Compact, Inexpensive X-Band Linacs as Radioactive Isotope Source Replacements

Salime Boucher

RadiaBeam Technologies, LLC

Work supported by DNDO Phase II SBIR HSHQDC-10-C-00148 and DOE Phase II SBIR DE-SC0000865.

Replacement of Radioisotopes

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- 55,000 high-activity radionuclide sources are in use in the United States today (NRC report, 2008)
  - 85% are Category 2 gamma emitters (e.g. Ir-192, Cs-137, Co-60), used for NDT, borehole logging and irradiators
  - High risk for accident, or use in a "dirty bomb"
- DNDO, NNSA, etc. want to *"dramatically reduce the amount of radioactive material in common use in order to improve public security and prevent the diversion of radioactive material for Radiation Dispersion Devices…"*

Radiation Source Use and Replacement: Abbreviated Version
Committee on Radiation Source Use and Replacement, National Research Council
ISBN: 0-309-11015-7, 232 pages, 8 1/2 x 11, (2008)
http://www.nap.edu/catalog/11976.html

Industrial Radiography

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- High-energy radiography is used to inspect pipes, welds, castings...
- Field radiography often done with X-ray tubes, but often higher energy is required
- Ir-192 is the most commonly used, but radiographer will typically use two or more isotopes to optimize contrast
  - Typical activity ~100 Ci
  - Short half life (74 days), has to be recharged often
  - Numerous, portable and easily diverted
- To replace isotopes, the new device MUST have a high energy source (~1 MeV peak to match Ir-192)

Isotope	Half life	Avg Energy	Steel range
Yb-169	32 days	145 keV	6-20 mm
Se-75	120 days	217 keV	10-40 mm
Ir-192	**74 days**	**380 keV**	**20-90 mm**
Co-60	5.3 years	1.25 MeV	40-200 mm

Self-contained Irradiators

- Used for blood irradiation, research, electronics testing, etc.
- Most use Cs-137 (up to 2,000 Ci), some Co-60 (24,000 Ci)
- Blood irradiator needs to deliver 25 Gy to ~1.5 L of blood in ~5 minutes
- Usually in poorly secured locations
- Cs-137 is especially bad (water soluble, long half life)

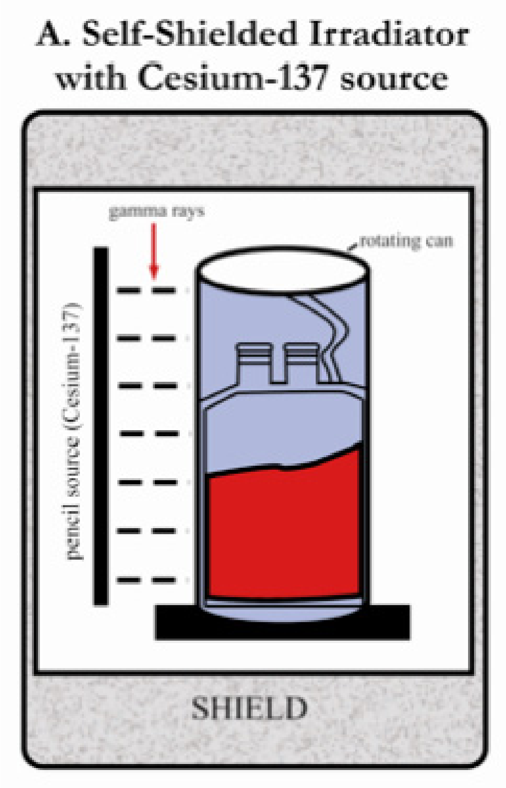


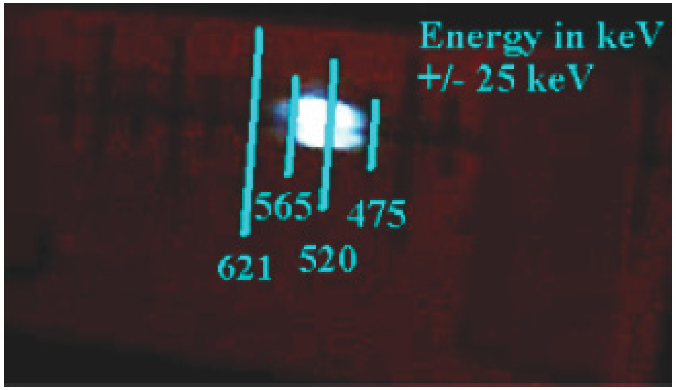
Image from Radiation Source Use and Replacement: Abbreviated Version http://www.nap.edu/catalog/11976.html

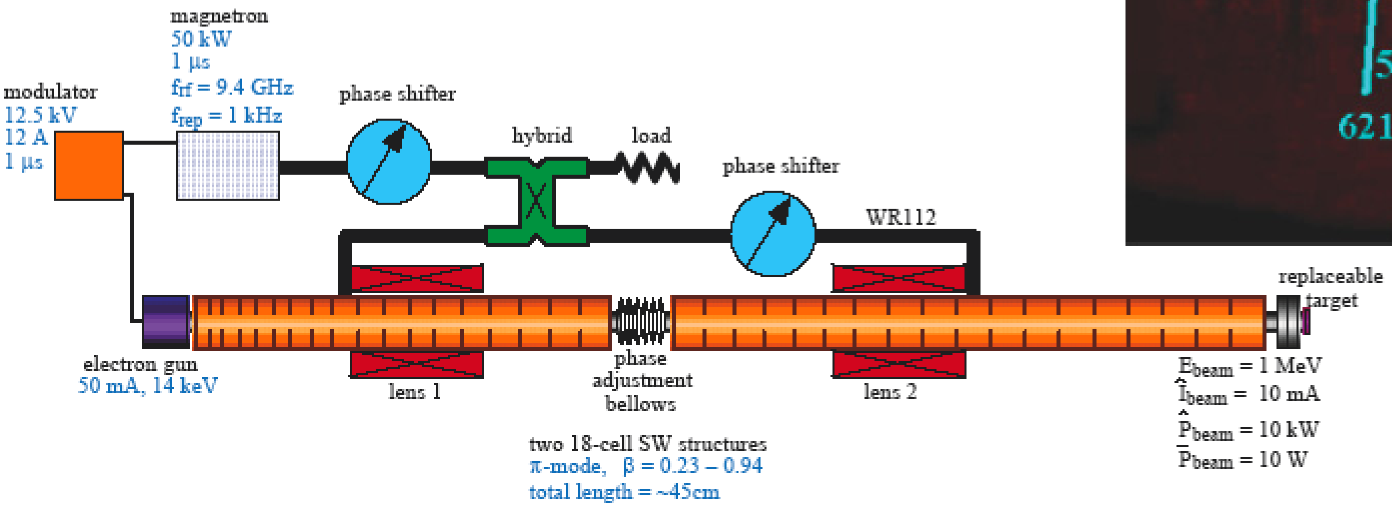
Potential Replacement

- **The MicroLinac: portable, inexpensive X-band linac**
- Linacs have been used for radiography for > 30 years
  - Mature, proven, well-understood technology
  - But they are very expensive: RF power system major cost
- The primary innovation of the MicroLinac: **use very low RF power**
  - Greatly decreases size, weight and cost of power source
  - Reduces (or eliminates) the need for cooling
- Benefits for radiography:
  - Inherently safer: radiation is electronically controlled, no disposal issues
  - No need to replenish isotopes: potentially lower maintenance costs
  - Variable energy: one MicroLinac can replace 3+ radioisotopes for radiography
  - Small source size: increased resolution and/or lower exposure time

SLAC MicroLinac Project

- The MicroLinac concept as presently adapted by RadiaBeam was originated at SLAC (Stanford Linear Accelerator) in 2005
- Utilized inexpensive 50 kW, 9.4 GHz magnetron, π-mode structure for simpler machining
- 500 keV energy achieved from two structures (½ of goal) due to power flow phase shift
- Ran out of money to continue





Courtesy of SLAC

The RadiaBeam MicroLinac

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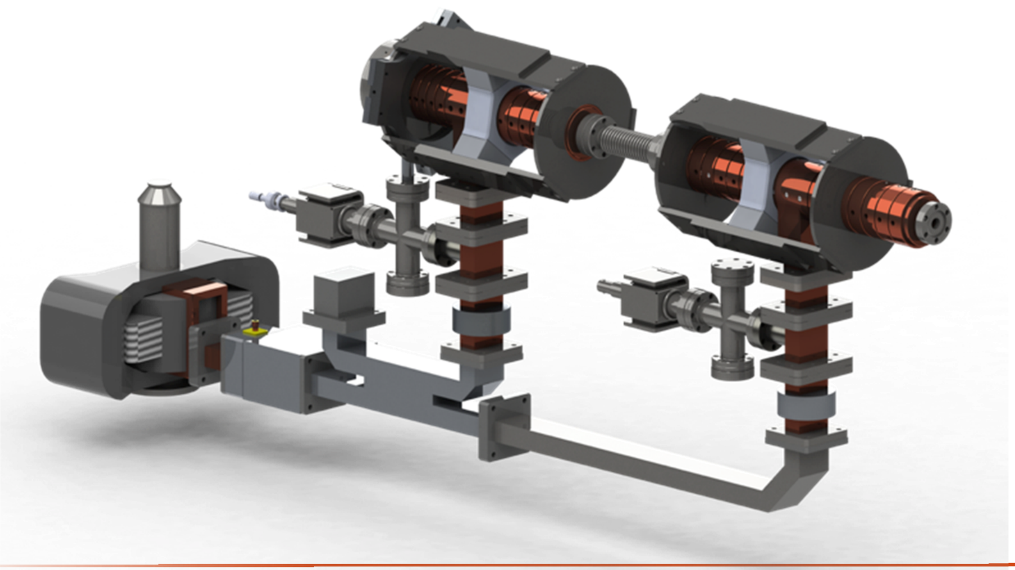
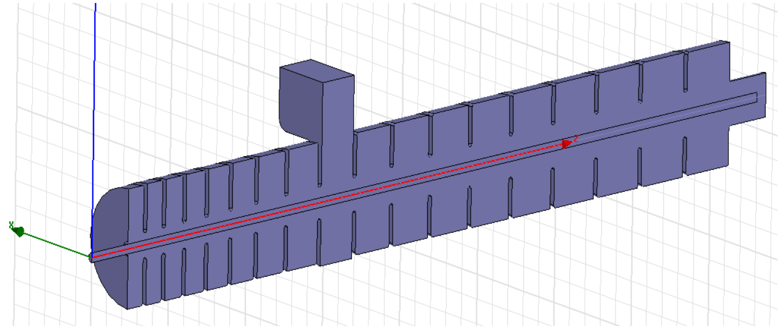
- In 2008, we won a Phase I SBIR from DNDO to develop the MicroLinac.
  - Beam dynamics simulations, RF design and initial engineering
- In 2010, started Phase II to complete engineering and build the prototype.
- Also working on a 2 MeV structure for self-contained irradiator, funded by DOE.

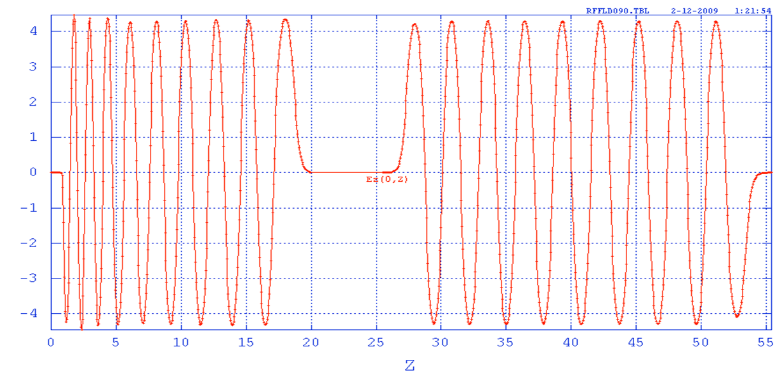


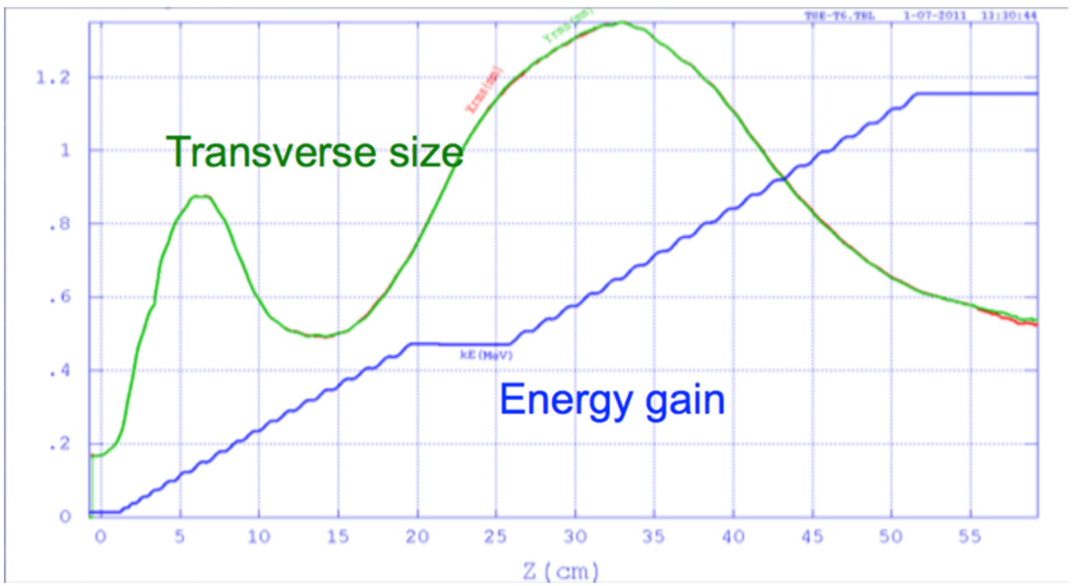
Accelerating gradient	3 MV/m
RF frequency	9.4 GHz
Power dissipated/structure	25 kW
Beam Current, input	50 mA
Duty Cycle	0.001
Beam Energy, input	14 keV

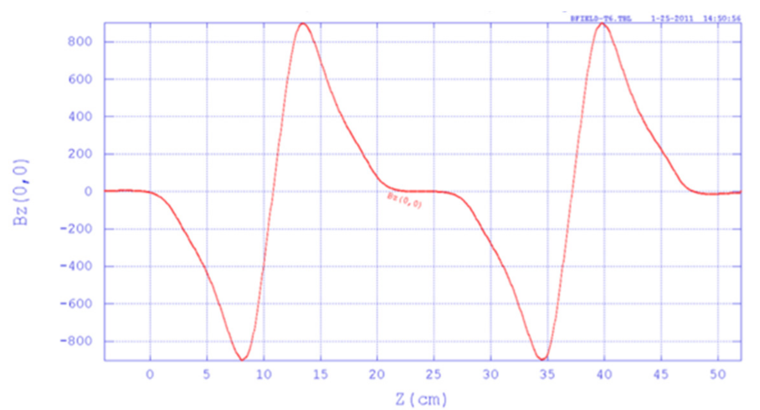
Linac Design

- Project started by completing design
  - Corrected for power flow phase shift
  - 3D simulations to take into account coupler
  - Analyzed requirements for machining tolerances and tuning



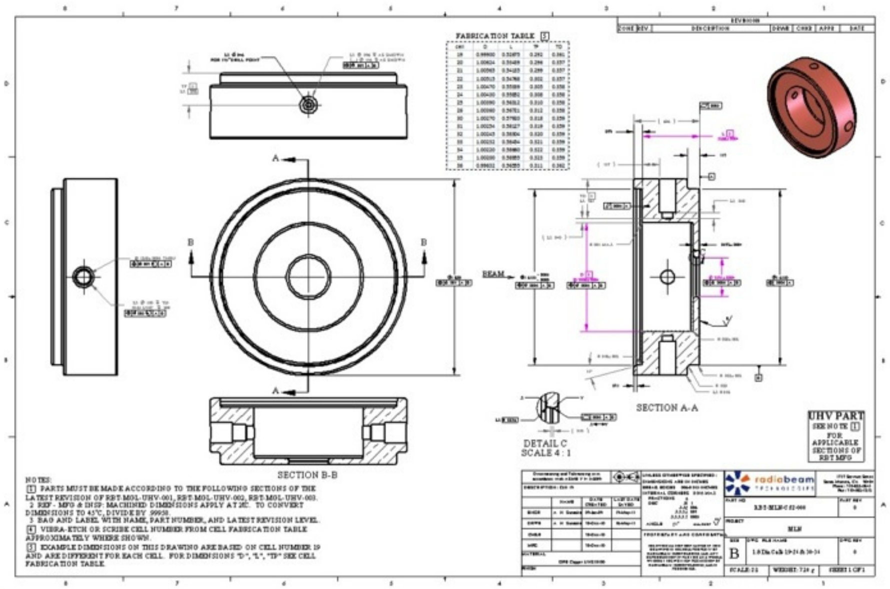


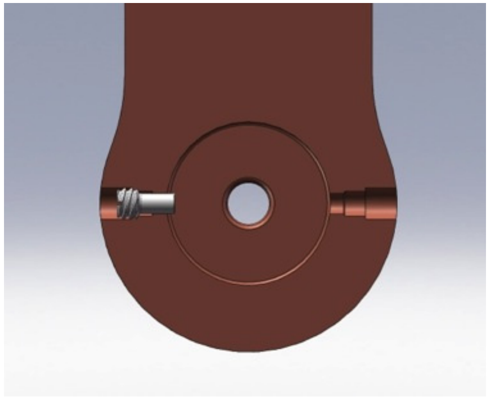


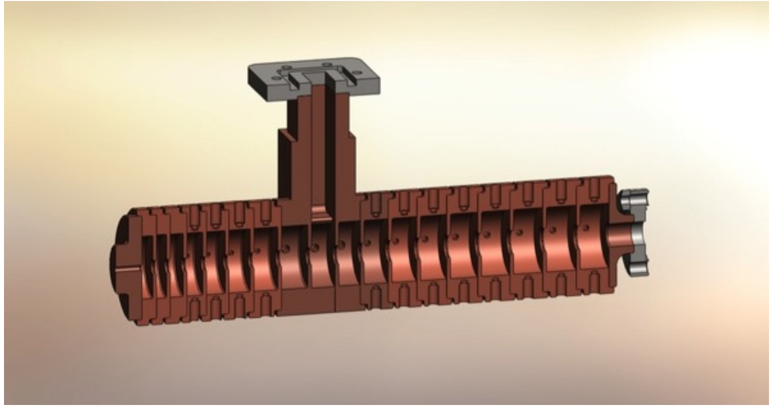


Linac Engineering

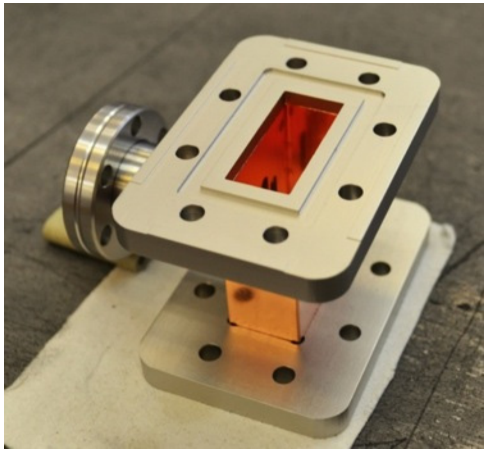
- > 100 parts, dozens of sub-assemblies were designed and engineered for fabrication
  - Linac cells, coupler, windows, flanges, braze shims & fixtures, test fixtures, diagnostics, etc.
- Cell tuning was a major issue
  - Used rough tuning and fine tuning pins for first structure

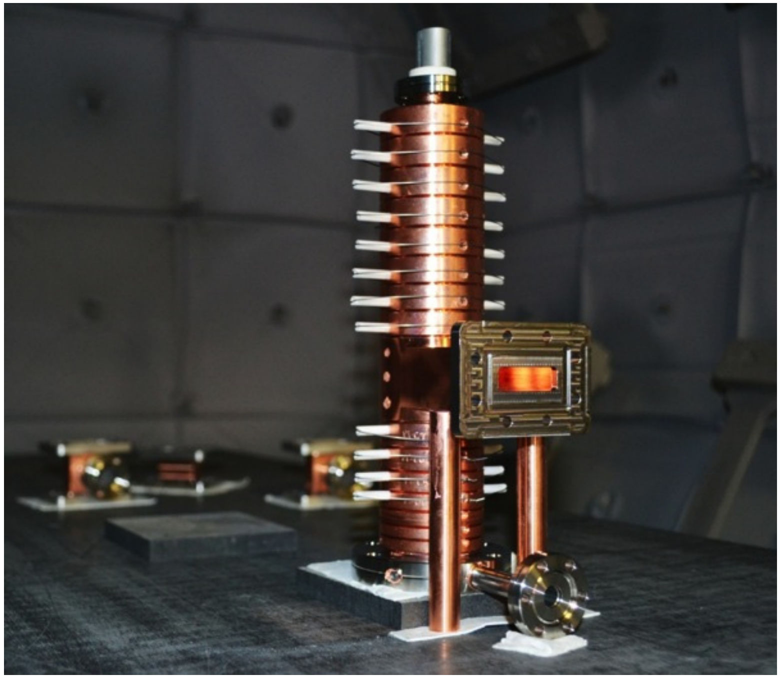


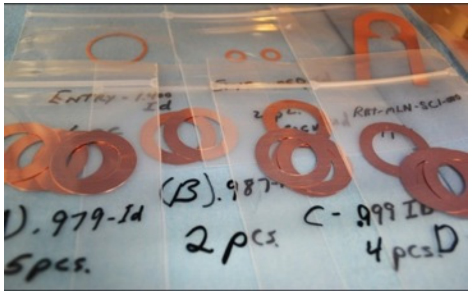




Linac Machining & Brazing

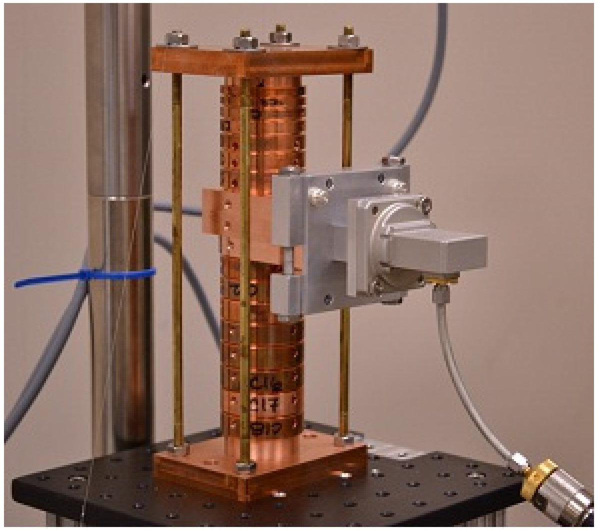


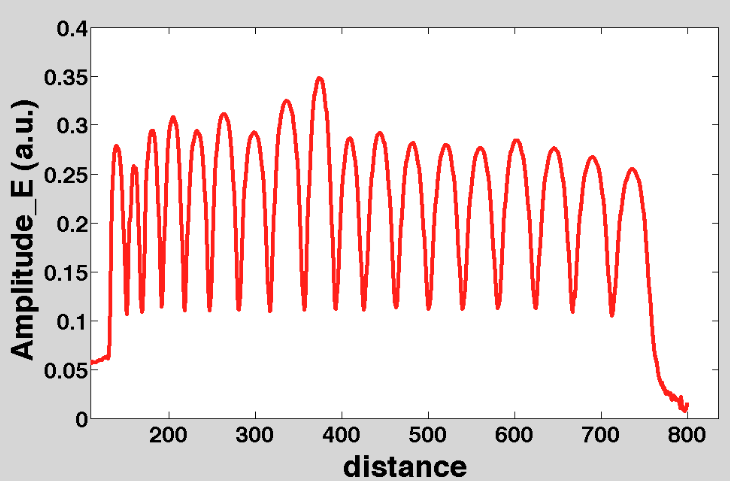


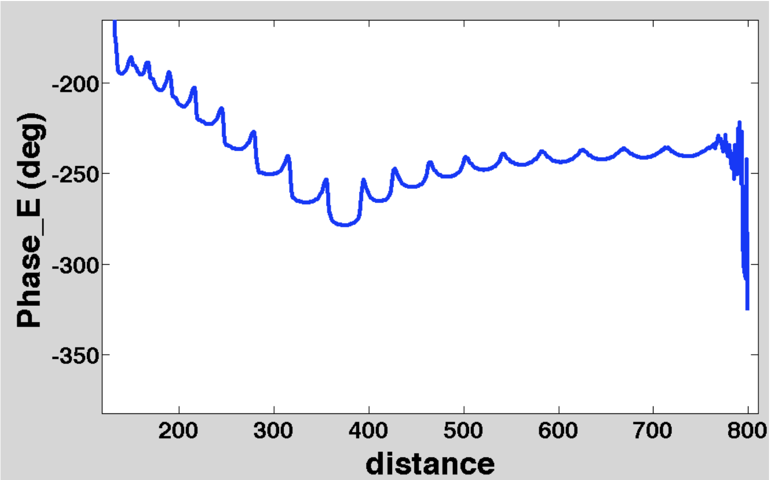


Linac Cold-testing/Tuning

- Several different testing/tuning fixtures made
- Bead pull most important for tuning
- Structure tested before and after brazing
- Pins were not usable in first few cells
  - Redesigned for next version

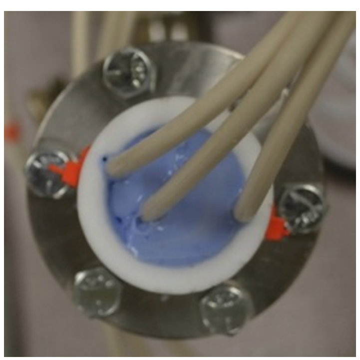


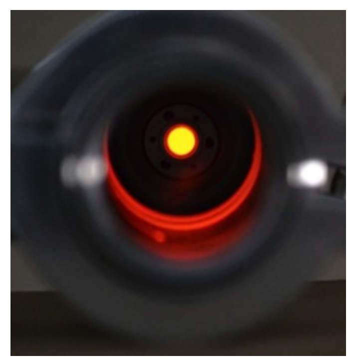




Electron Gun and Driver

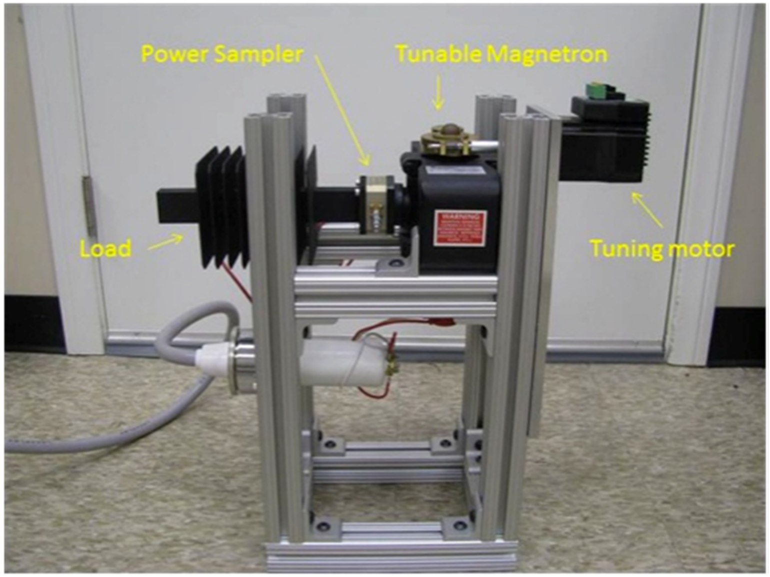
- L-3 M592 electron gun
  - Commonly used for medical linacs, fairly inexpensive
- Used "gun deck" purchased to provide cathode HV, heater, and grid voltages
  - Worked pretty well, but not easily controllable.
  - Future versions will not need gun deck.





RF Power System

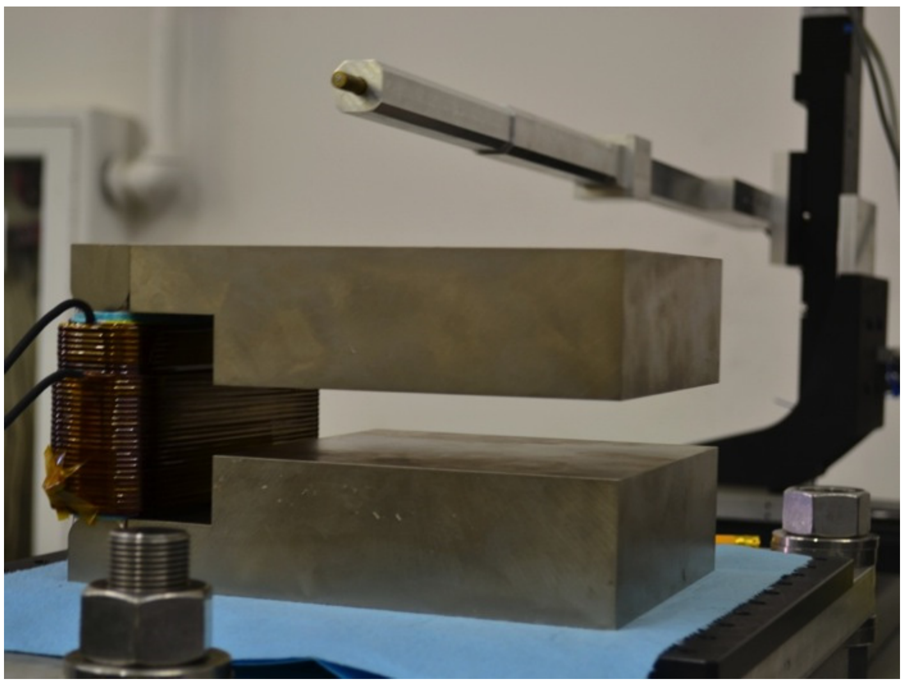
- Purchased 220 kW tunable peak power magnetron for flexibility during testing
  - Turned out to be not so flexible (hard to tune power)
- Purchased Scandinova solid-state modulator
  - Fairly inexpensive, compared to other options
  - Well engineered, reliable, flexible control



Courtesy of ScandiNova Systems AB

Diagnostics

- Spectrometer system for measuring beam energy
- Faraday cup and CT for measuring current
- Beam profile monitor to view beam size on straight-through port

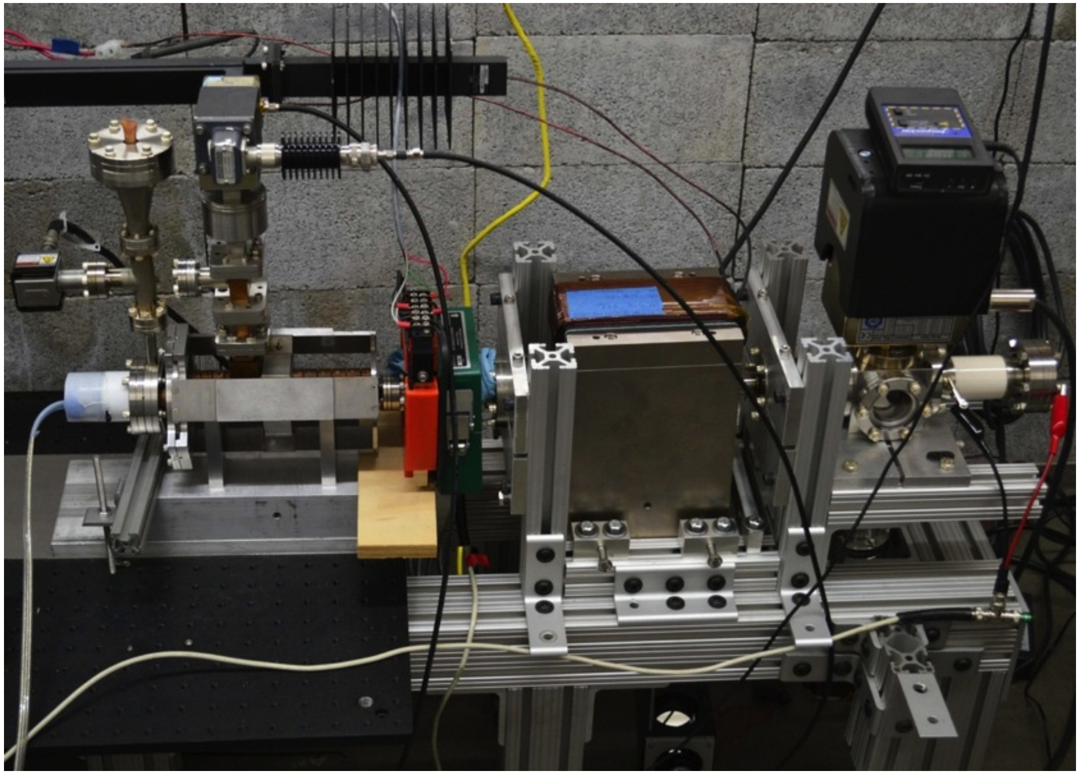


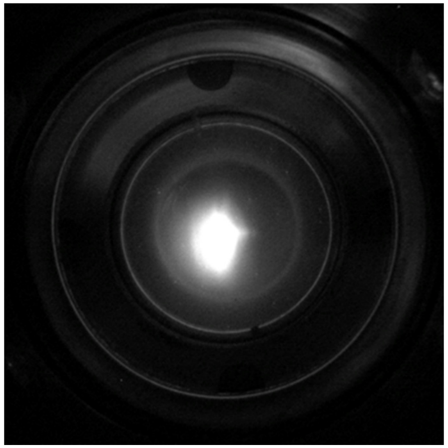
Radiation Shielding

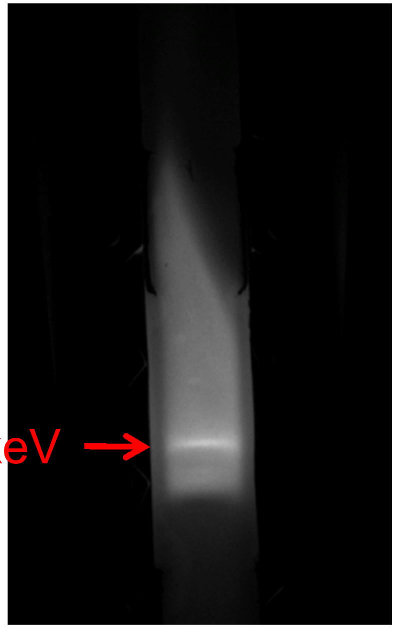
- Constructed small bunker (up to 2 MeV) in our warehouse
- 18” thick concrete block wall and steel plates on top
- Established radiation safety program (policy, badges, surveys, etc.)
- Shielding planned to be expanded for commercial projects

Results

- Highest energy part of beam seen at 520 keV
- Lots of scattered electrons due to poor focusing through spectrometer
- Broad energy spectrum, due to excessive power

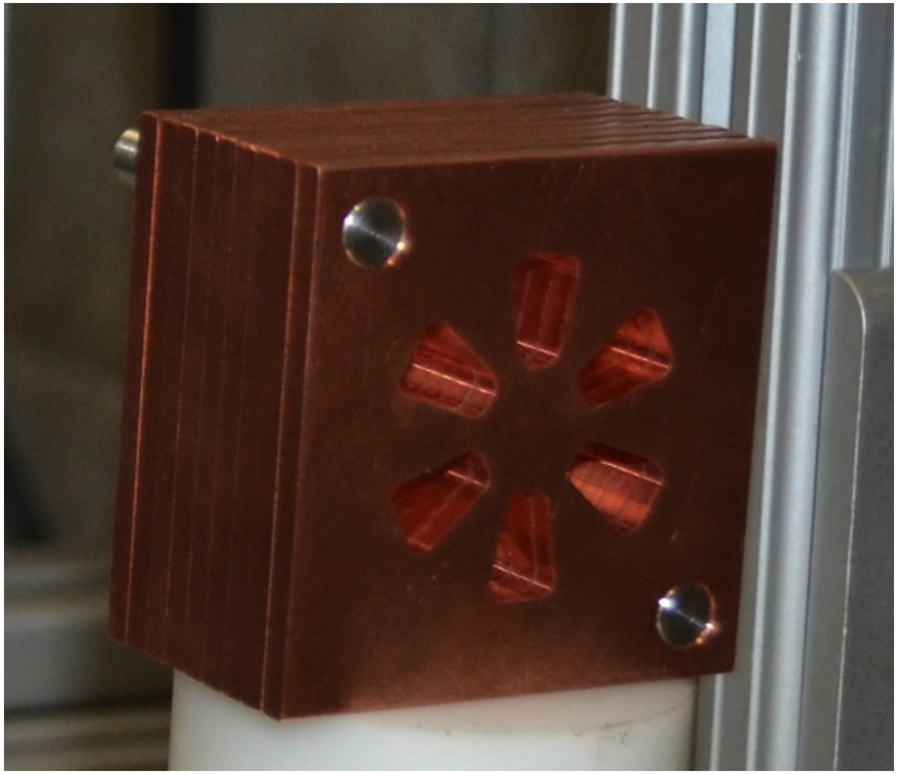


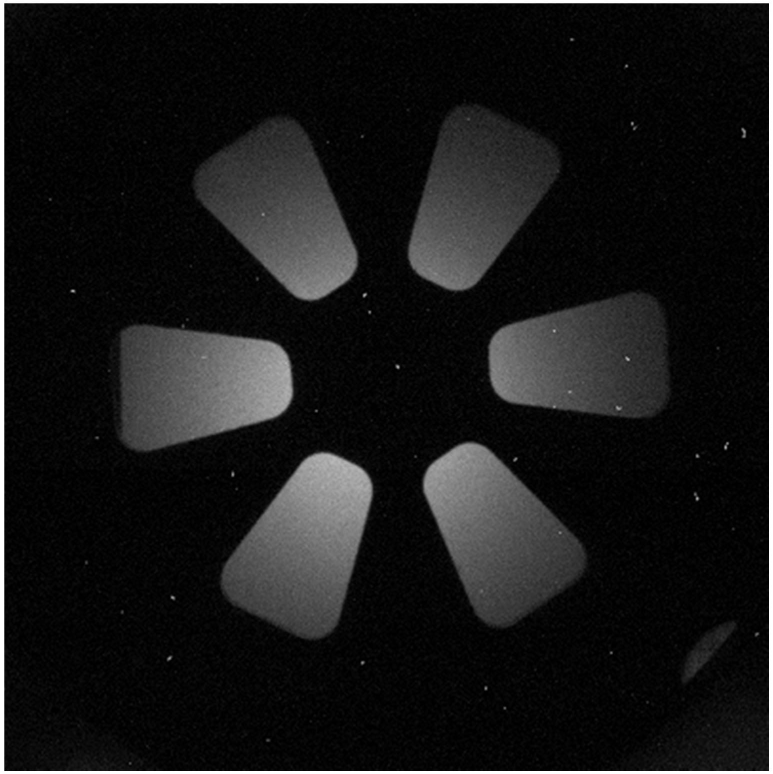




X-ray Imaging

- 50 µm steel window used as X-ray converter
- Radiograph taken with scintillator and camera
- Linac running at 5 Hz, camera integration time: 1 second





So How “Inexpensive”?

- Prototype cost ~$1 million
- Non-cost-optimized version would cost ~$200k
- Goal is to get price down below $100k
- This will require reduction in cost of linac manufacturing and tuning

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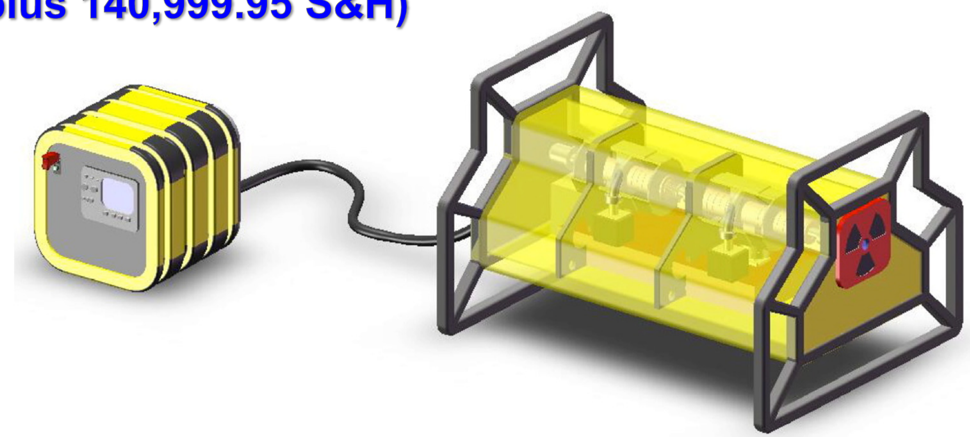

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Conclusions

- RadiaBeam is developing compact, inexpensive linacs as replacements for radioisotopes in a number of applications.
- First structure of the MicroLinac tested successfully at 500 keV.
- Cost-optimized prototype planned for development, but we can make more conventional designs now.

- Thanks to original SLAC MicroLinac team (N. Ackerman, G. Bowden, M. Breidenbach, G. Caryotakis, V. Dolgashev, G. Leyh, R. Miller, F. Murphy, R. Phillips, R. Reed, R. Ruth, S. Tantawi, J. Wang, D. Yeremian)
- Thanks to the RBT MicroLinac team (Ron Agustsson, Amber Becthtel, Tara Campese, Luigi Faillace, Josiah Hartzell, Alex Murokh, Steve Seung, Alexei Smirnov, Scott Storms)
- Thanks to DNDO and DOE for investing in this work!