Pulsed-Power Driver and X-ray Source Development for Core-Punch Radiography

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presented at the
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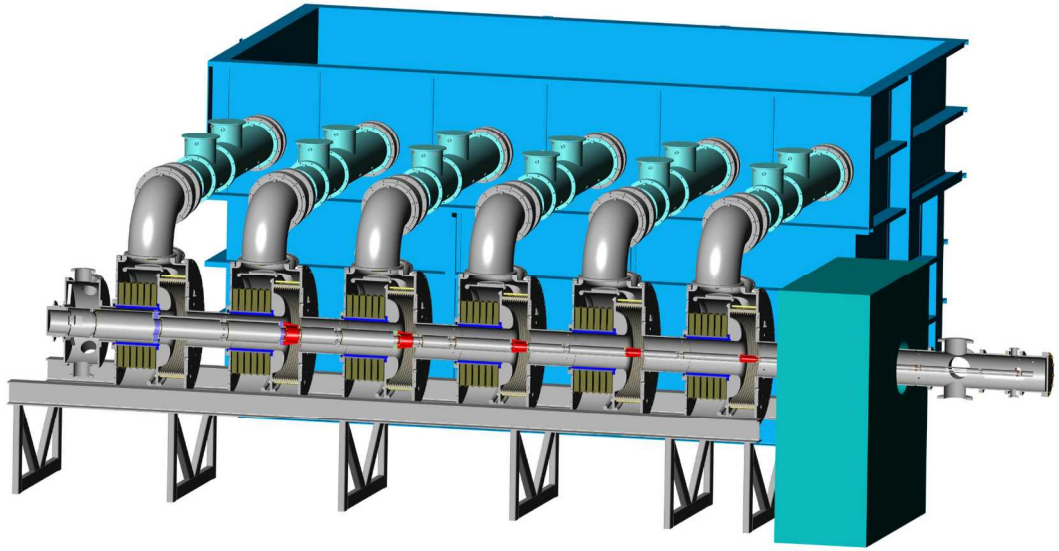

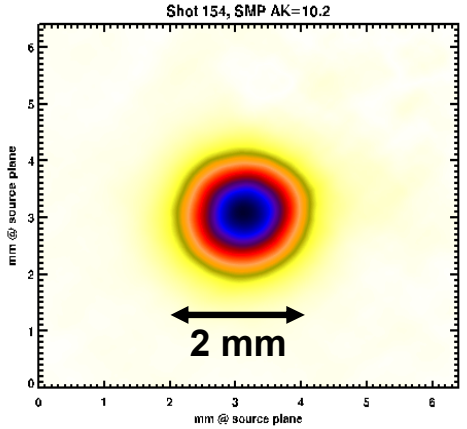

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Acknowledgements

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Sandia National Laboratories

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NRL Pulsed Power Physics

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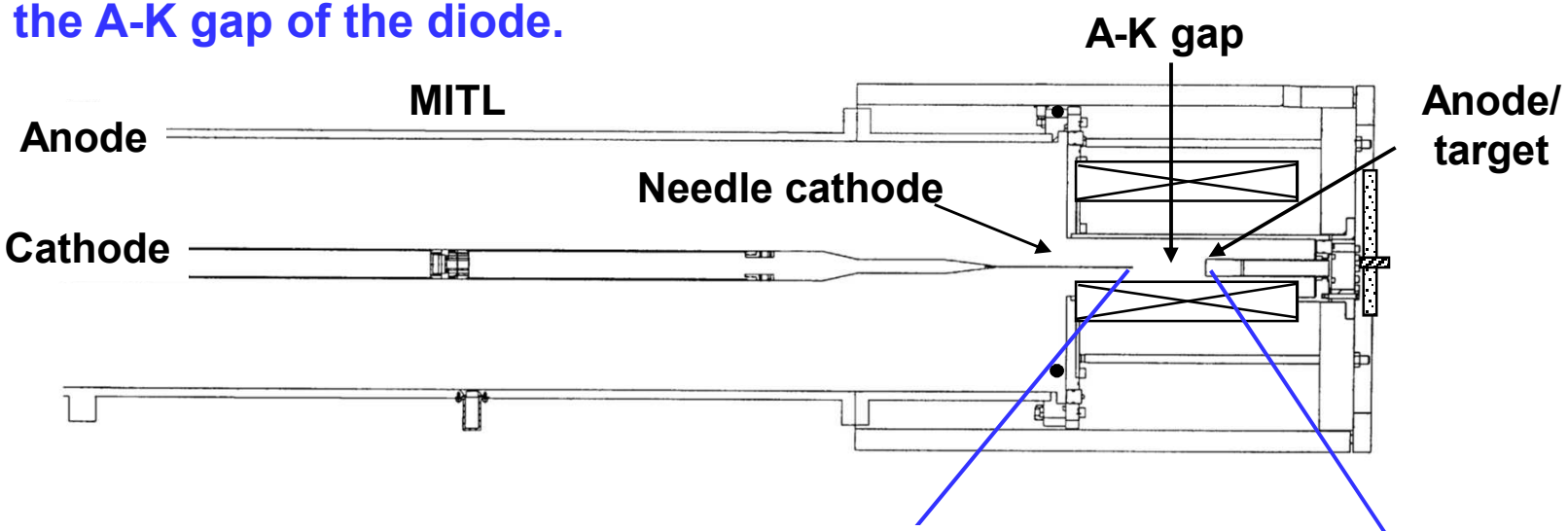
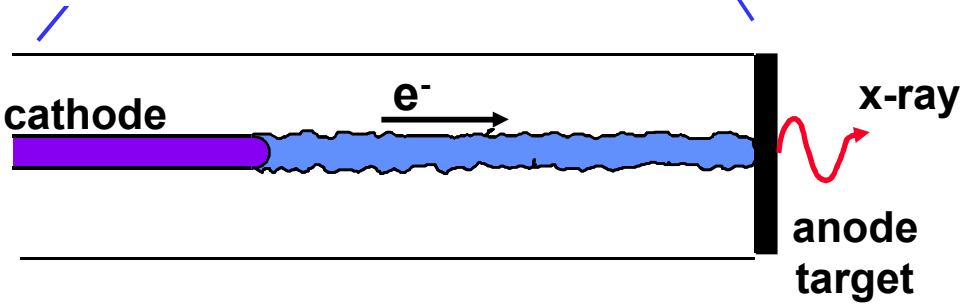
Voss Scientific
Bechtel Nevada
L3 communications Applied Technologies Pulse Sciences

Pulsed-power e-beam driven radiography

Power is fed from an Induction Voltage Adder (IVA) accelerator to a high current electron beam diode. The electron beam is created in the A-K gap of the diode.



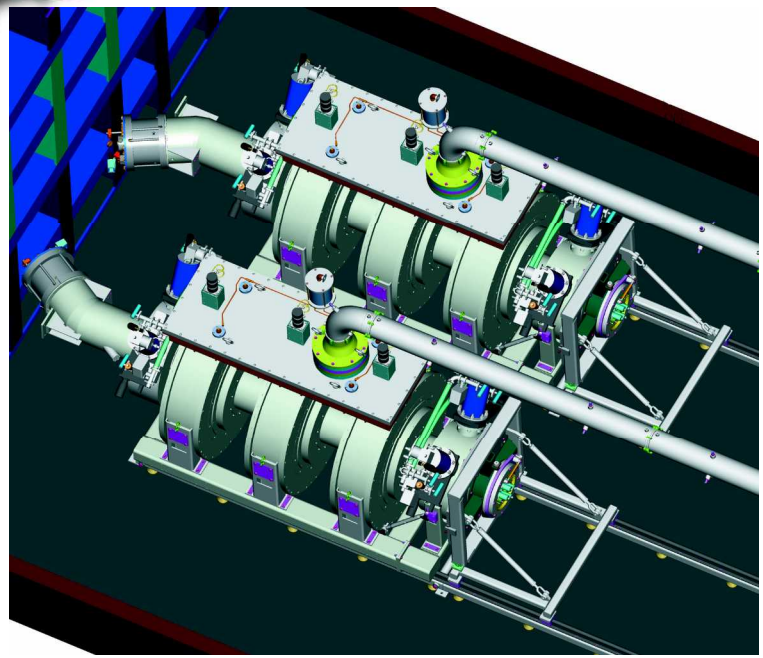
Bremmstrahlung x-rays are created when the e-beam is stopped in a high atomic number converter.



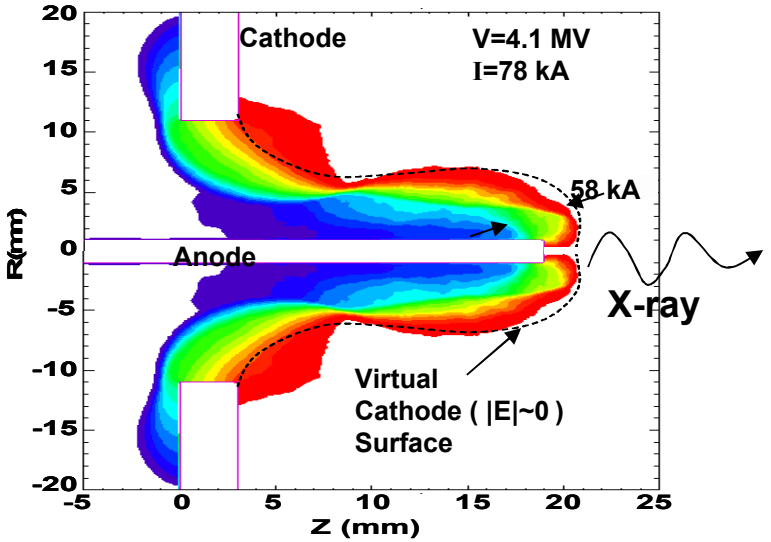
Energy = 2-10 MeV, Current = 20-150 kA, Pulse length = 50-100ns

Lower voltage but higher current than a LIA design e.g. DAHRT

Cygnus was our first IVA-driven Sub-Critical Experiment radiographic system



Normal Rod pinch diode



Radiograph of Thermos confirmatory

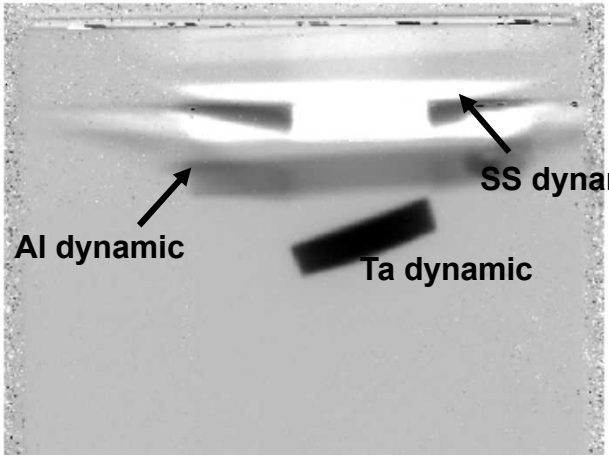


Fig. courtesy T. Haines LANL

- Provides dual axis radiographs at NTS, U1a
- Armando SCE studied Pu spall.
- Used on 12 Thermos experiments (Pu recovery) and upcoming Barolo series.
- Each 2.2 MV axis produces a > 4 rad@m, 1.1mm spot from a rod-pinch x-ray source.

Presently Looking to Optimize Cygnus

- **Each 2.2 MV axis produces 4 rad@m, 1.1-mm spots.**
- **LANL desire to optimize Cygnus**
- **Concentrate on spectral and spot variation:**
  - increase V, and more reproducible spectrum
  - decrease spot
  - bring sources closer together

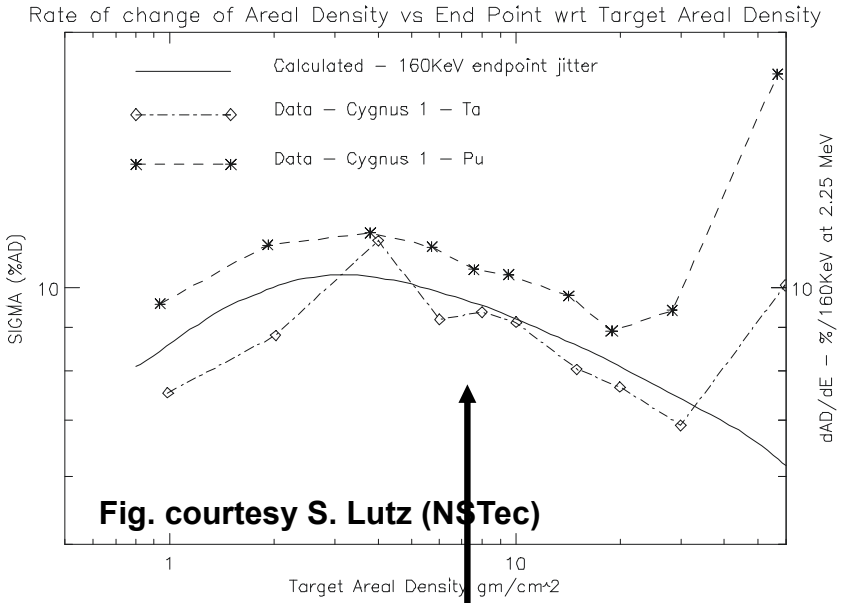
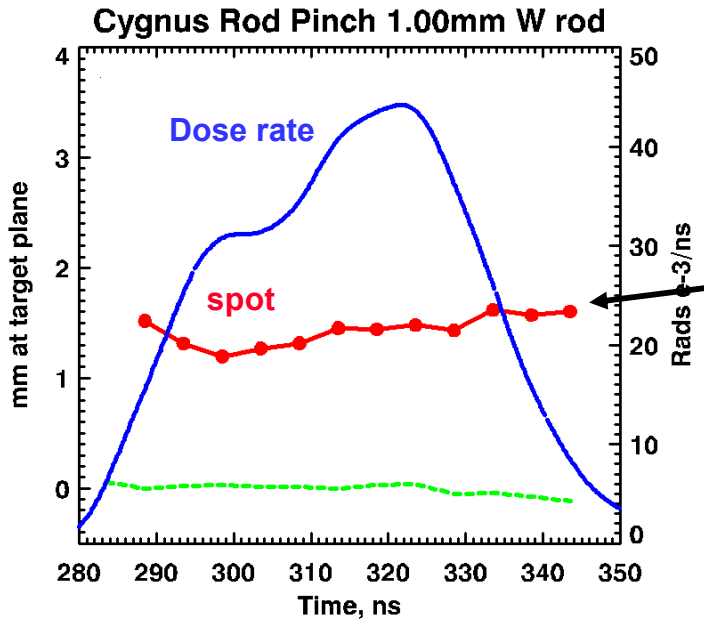


Fig. courtesy S. Lutz (NSTec)



% transmission variation due to 160 KeV (7%) voltage variation.

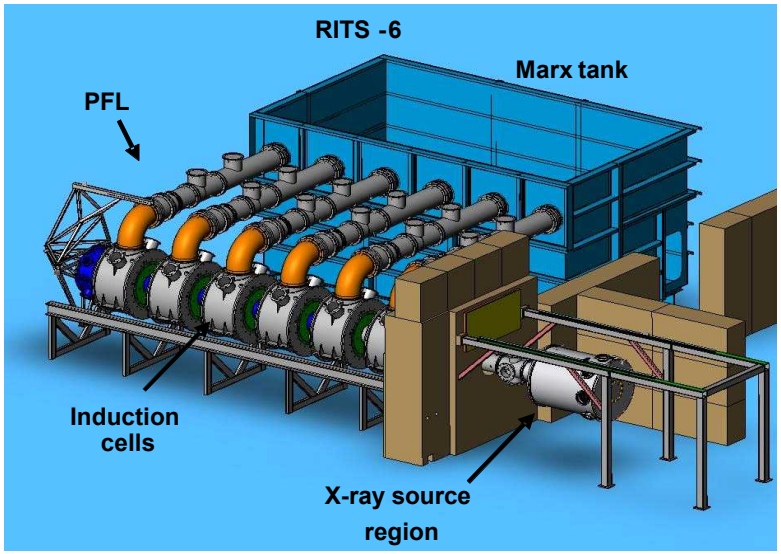
Spot growth late in time

RITS-6: Sandia's Radiographic Integrated Test Stand

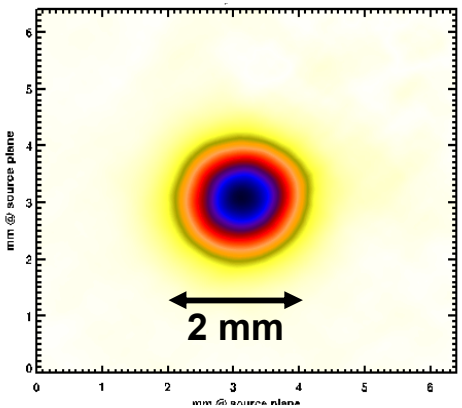
E-beam driven x-ray radiography system based on Induction Voltage Adder (IVA) technology.

RITS is the U.S. and U.K. test-bed for pulsed-power driven high voltage x-ray sources

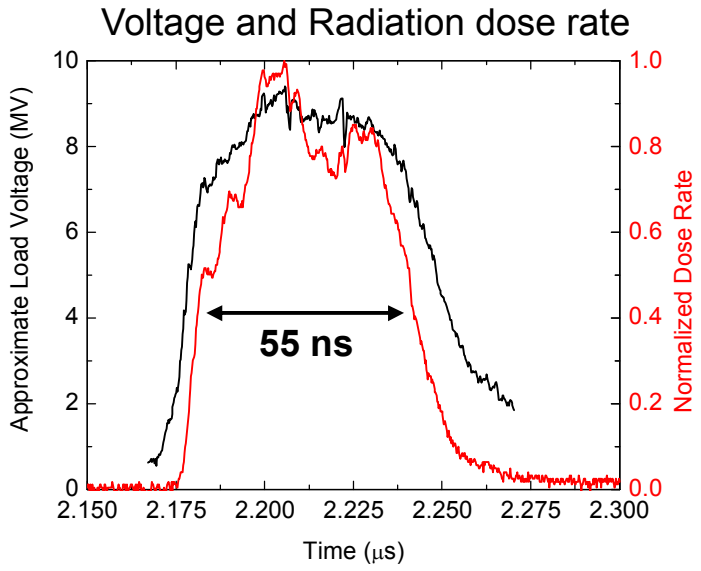
Flexible accelerator producing 5-11 MV, 125-190 kA, 55 ns radiation pulses and capable of generating > 500 rad@m.



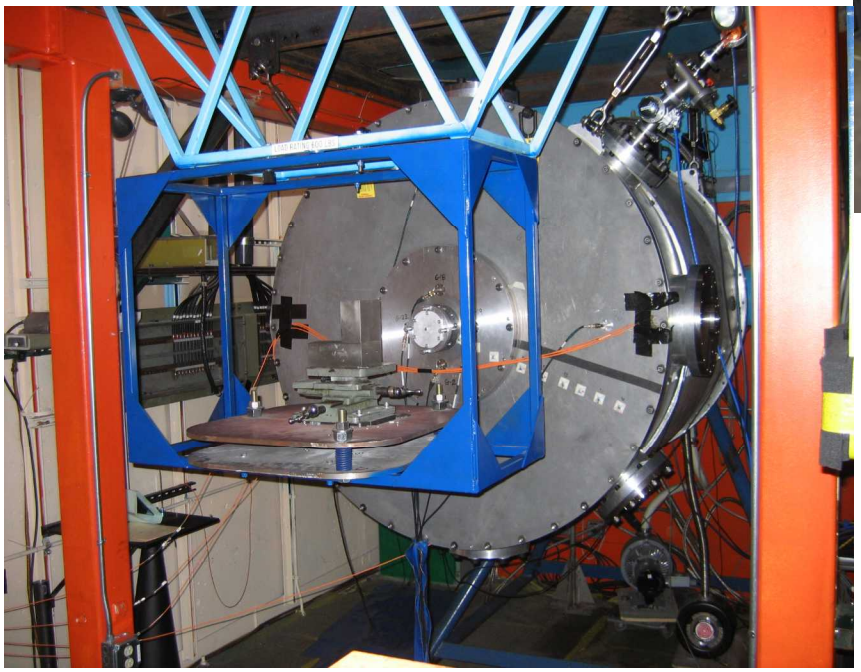
Demonstrated 6.5 MeV source: 350 rad@m, 2.6mm spot



Source size from self pinch diode

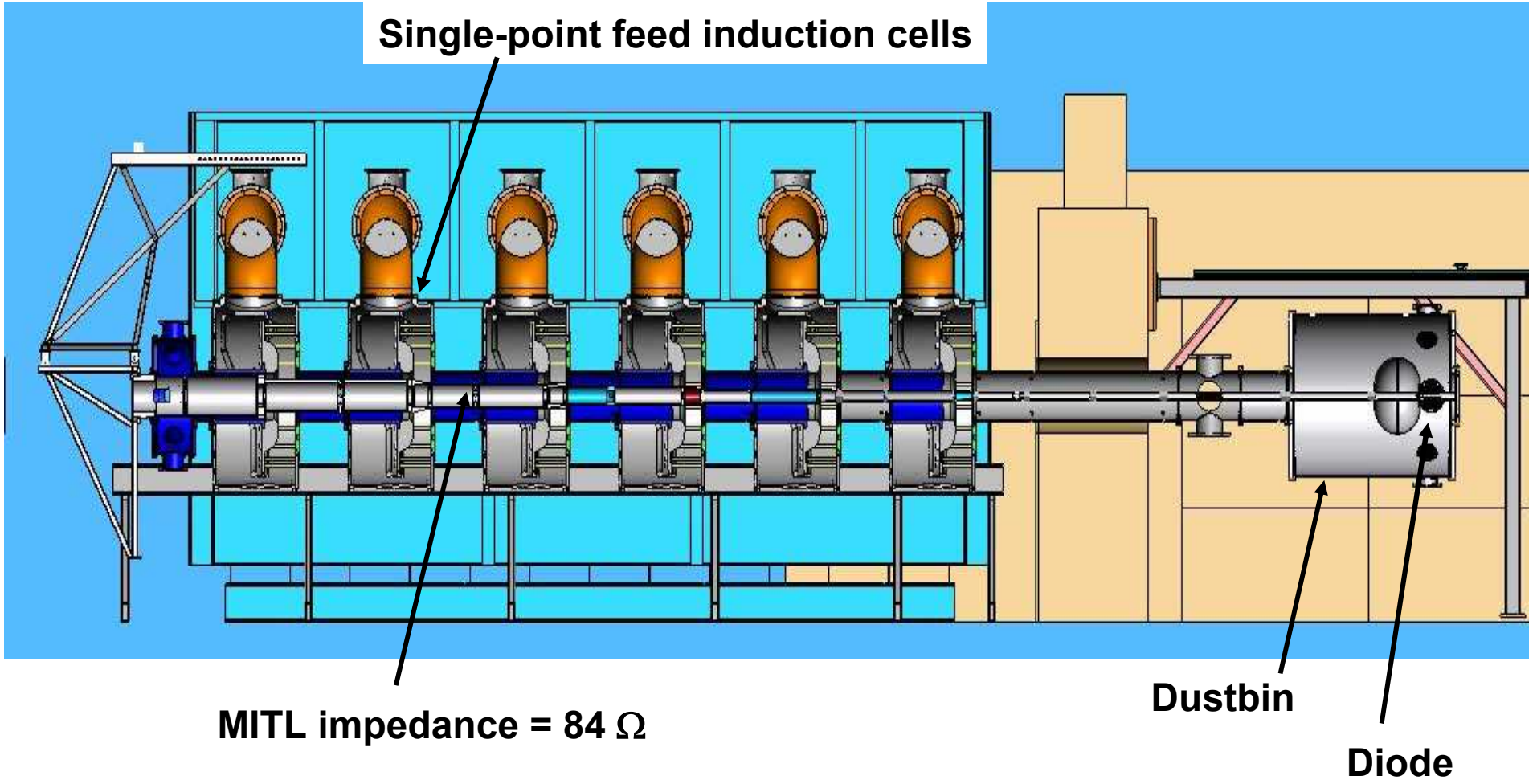


RITS-6

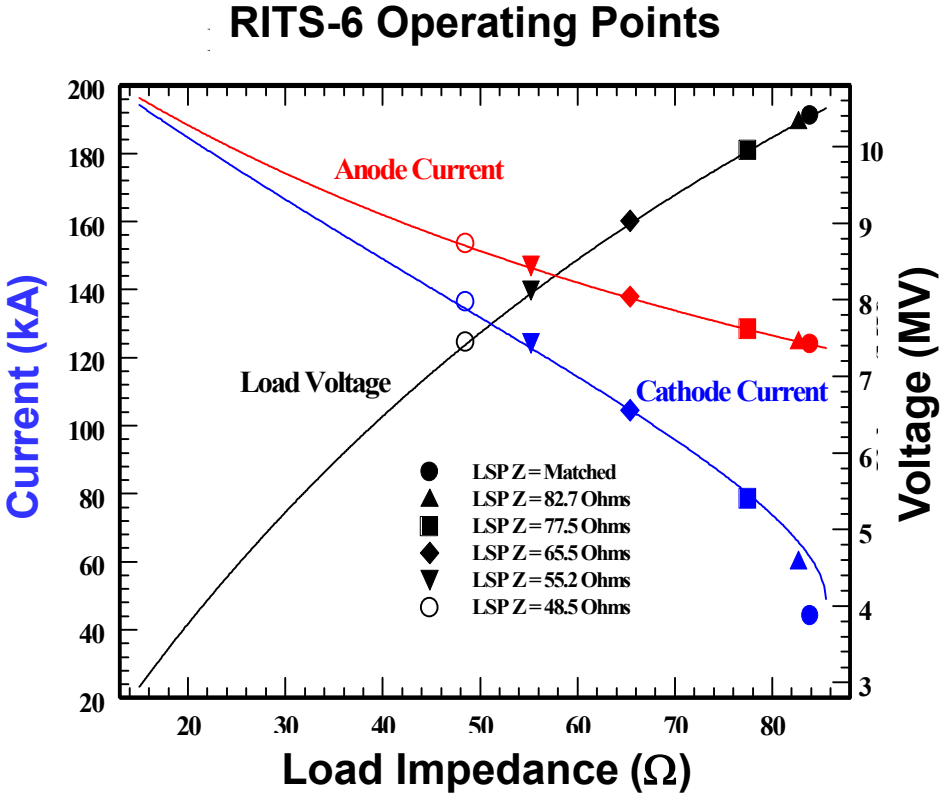


Diode/Radiation test cell.

RITS-6 Cross-section and MITL



RITS-6 is a flexible accelerator architecture for driving high voltage sources.



MITL Load impedance $Z_L = V/I_A$
Diode impedance $Z_D = V/I_C$

Dose ~ IV^{α}, $1<\alpha<3$:
can increase dose via current or voltage or both.

Non-linear MITL impedance V=IZ(V) enables efficient drive for a variety of diode impedances. Can obtain 300% increase in diode current for on ly 30% decrease in voltage!

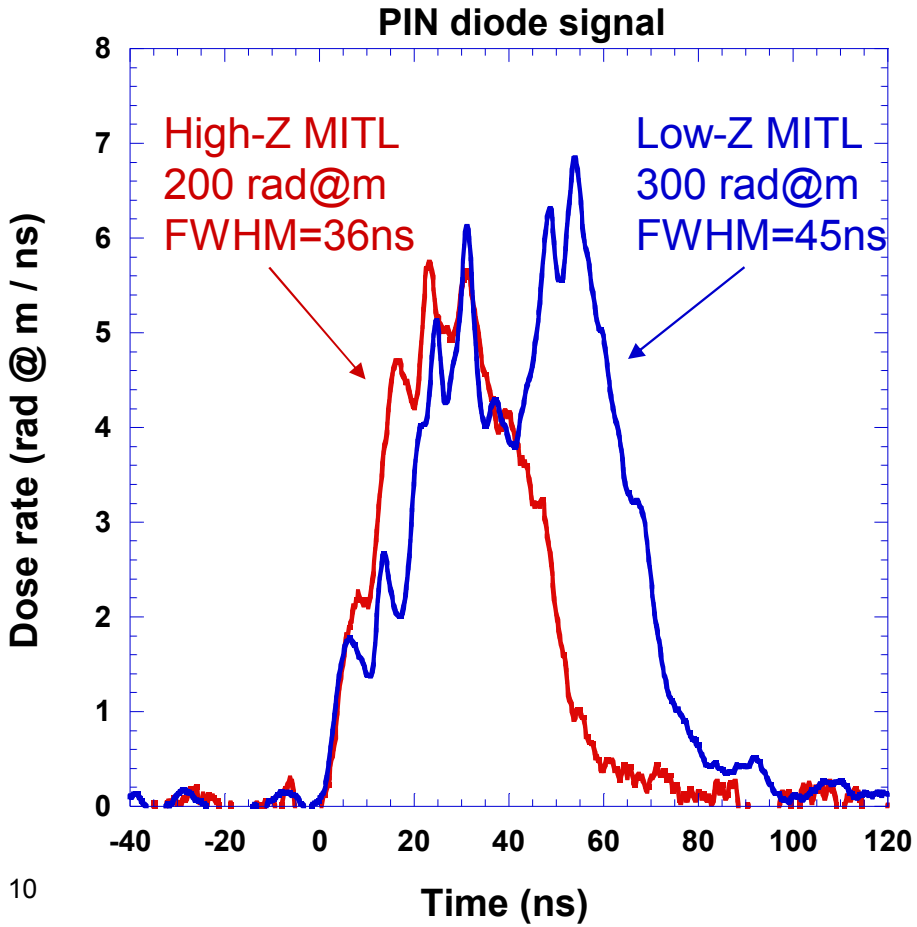
1. V. Bailey et al., proc. 14th Intl. PPC, 2003

Sandia National Laboratories

Minor changes to accelerator architecture increase power coupling to source

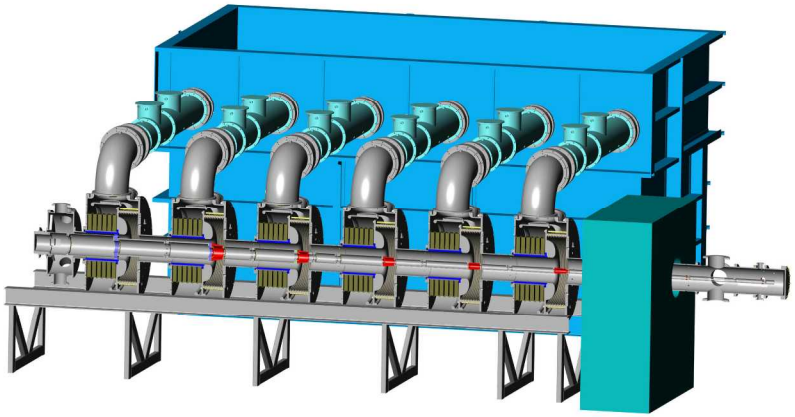
Designed a 42 Ohm MITL (vs. 82 Ohm) to thread the center of accelerator

~ $100k to design and build

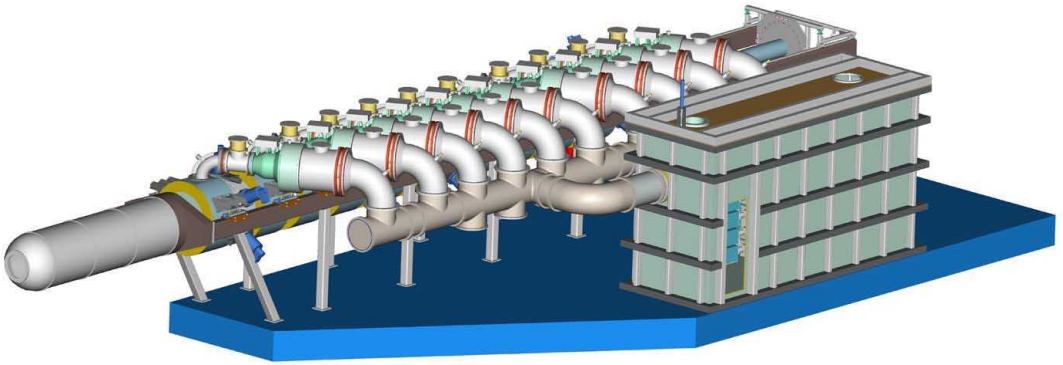


Low-Z MITL shots have produced > 400 rad@m, 2.8 mm spot from self-pinch diode

RITS is the pulsed-power-driven high voltage x-ray source test stand for the U.S. and U.K.



RITS-6, 11 MV



Hydrus, 14 MV

RITS-6 is the only relevant test bed for Hydrus

Collaborative research on development of near and long term x-ray sources

Near term goals (2008):

250 rad@m, 2.7 mm spot

600 rad@m, 5 mm spot

(or equivalent > 350 rad@m, 2.7mm)

Long term (2012):

1000 rad@m, 2 mm spot

Future radiography requirements are driving research on Self-pinch and Paraxial diodes*

250 rad@m, 2.7 mm spot

Self-pinch diode is leading candidate,
Low impedance 40 Ohm,
6 MV, 120kA. Demonstrated 200+ rad@m, 2 mm spot on Mercury accelerator at NRL.
350+ rad@m, 2.7 mm spot on RITS-6 at SNL.

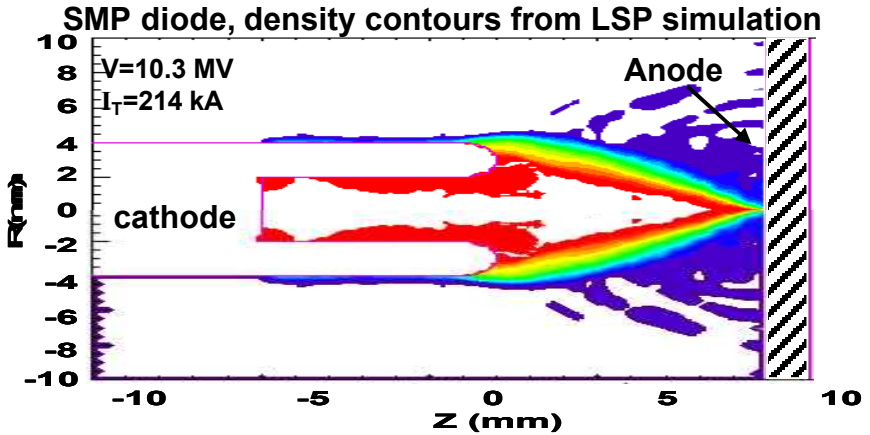
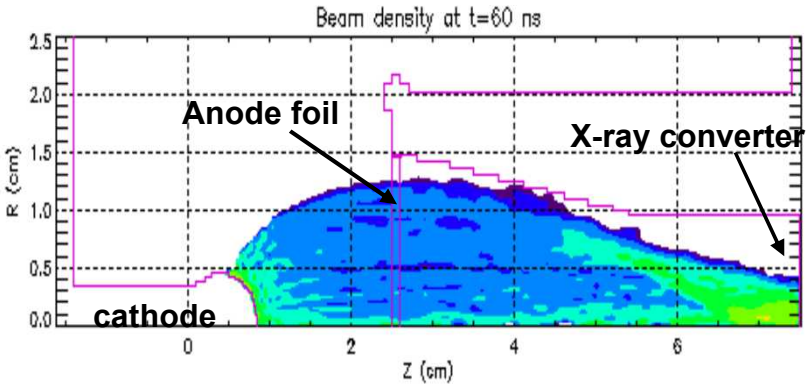


Fig. courtesy S. Swanekamp, NRL

600 rad@m, 5 mm spot

Paraxial diode is leading candidate,
High impedance 200 Ohm
Demonstrated 5-mm spot, 3 - 9 MV (AWE)
Demonstrated 7-mm, 500 rad@m at 11. MV on RITS-6



Paraxial diode, density contours from LSP simulation

1000 rad@m, 2 mm spot

Will require increased R&D effort to provide Improved diode designs.

*Research conducted in collaboration with AWE, Aldermaston U.K.

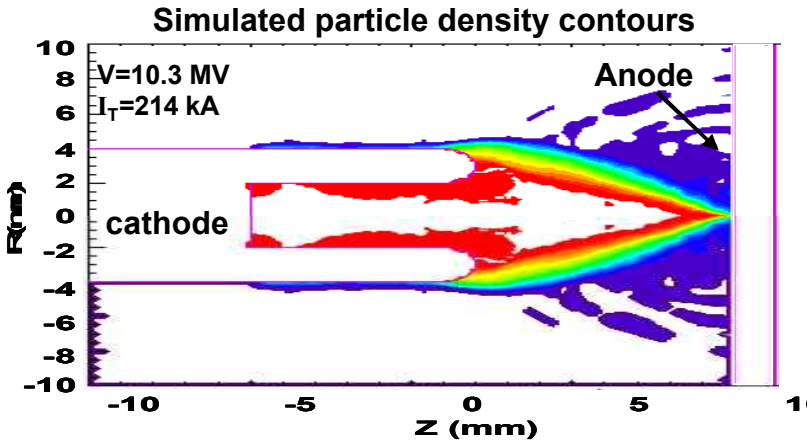
We recently demonstrated scaled core-punch capability with the Self-pinch diode source

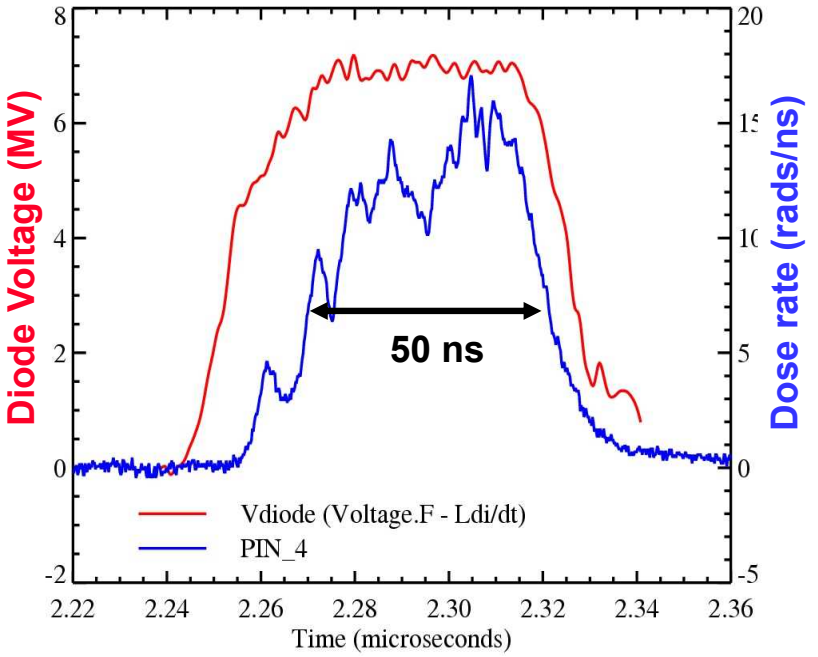
SNL, AWE, NRL team demonstrate on RITS with a Self-Magnetic Pinch Diode:

210+ rads@m from 2.75-mm spots at 5.5 MV.

350+ rads@m from 2.6-mm spots at 6.5 MeV. Exceeds AWE scaled requirement

Compare to Monroe: 80 rads @ 1m from 4.5 mm spot. 13 times brighter source!

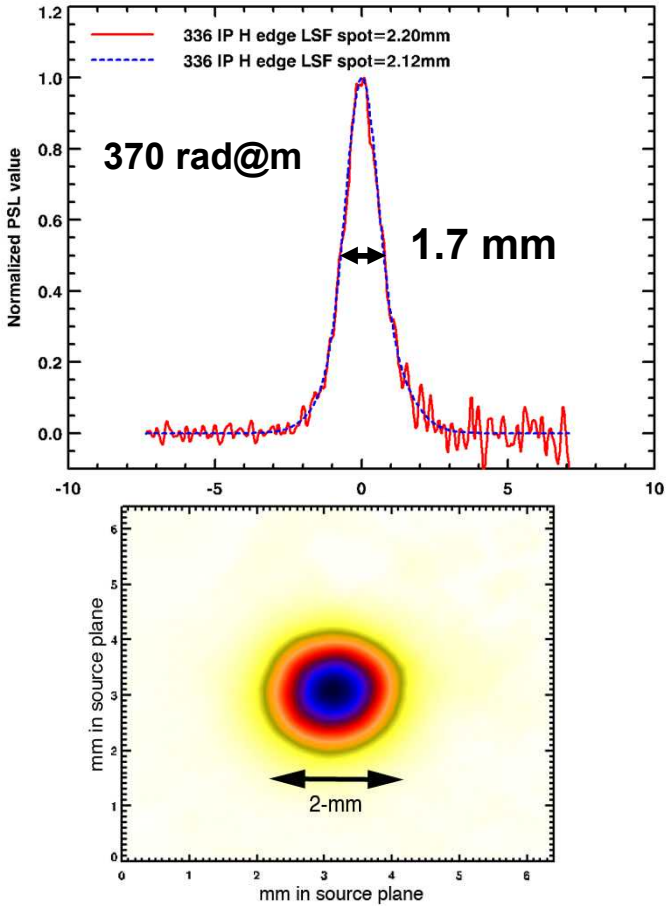


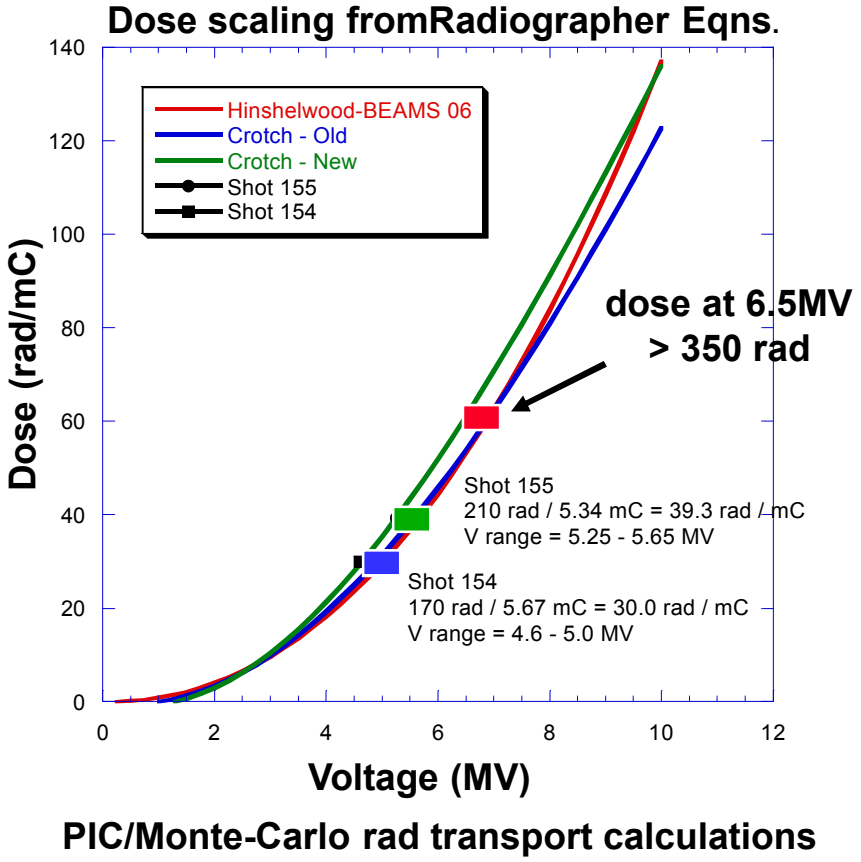


Self-pinched diode source should have higher resolving power than a 2.7 mm spot suggests.

AWE definition spot = 2.7 mm ± 0.2 mm
A LLNL definition (1.44x fwhm LSF) = 2.2 ± 0.1 mm
Implies a peaked core (non Gaussian) spot.

Measured x-ray source spot

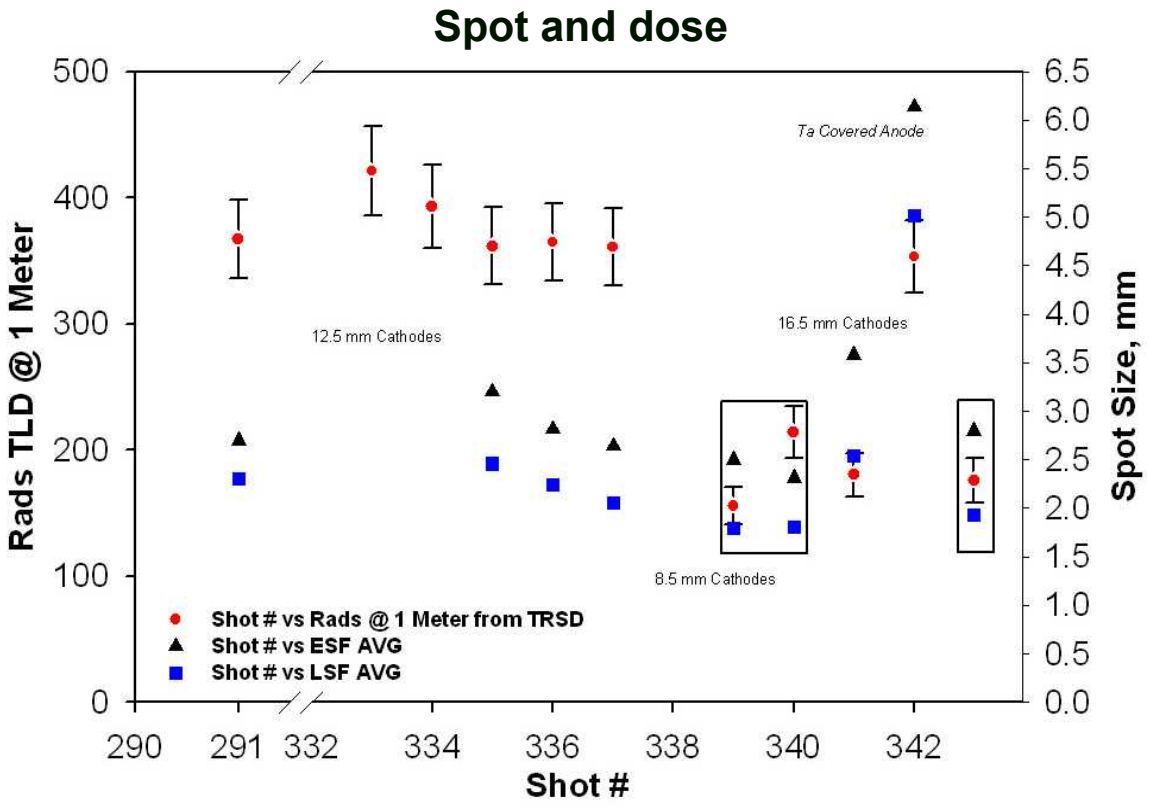


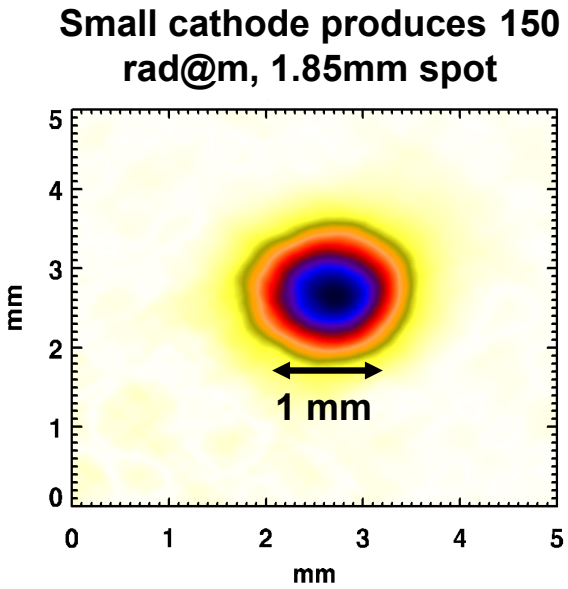


PIC/Monte-Carlo rad transport calculations

Demonstrated brightness > 50 rad/mm²

Self-pinched diode geometric changes can produce smaller spot at reduced dose.





Source development: Ongoing optimization of the Paraxial source

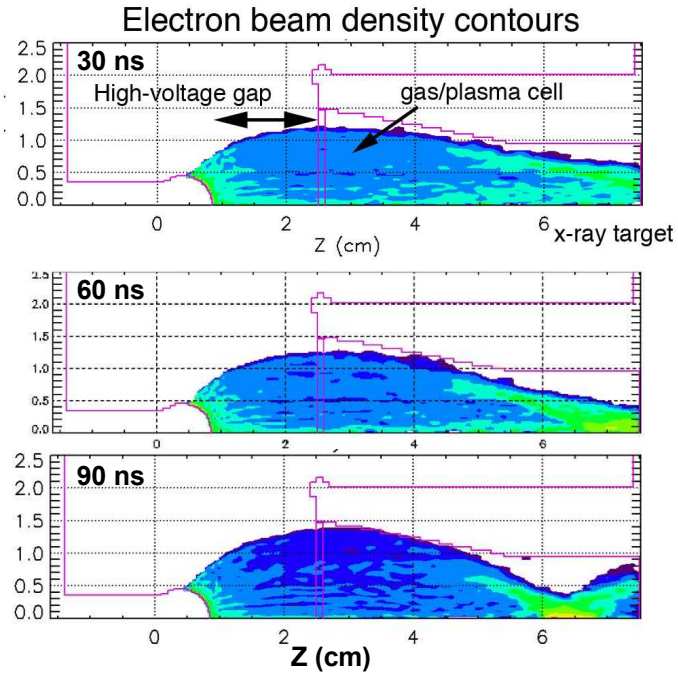
The baseline AWE x-ray source is being improved

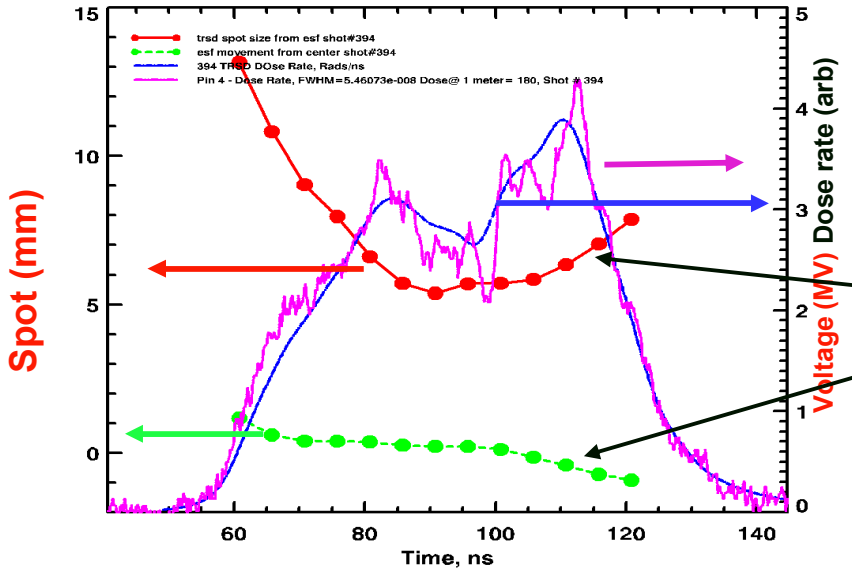
- Hybrid (PIC-Fluid-Monte Carlo) 3D simulations
- Time resolved spot diagnostic
- Spectroscopy for plasma densities and constituents
- Expect to decrease the spot by a factor 2.

LDRD in '07-'08 supports source improvement.

11 MeV Paraxial source on RITS

500 rads @ 1m from a
7.0 mm (0-100% AWE) spot





First measurements of beam sweep and spot wander

Radiographic Diagnostic Development

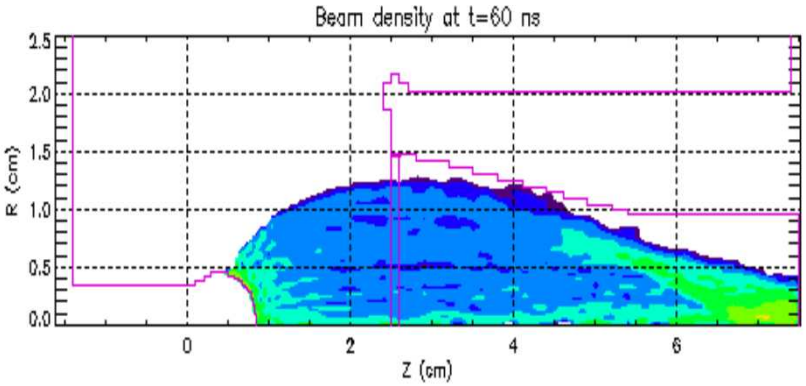
Time-resolved x-ray spot

Time Resolved Spot Diagnostic

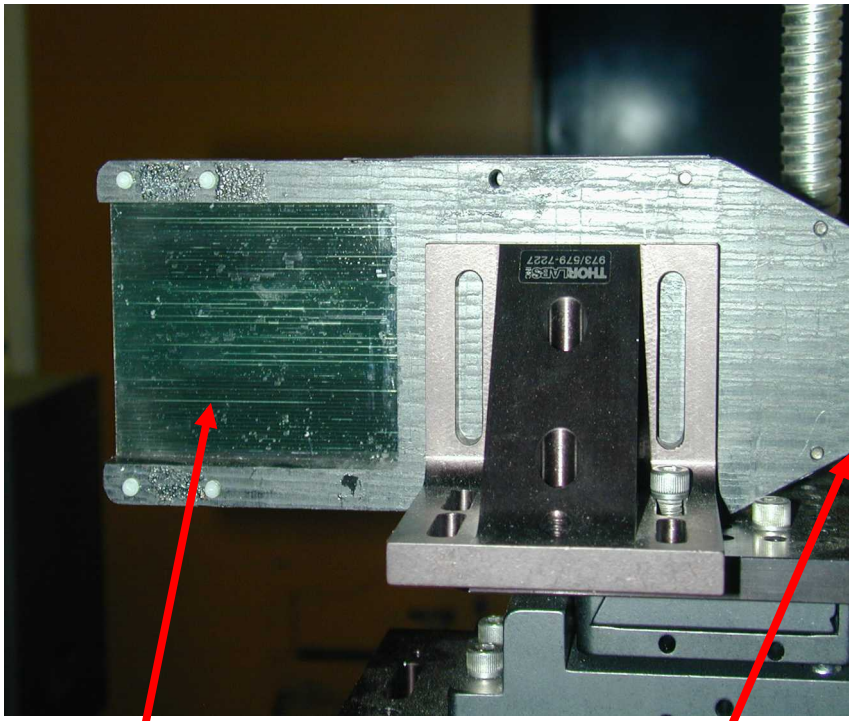
The TRSD measures the time history of the spot and dose (dose rate)

It is an array of scintillation fibers butt-coupled to a streak camera.

Enables time-dependent characterization of the beam dynamics.



Can measure beam sweep of Paraxial gas-cell diode



Scintillation Fibers

Streak Camera

Alternative source development: Negative Polarity Rod-Pinch

Dose at 0^0 scales weakly with voltage[1]!

$$D\ (rad) \propto \int I_e V^{1.25}\, dt$$

Dose at 180^0 in backwards direction is maximized[2]

$$D\ (rad) \propto \int I_e V^{2.22}\, dt$$

Dose rate dependence on angle

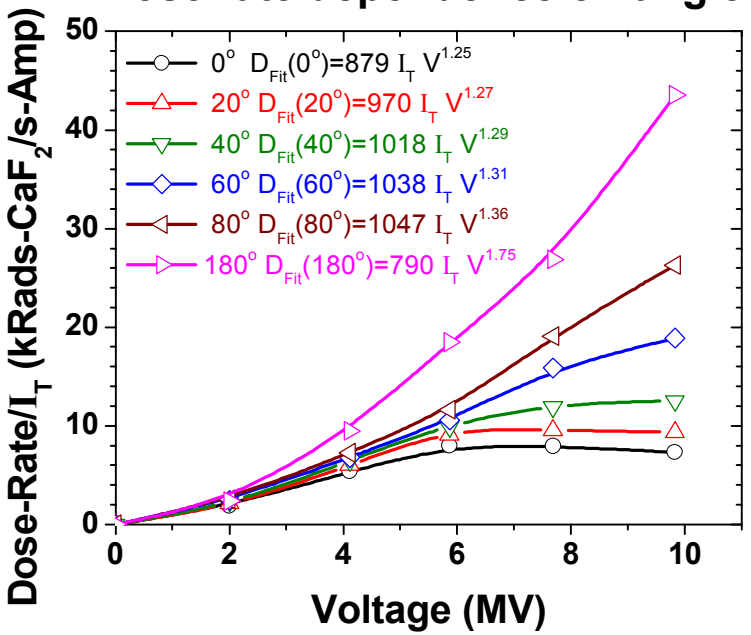
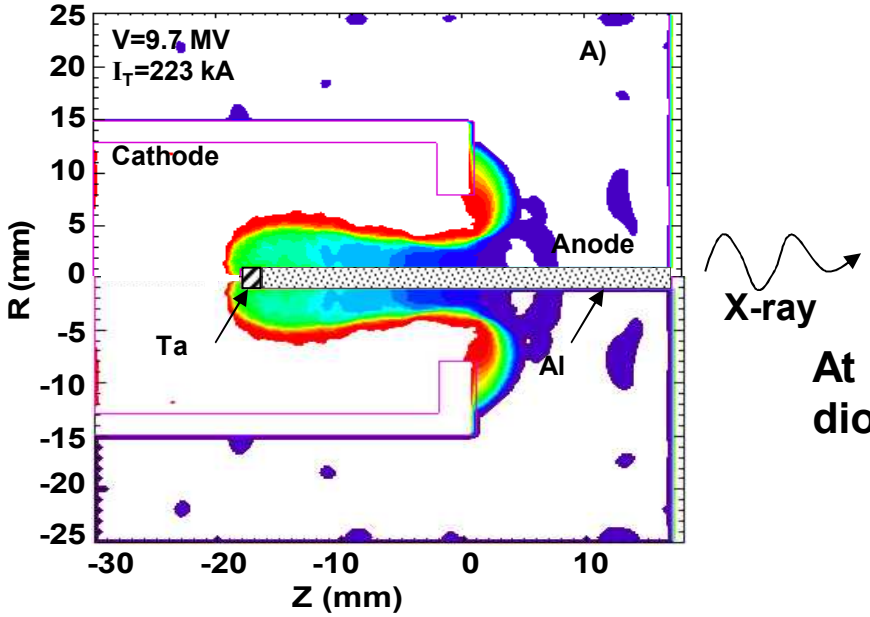


Fig. courtesy of S. Swanekamp, NRL

Reentrant Rod pinch diode



At high voltages the Rod-pinch diode dose is maximized at 180^0

1. D.V. Rose et al. JAP,**91**,3328 (2002)
2. S.B Swanekamp, G. Cooperstein, J.W Schumer et al. IEEE Trans. Plasma Sci. **32**, 2004 (2004)

Negative Polarity Rod-Pinch results @ 6.5 MV

Collaboration with NRL.

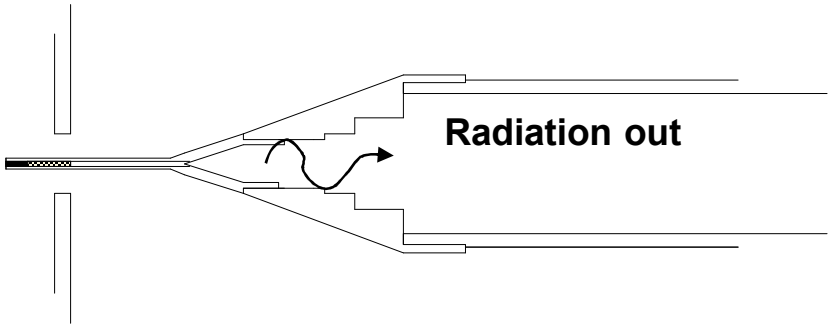
Rod on-axis, with hollow Al tube and W plug

Radiation in the backward direction is 2.5x higher than the forward direction at 6.5 MV

Demonstrated 90 rad@m, 2.2 mm spot (RITS)

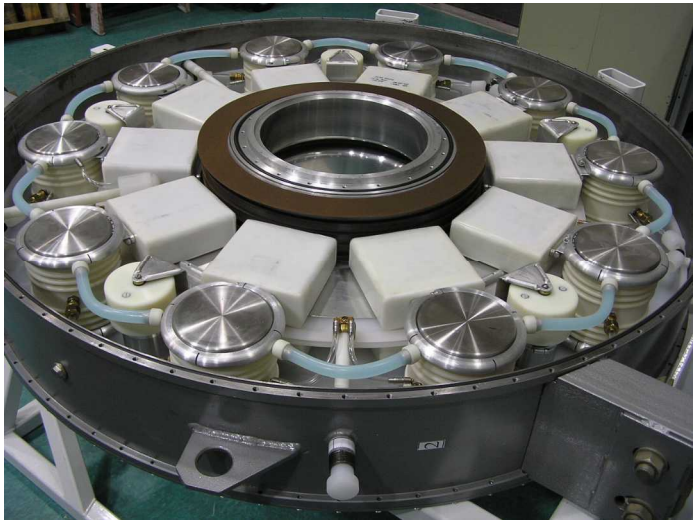
75 rad@m, 1.8 mm spot (Mercury, NRL)

6 times brighter source than Cygnus



Future driver architectures: 1-MV Radiographic LTD at Sandia

- A 1-MV, 140 kA radiographic Linear Transformer Driver (LTD) has been assembled and tested in Russia and now at Sandia
- Voltage adds along coaxial vacuum line, like an IVA
- Successfully tested with electron-beam diode load for more than 100 shots

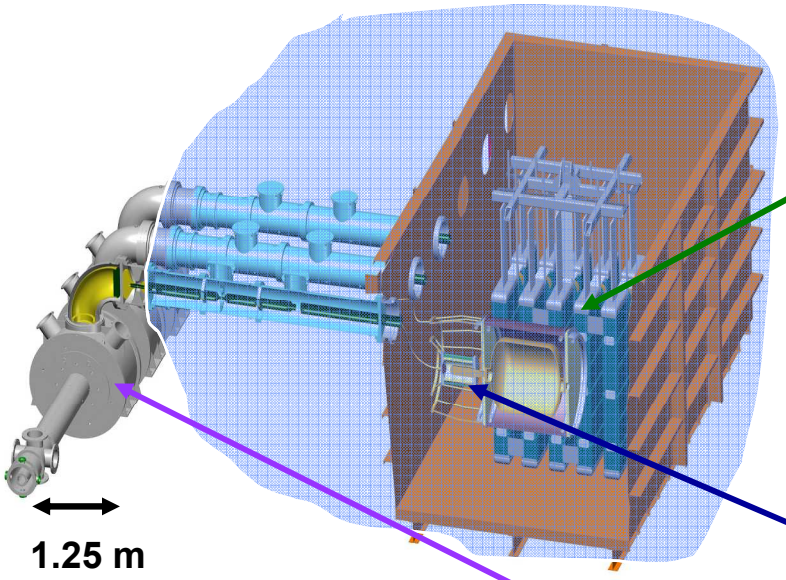


Advantages: lower cost and smaller foot-print: Can pack more capability into R306 or U1a firing sites.

Status: Demonstrated both single and stacked-cavity performance to 1 MV. Engineering development/demonstration still required for radiography.

The LTD is much more compact than conventional IVAs

Inductive Voltage Adder (IVA)

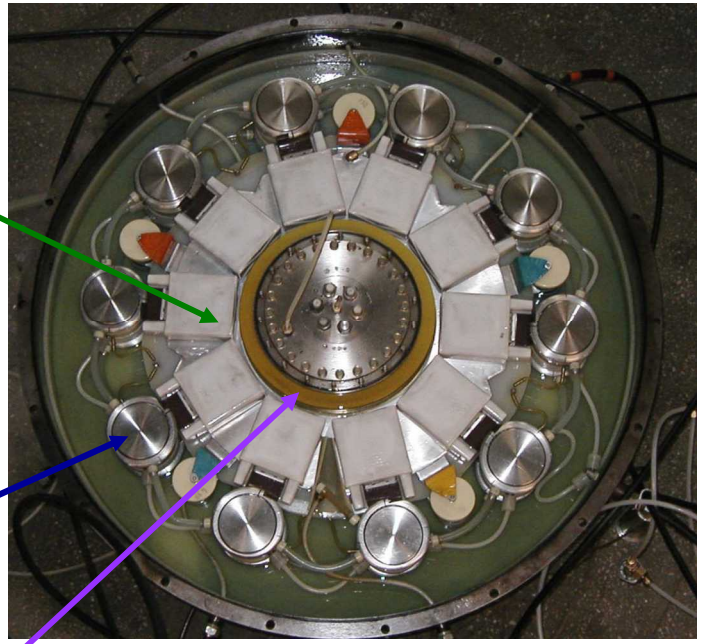


1.25 m

Remove pulse formation and compression hardware

10 m

Linear Transformer Driver (LTD)



Capacitors

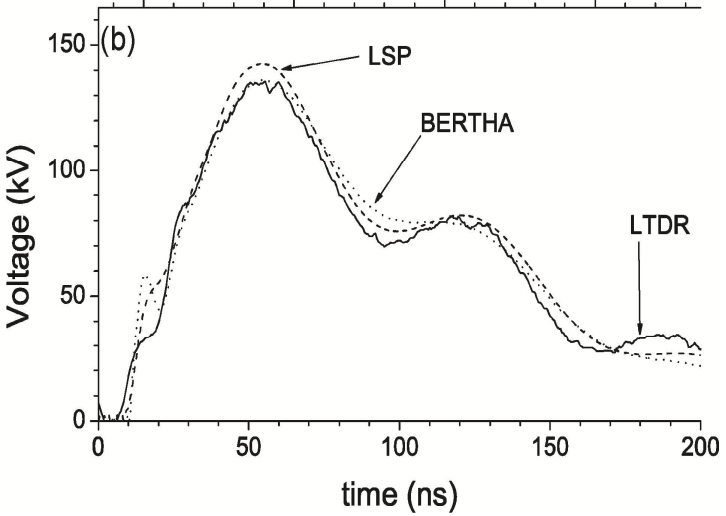
switches

Inductive isolation

1.25 m

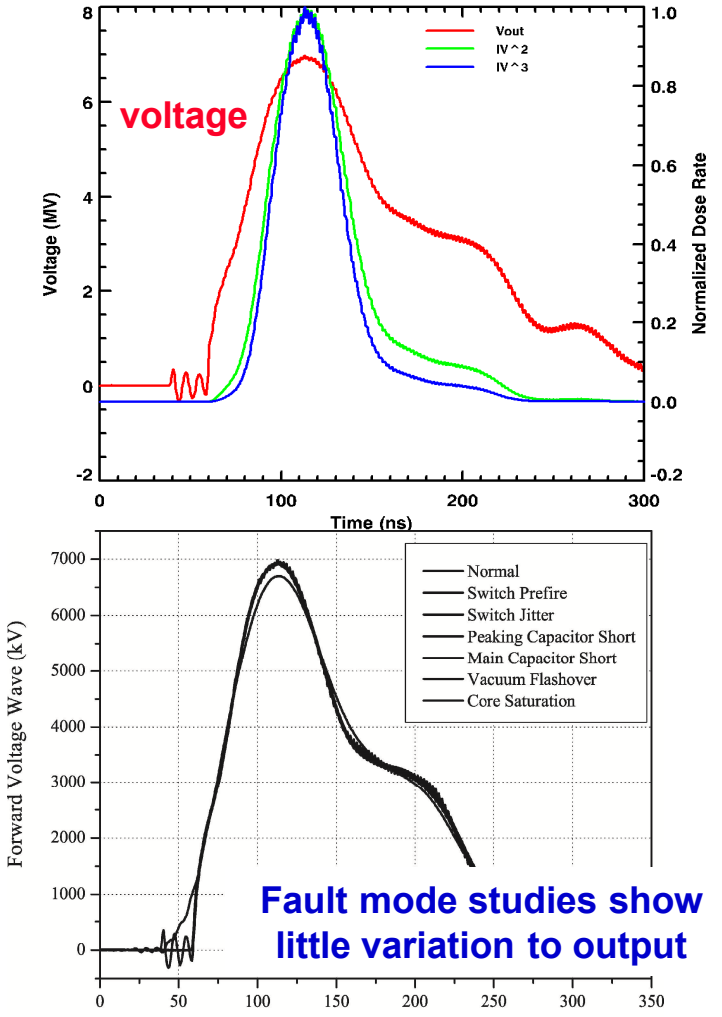
Modeling suggests favorable scaling of LTD to 6.5 MV

Results of simulation and data from the 1 MV test stand*



*Rose, Welch, Oliver et al., IEEE Trans. Plasma Sci, 2006

Simulated voltage and radiation pulse width for 6.5 MV system*



*Leckbee et al., IEEE Trans. Plasma Sci, 2006

Laboratories

A 2-axis LTD can provide 6.5 MV, 250 rad@m, 2.5mm spot in same foot print as Cygnus

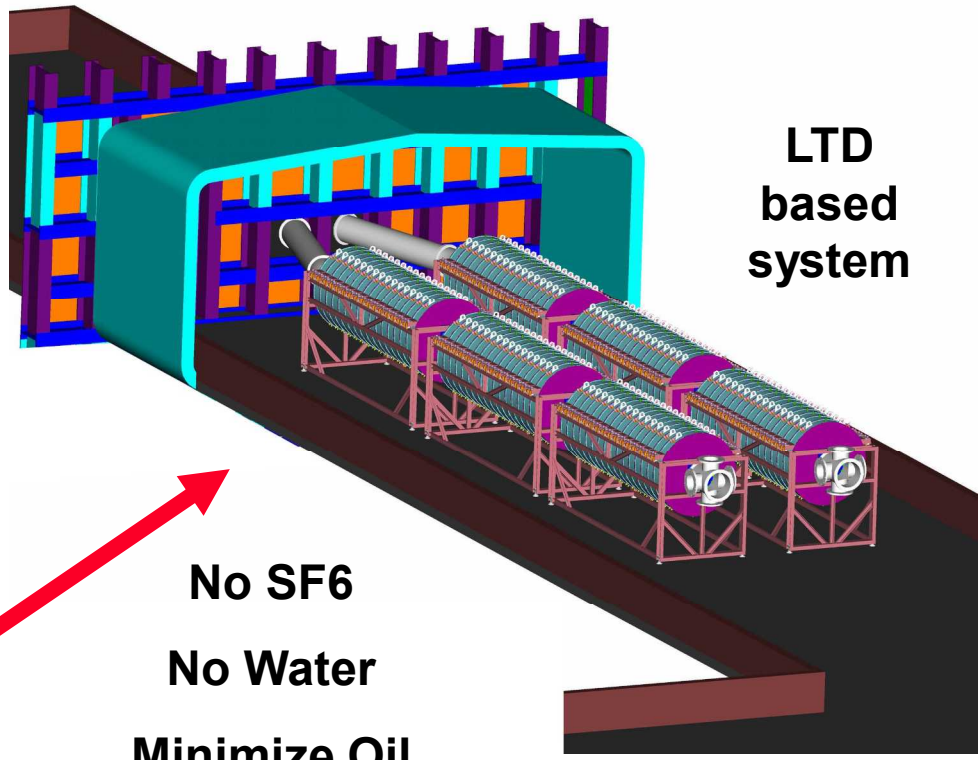
12’ wide x 50’ long x 6’ high

Can replicate existing Cygnus capability

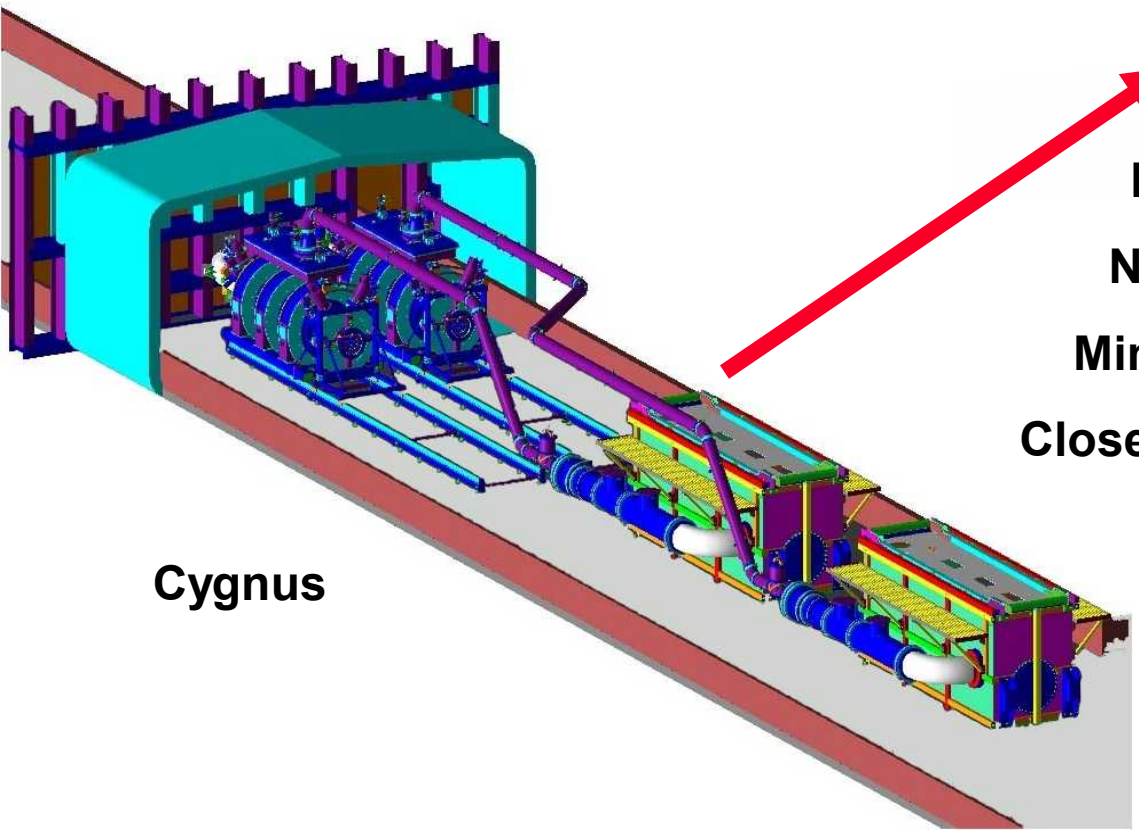
As well as provide increased capability

in steps up to 250 rad@m, 2.5-mm spot

3 - 4 yrs needed to deploy in U1a



LTD based system



Cygnus

No SF6

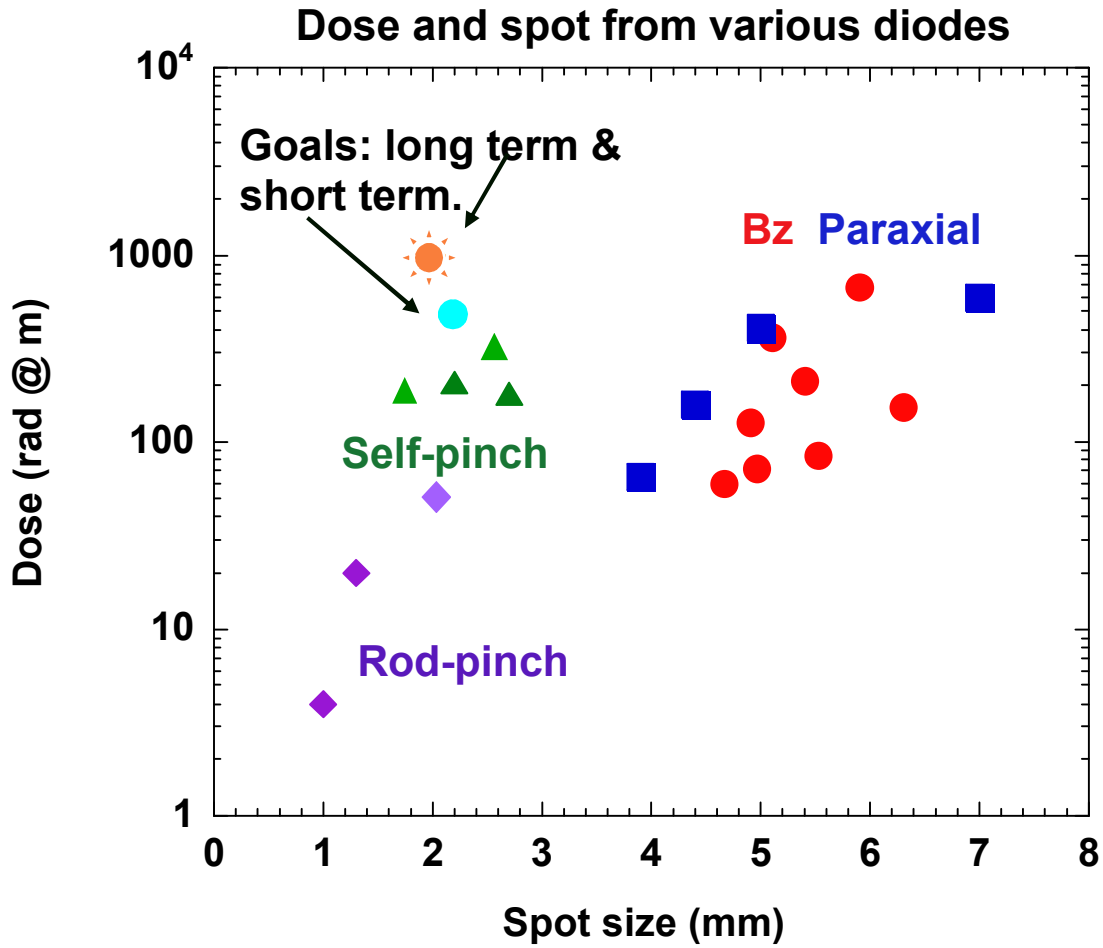
No Water

Minimize Oil

Closed geometry

Sandia National Laboratories

FY08 and beyond: X-ray source development towards a long term goal of 1000 rad@m from a 2 mm spot



Program plan: Demonstrate full scale source (400 rad@m, 2.7 mm spot) in 2008 and demonstrate scaling to the long term source by 2010 on RITS

Extra slides

Radiation Diagnostic Layout