

# A COMPACT, 1-MV, 6-kA RADIOGRAPHY SOURCE WITH A ONE-METER EXTENSION AND RIGHT-ANGLE BEND\*

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## Abstract

The Hybrid Radiation Source (HRS) is a compact pulsed power generator consisting of a commercial flash x-ray system that has been retrofitted with a custom front-end assembly, replacing a sealed glass tube<sup>1</sup>. A new high impedance (~120 Ohm) space-charge-limited (SCL) diode was fielded on the HRS. This diode produces a ~1.6 mm diameter x-ray spot suitable for high-resolution radiography<sup>2</sup>. This system has been modified by extending the diode from the generator with a one-meter-long vacuum transmission line. Also, the anode has been oriented to point perpendicular to the transmission-line axis. The extension and re-direction allow for the placement of the high-yield, small-spot-size, HRS radiographic source in previously unreachable locations. Parameters such as voltage, current, and source size have been measured and analyzed, allowing for optimization of the radiographic source. Discussion will also include circuit diagrams, simulation models, and diagnostic traces.

## I. RADIOGRAPHY SOURCE AND DIAGNOSTICS

The HRS uses a 1-MV Pulserad base and a scandiflash-like tube, as shown in Figure 1.

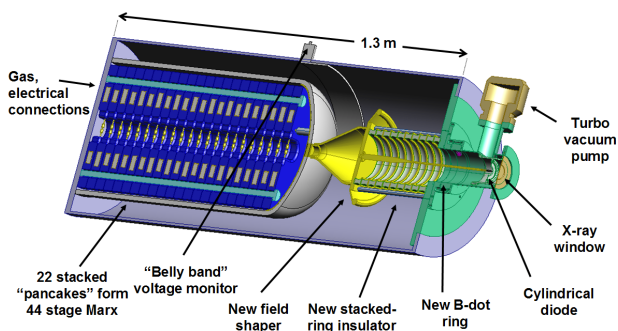


Figure 1. HRS radiography source system diagram.

The modifications to the base unit allow for reduced spot size, increased dose, and allow for an easily replaceable anode. New hardware on the device includes a field shaper, stacked-ring insulator, B-dot ring, and turbo vacuum pump.

### A. Vacuum Extension Hardware

A one-meter extension was added to the end of the unit, as shown in Figure 2. The outer conductor consists of two ISO-63 tubes, terminated in a shorter ISO-63 tube with two small windows 180° apart. The main advantage of the extension is to distance the diode from the generator, which can be useful in explosive experiments. If the extension were damaged, it is simple to repair, compared with a damaged generator which can be rather expensive and time consuming.

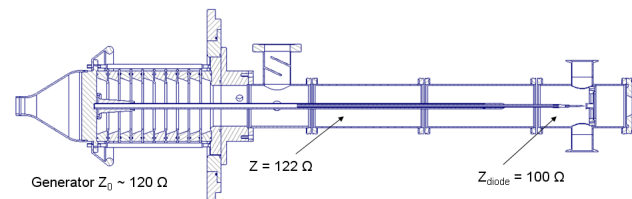


Figure 2. One-meter vacuum extension isolates generator from diode.

The main portion of the extension has a 3.8" O.D. and a 0.5" I.D, therefore the vacuum impedance is 122 Ω. At 1-MV, the field on the outer conductor is ~100 kV/cm, close to the emission threshold. Care was taken to minimize field enhancement on the outer conductor. Sharp edges were removed, and extra clamps were used on the tube joints to ensure good current contact.

Modeling and measurements show that the diode impedance decreases from ~160 Ω to 60 Ω during the x-ray pulse, and is ~100 Ω at the x-ray peak. Circuit modeling also shows that this extension has very little effect on the diode operation.

### B. Center Conductor Extension

Several types of metal tubes were tested to minimize center conductor droop. The first material tested was

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## Report Documentation Page

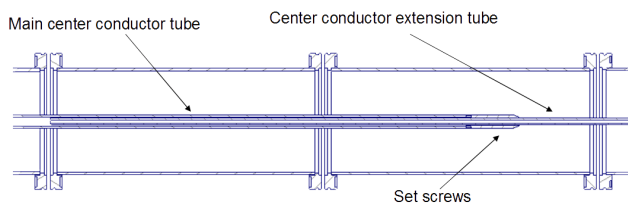
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14. ABSTRACT <b>The Hybrid Radiation Source (HRS) is a compact pulsed power generator consisting of a commercial flash x-ray system that has been retrofitted with a custom frontend assembly, replacing a sealed glass tube<sup>1</sup>. A new high impedance (~120 Ohm) space-charge-limited (SCL) diode was fielded on the HRS. This diode produces a ~ 1.6 mm diameter x-ray spot suitable for high-resolution radiography<sup>2</sup>. This system has been modified by extending the diode from the generator with a one-meterlong vacuum transmission line. Also, the anode has been oriented to point perpendicular to the transmission-line axis. The extension and re-direction allow for the placement of the high-yield, small-spot-size, HRS radiographic source in previously unreachable locations. Parameters such as voltage, current, and source size have been measured and analyzed, allowing for optimization of the radiographic source. Discussion will also include circuit diagrams, simulation models, and diagnostic traces.</b>					
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aluminum, in the form of both tubes and rods. Both types drooped more than 2 cm over a one-meter span, which is too much to be useful. A solid stainless steel rod was too heavy, while hollow stainless steel tubes with a 3.81-mm wall thickness drooped less than 2.0 mm for a one-meter span.

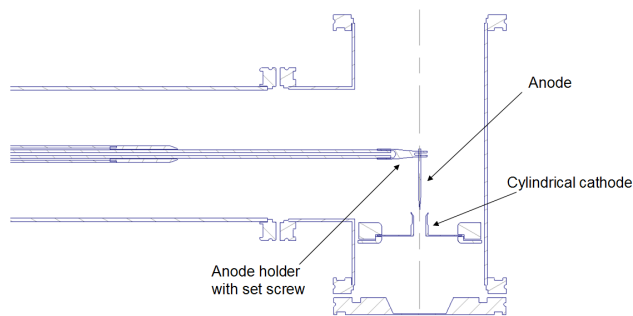
The final center conductor design consists of two parts, as shown in Figure 3. The first part is the aforementioned hollow stainless steel tube. A 6.35-mm diameter aluminum tube fits inside the larger rod and serves as an adjustable extension to provide a custom fit to the diode. Since the smaller tube is only extended 130 mm, it is a short enough distance that any droop can be corrected with set screws in the junction between the two rods. The aluminum tube has threads on the end for an anode holder to be mounted to the center conductor. The anode holder has a hole drilled on the center line for anode placement.



**Figure 3.** Main center conductor is made from a stainless steel tube with an inner adjustable extension tube.

### C. Right Angle Modification

A modification was made to the one-meter extension to allow the diode to be 90° from the center conductor axis. As shown in Figure 4, the anode holder has a hole that holds the anode at a right angle, and a set screw secures the anode in place. The anode can be moved forward or back to adjust the AK gap as necessary. Additionally, the diode can be rotated around the center axis 360° to accommodate the radiographic target. Precise 2-D alignment of the anode to the cathode is made by removing the flanges on both ends of the vacuum tee.

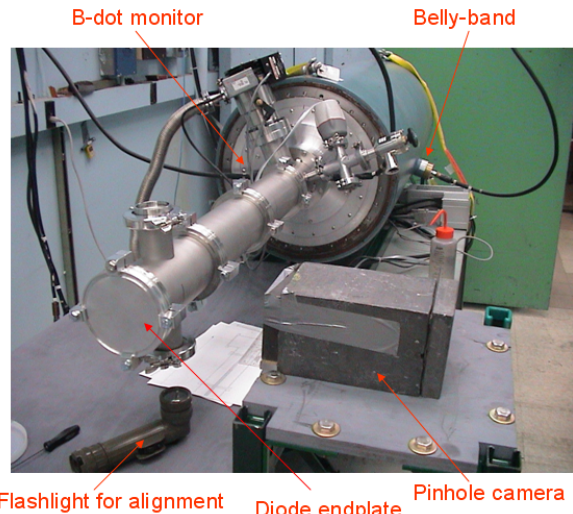


**Figure 4.** Right-angle bend with anode and cathode detail.

Asymmetric power flow due to the right angle extension was minimized by the large inductance of the anode and the cylindrical shape of the cathode.

### D. Electrical and Radiation Diagnostics

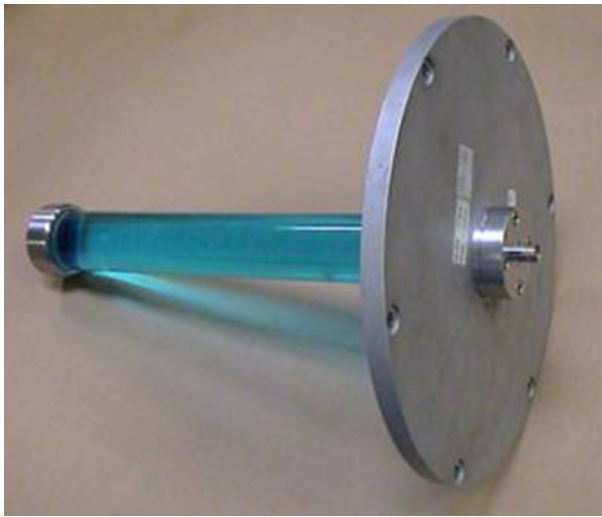
A number of electrical and radiation diagnostics were used to characterize the HRS source, as shown in Figure 5. The diode current was measured using two B-dot monitors mounted on a ring around the center conductor. The diode voltage was measured using the built-in “belly band” capacitive voltage monitor. The radiation dose was measured with a pocket dosimeter located 10° off axis at one meter. The radiation pulse shape was measured with a Si PIN diode positioned next to the dosimeter.



**Figure 5.** HRS with one-meter extension and diagnostics.

The source size was measured with both on-axis and off-axis diagnostics. A tungsten 2-D rolled-edge was used to measure the on-axis source size. The rolled-edge was placed on axis 30 cm from the anode tip, and a digital image plate was located 120 cm from the anode tip. The off-axis source size was measured using a pinhole camera with a 0.25-mm diameter pinhole. The pinhole was 20 cm from the anode, and 20.5 cm from the digital image plate.

Calibration of the B-dots was performed on a separate test stand, by sending a pulse through a pre-calibrated shunt. Once the B-dots were calibrated, they were installed in the B-dot ring and mounted on the front end of the HRS. The voltage monitor was calibrated using a dummy load resistor, as shown in Figure 6, which was installed as the center conductor. The current from the B-dots was averaged and used with the dummy load resistance to calibrate the voltage monitor. A slight inductance and droop correction was added to the voltage monitor to determine the voltage to the load.



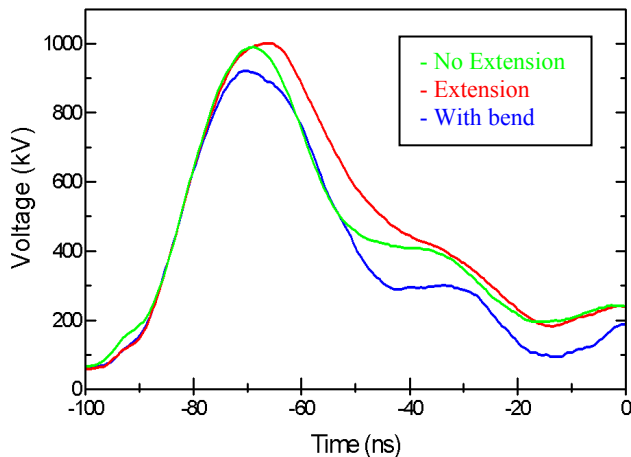
**Figure 6.** Dummy load resistor for voltage monitor calibration.

## II. HRS MODES OF OPERATION

The HRS was operated in three different modes: no extension, one-meter straight extension, and one-meter extension with right angle. The electrical and radiation diagnostics were compared for these three modes.

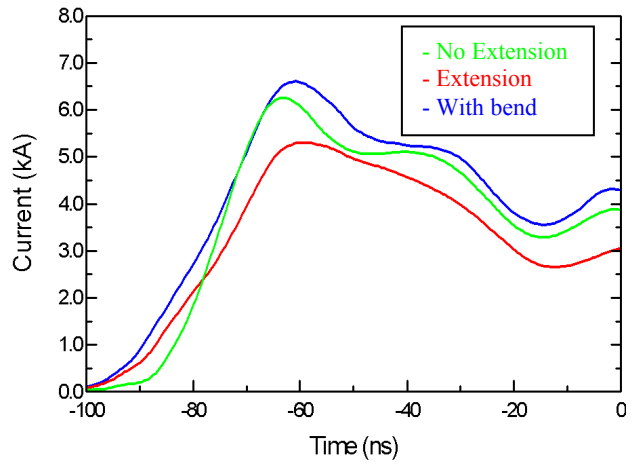
### A. Electrical Measurements

The voltage, current, and radiation are very similar for all three modes of operation. As shown in Figure 7, the peak voltage is nearly 1 MV with the extension and with a one-meter straight extension, and only slightly lower at 900 kV with the right-angle.



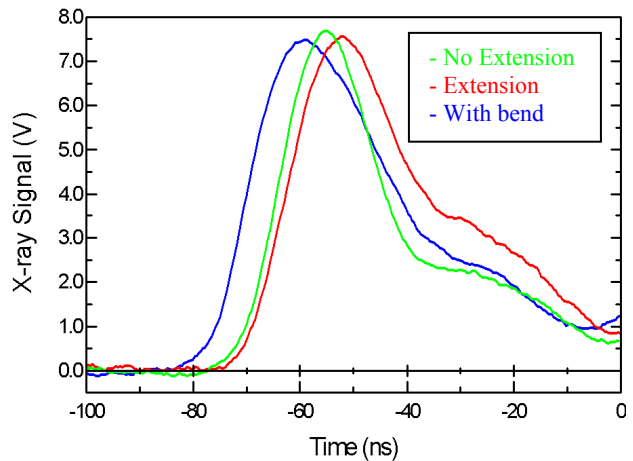
**Figure 7.** Voltage traces for modes with no extension, straight extension, and extension with right-angle bend.

The current traces, shown in Figure 8, peak at 5 to 6.5 kA for all three modes, with some slight time differences on the peaks.



**Figure 8.** Current traces from B-dot ring for all three cases.

The radiation traces, shown in Figure 9, also show similar shapes. The modes without the extension and with the right angle both have slightly higher yield than with the one-meter straight extension.



**Figure 9.** Radiation traces from the Si PIN diode  $10^\circ$  off axis at one meter for all three modes.

### B. Pinhole Camera Imaging

Side-viewing pinhole camera images were compared for the three modes of operation. The pinhole camera images are shown in Figure 10. For all three modes, the images are virtually identical.

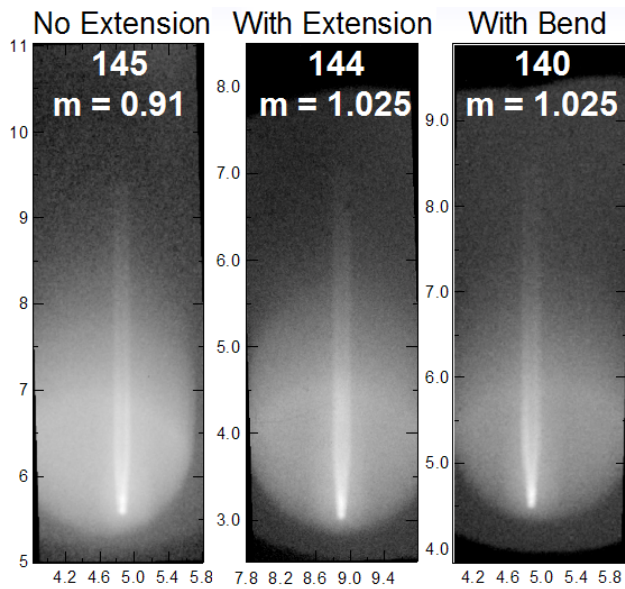


Figure 10. Side-viewing pinhole camera images.

Axial intensity distributions along the anode rod are shown in Figure 11. The axial emission is unchanged by adding the extension and the right-angle bend.

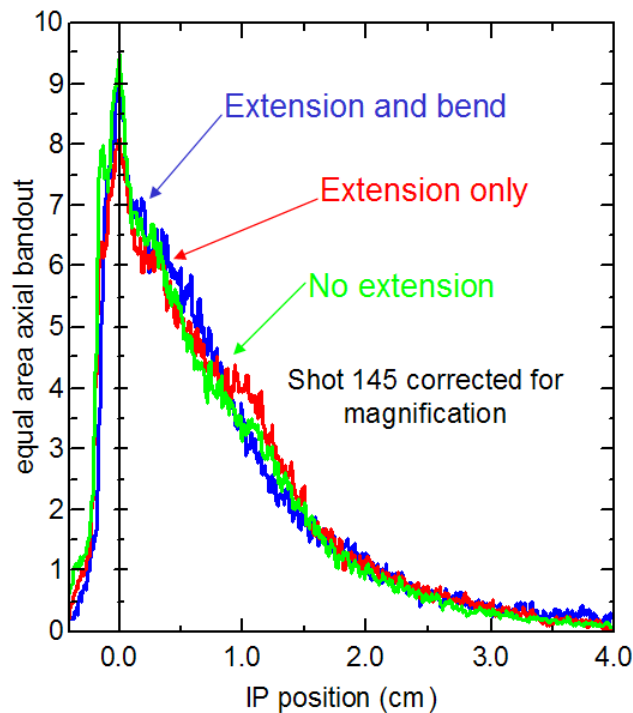


Figure 11. Axial intensity distributions from pinhole camera images.

### C. Source Size Comparisons

The horizontal and vertical edge spreads are extracted from scans of the rolled-edge image-plates and are used to determine the on-axis source size. A typical scan is shown in Figure 12, and edge spreads from the horizontal and vertical bands are shown in Figure 13.

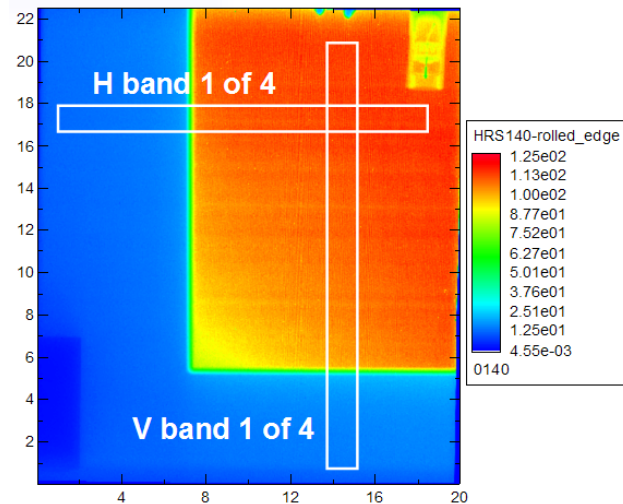


Figure 12. Rolled-edge image-plate scan with horizontal- and vertical-band areas highlighted.

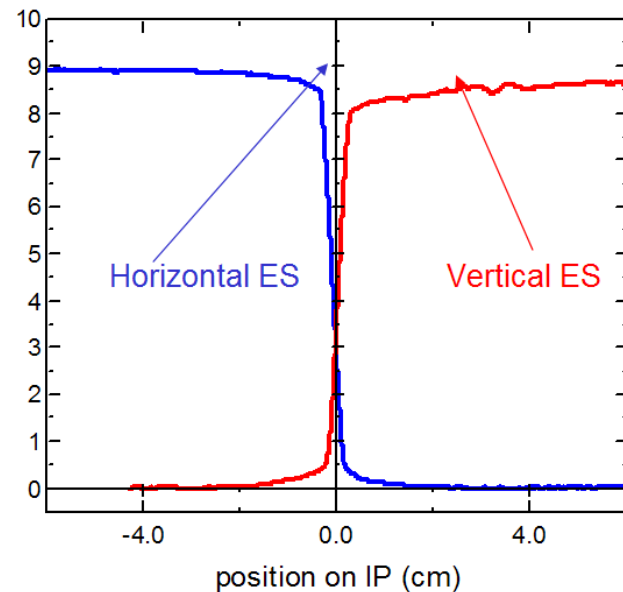
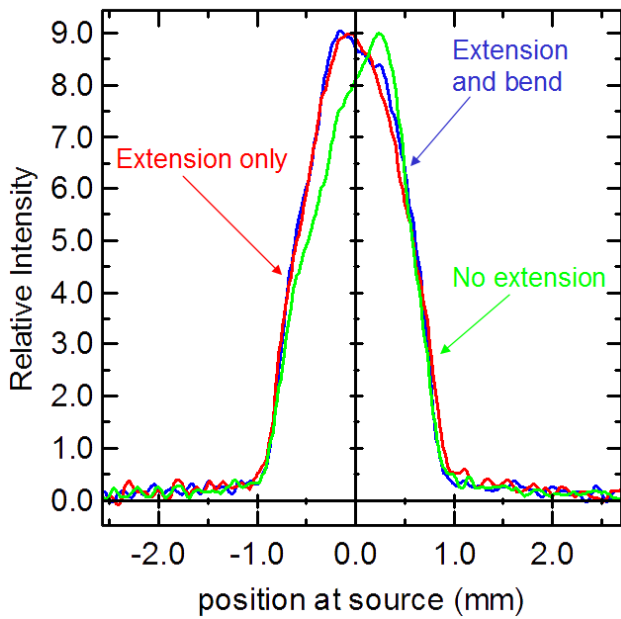


Figure 13. Horizontal and vertical edge-spread measurements from image plate.

The derivative of the edge spread is the line spread, which is used to calculate the source size. A magnification correction is applied to give the line spread at the source. A comparison of the source sizes for all three modes is shown in Figure 14. The average of the horizontal and vertical line spreads is used for these comparisons. The values of the source sizes listed in Table 1 indicate that the size is unchanged by adding the one-meter extension and the right-angle bend.



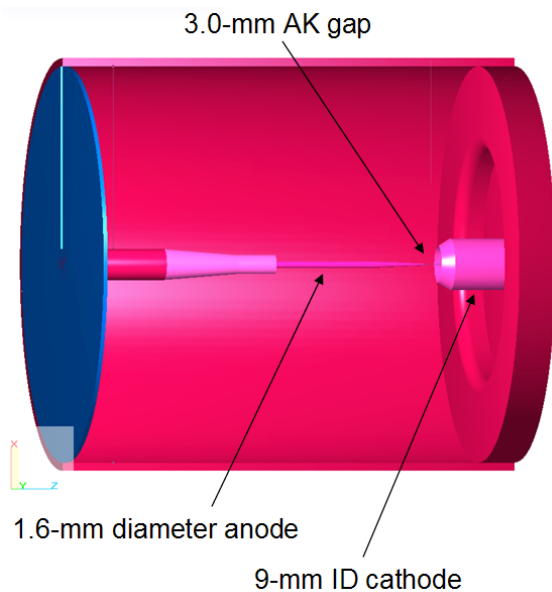
**Figure 14.** Source-size comparisons based on line spreads.

**Table 1.** Source Size Measurements

	Horizontal (mm)	Vertical (mm)
With Right-Angle Bend	1.69	1.61
Extension Only	1.61	1.61
Without Extension	1.57	1.72
All spot sizes use AWE definition		

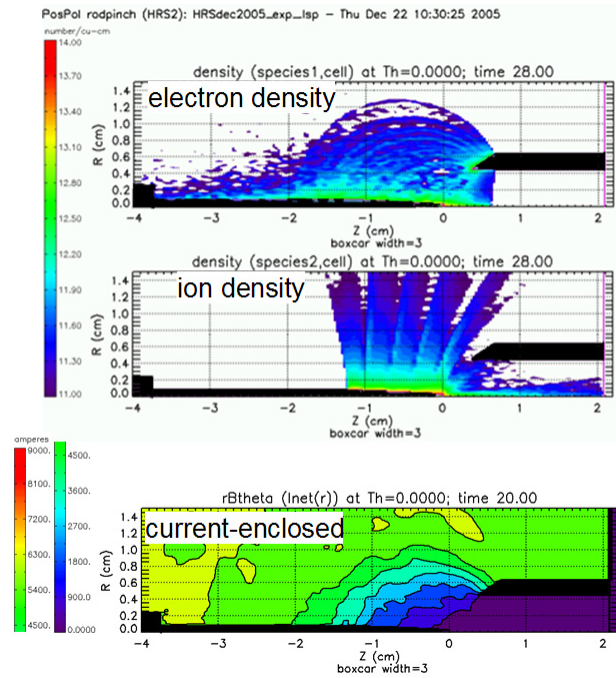
#### D. PIC Simulations using LSP

Particle-in-cell (PIC) simulations using LSP [3] were performed to help understand the influence of ion space-charge on the diode impedance behavior. Figure 15 shows a diagram of the model used for the simulations.



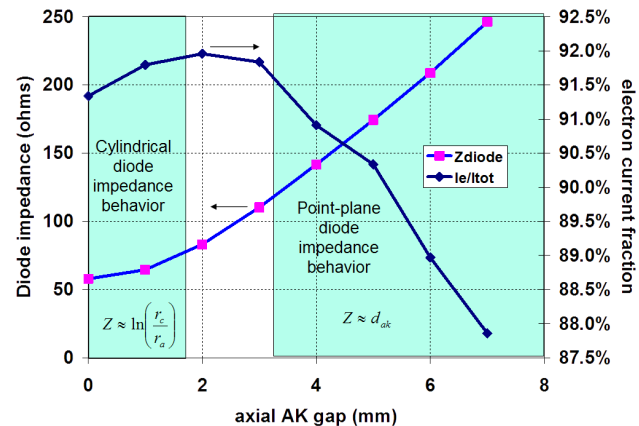
**Figure 15.** Model used for PIC simulation using LSP.

The electron density, ion density, and current-enclosed contours plots are shown in Figure 16. They are representative of steady-state behavior in the diode at 1 MV for a case in which the electrons are emitted from only the angled portion and ions are emitted from only the tapered region of the anode. Electrons follow potential field lines while the ions stream radially outward; it is conjectured that the large ion-space-charge near the surface of the anode is what allows the enhancement of the electron current above that expected simply from bipolar flow.



**Figure 16.** Results of PIC simulations with electron density, ion density, and current enclosed.

Figure 17 summarizes a series of PIC simulations with different AK-gaps, run to steady-state behavior at 1-MV.



**Figure 17.** Gap scan using PIC with steady-state voltage at 1-MV.

The scan shows semi-classical impedance behavior, with relatively-stable ion currents over a large impedance variation. Note that an impedance variation from 50  $\Omega$  to 200  $\Omega$  only has a 3% variation in the electron current fraction. With an AK gap of less than 2 mm, the diode with show cylindrical impedance behavior. An AK gap of greater than 3 mm will tend to show a point-plane diode impedance behavior.

### III. SUMMARY

A one-meter extension and right-angle bend have been successfully fielded on the HRS. The voltage, current, and radiation traces are similar with and without the one-meter extension and the right-angle bend. Side-viewing pinhole camera images show similar axial intensity distributions. Rolled-edge measurements show that the source size is unchanged by adding the extension and the right-angle bend.

PIC simulations show semi-classical impedance behavior, with relatively-stable ion currents over a large impedance variation. Ion space charge enhances electron current by more than five times.

Future work on the HRS will focus on obtaining smaller source sizes. The current anode diameter is 1.6 mm, with a 1.6-mm source size. Obtaining a size of less than 1.0 mm may be possible with smaller diameter rods.

### IV. REFERENCES

- [1] R. J. Allen, G. Cooperstein, F.C. Young, J.W. Schumer, D.D. Hinshelwood, D. Mosher, D. Holmberg, S.E. Michell, "Characterization and Optimization of a Compact, 1-MV, 6-kA Radiography Source," 14th International Pulsed Power Conference Digest of Technical Papers, June 15-18, 2003, pp. 883-886.
- [2] G. Cooperstein, R.J. Allen, R.J. Commisso, B.M. Huhman, D. Mosher, P.F. Ottinger, J.W. Schumer, S.B. Swanekamp, F.C. Young, "A High-Impedance, High Resolution, 1-MV Radiography Diode," 33rd IEEE International Conference on Plasma Science Conference Records - Abstracts, June 4-8, 2006, p. 283.
- [3] LSP is a software product of ATK Mission Research, Albuquerque, NM 87110.