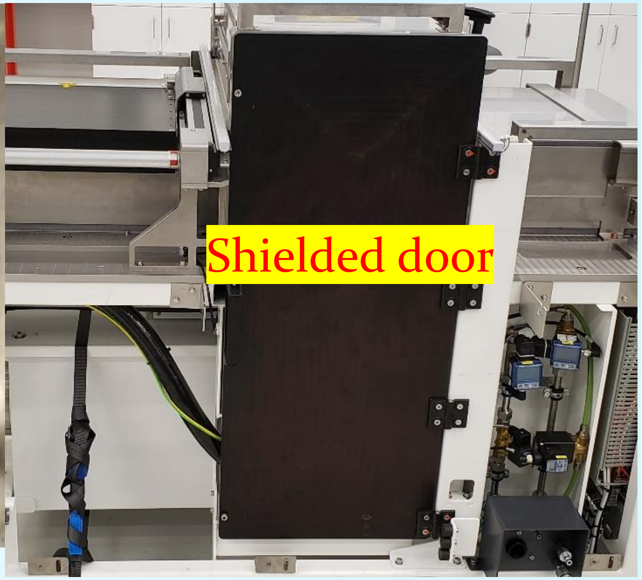


How Do We Get from “Passive” to “Active”?

- Closed system, limited access to chamber
- Need to be able to stage devices/instruments, introduce signal and power cables
  - Wireless communication?
    - Signals won’t penetrate enclosure
  - Data logger?
    - Instrument might not survive radiation environment
- Send signals to external instruments







Applications

- High fluence radiation testing of thin Si diodes and other solid-state devices
- Calibration of low-energy dosimeters for radiological event exposure
  - Dosimeters embedded in ID cards can provide rapid assessment of exposure (portable ESR sensor)*
- Testbed for surface curing, sterilization studies

* https://www.nist.gov/noac/technology/radiation/emergency-dosimetry

Conclusions/Future Plans

- Need for low-energy e-beam dose traceability and standards
- EBLab-300 will provide a useful tool for materials modification and dosimetry studies
- Adapt the EBLab-300 laboratory unit for real-time dosimetry
- Develop methods and systems for low-energy dosimetry
- Materials modification and radiation hardness testing