SAND2009-3971C

CYGNUS SOURCE EMISSION *

D. Nelson[ξ], M. Burke, J. Chael, E. Ormond
Sandia National Laboratories, PO Box 238, Mail Stop 944
Mercury, NV 89023 USA

S. Cordova, I. Molina
Sandia National Laboratories, PO Box 5800, Mail Stop 1176
Albuquerque, NM 87185-1193 USA

Abstract

The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources each with a dose rating of 4-rad at 1 m, and a 1-mm diameter spot size. The development of the rod pinch diode was responsible for the ability to meet these criteria. The rod pinch diode in a Cygnus machine uses a .75-mm tungsten diameter tapered anode rod, which extends 10-mm through a 9-mm diameter cathode aperture. The electron beam born off the aperture edge can self-insulate and pinch onto the tip of the rod, creating an intense, small x-ray source. The Cygnus sources are utilized as the primary diagnostic on numerous experiments which include high-value, single-shot events. In such an application there is an emphasis on reliability and reproducibility. A shot-to-shot evaluation of the machine performance will be conducted and evaluated using an x-ray pinhole camera.

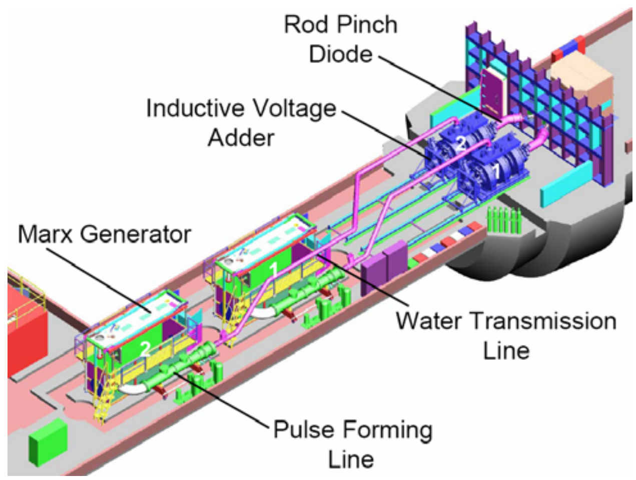


Figure 1. Layout of Cygnus machines in an experiment facility.

I. GENERAL SYSTEM OVERVIEW

The machines were specially designed to fit in an underground tunnel laboratory and therefore were arranged in a linear fashion. Other requirements are collimated beams with a spatial separation of 60 degrees, and independently adjustable temporal separation. The layout of both machines in the underground facility is shown in Figure 1. The major components of each Cygnus source are: Marx generator, Pulse Forming Line (PFL), Water Transmission Line (WTL), Inductive Voltage Adder (IVA) which uses a Vacuum Insulated Transmission Line (VITL), and Rod Pinch Diode. Both machines have identical components except that the Cygnus 2 WTL is longer than the Cygnus 1 WTL.

II. ROD PINCH DIODE OVERVIEW

The rod pinch diode used on the Cygnus machines uses end point energy of 2.25MeV. They are capable of high-resolution flash radiography with a pulse length of 50ns. The diode consists of a .75mm diameter Tungsten (W) tapered anode rod which extends 10mm through a 9mm diameter 3mm thick Aluminum (Al) aperture. The majority of the current in the electron beam is created on the edges of the cathode aperture and when properly configured, the electrons will self insulate, travel down the extension of the rod, and pinch onto the tip of the rod [1]. A detailed illustration of the Cygnus rod pinch diode is shown in figure 2.

As evidenced by the radiograph (see figure 3), an unwanted condition is displayed where a second source of x-rays appear at the rod holder and for future reference

* Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

ξ email: dsnelso@sandia.gov

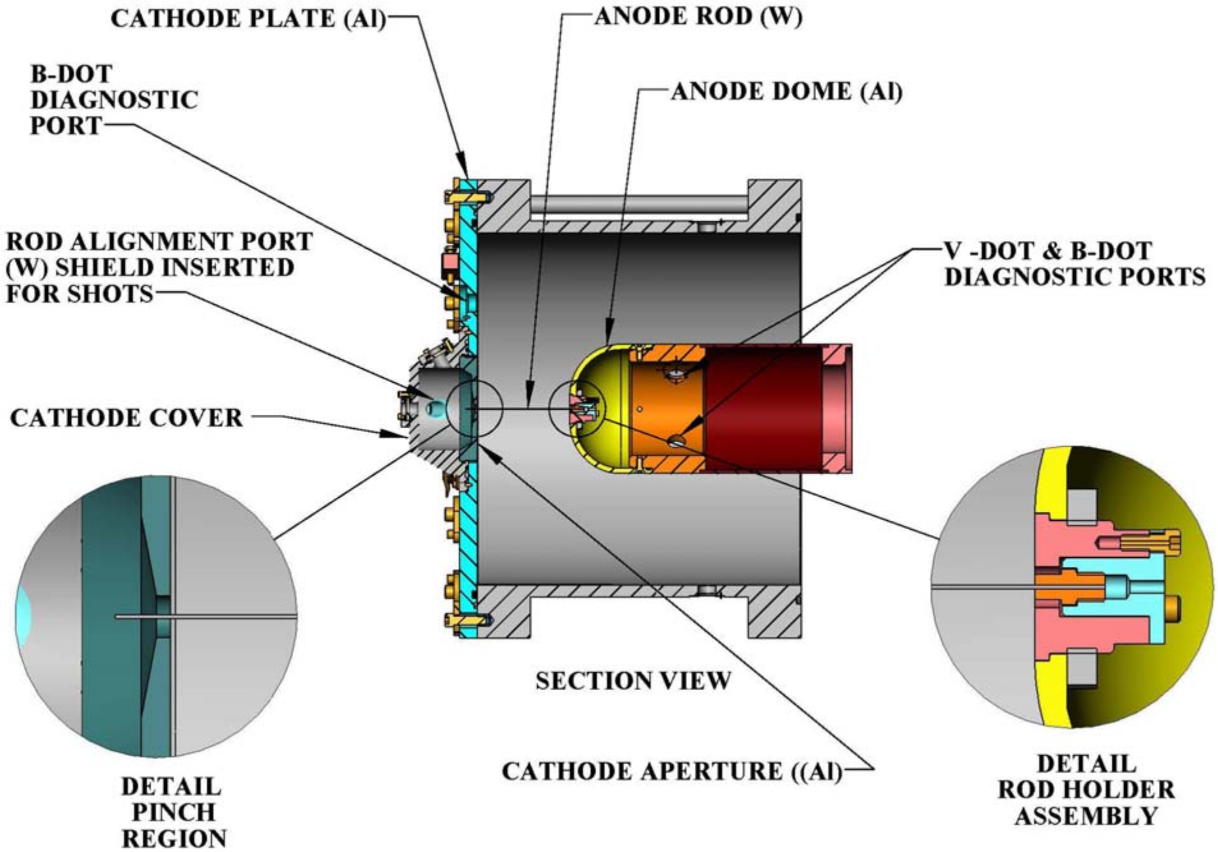


Figure 2. Cygnus rod pinch diode assembly. Detailed pinch region showing 3mm thick Al aperture and W rod with a 10mm extension. Detailed rod holder region showing the standard 3 piece stainless steel holder assembly (gray-nut, pink-cylinder and turquoise-insert). The orange graphite piece has a tungsten anode rod friction fit into it and this rod graphite sub assembly is threaded and screwed into the 3 piece stainless steel holder.

will be labeled spot2. The rod pinch area will be labeled spot1. This undesired second x-ray source creates blur, reducing image clarity which negates the original intent of a high resolution source.

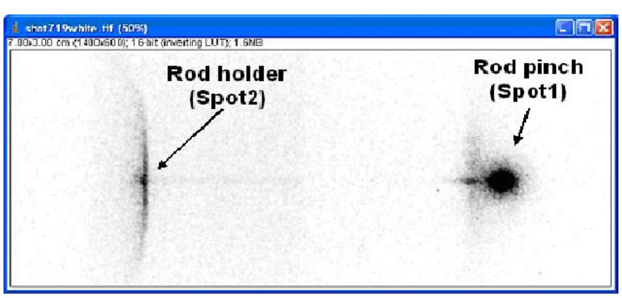


Figure 3. Rod pinch diode radiograph displaying the unwanted x-rays at rod holder area (spot2) and the desired x-rays at rod pinch area (spot1).

The unwanted x-rays at spot2 are thought to be either a second bremsstrahlung source created via free electrons or an indirect source (scatter) created by the spot1 x-rays hitting the rod holder materials. Two possible solutions one identify and eliminate any unwanted electron source feeding the rod holder and two reducing the foot print of the rod holder assembly and substituting rod holder materials with ones which are less dense. The first condition, locating and eliminating the source of the rogue electrons, will be addressed. Possible electron sources are as follow:

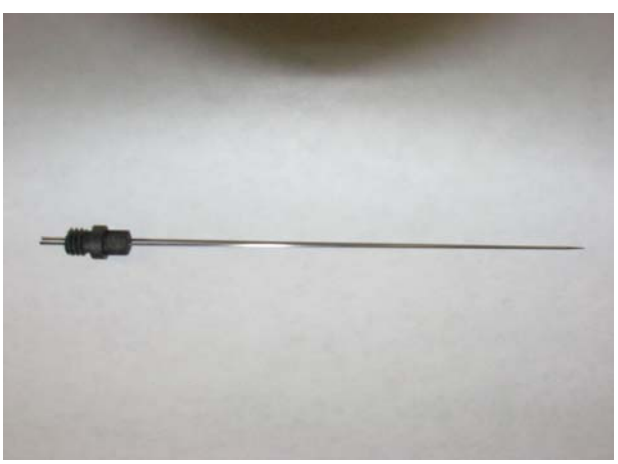
- Aluminum cathode plate
- Aluminum cathode aperture
- Aluminum or Stainless steel B-dot diagnostic housings on cathode plate and surrounding area
- Upstream edge of aperture on the cathode aperture

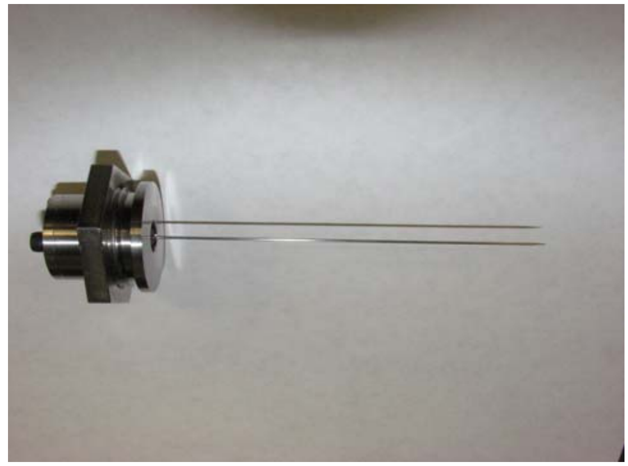
The materials listed in the first three items will be anodized to stop any electrons born off of their surfaces.

The 4th item will be addressed by putting a radius on the aperture on the upstream side and anodizing the entire upstream side of the cathode aperture including the radius. Examples of some of these items are shown in figure4.

Figure 4. Eliminating possible electron sources by anodizing individual parts. Cathode plate and 3 B-dot diagnostics before and after anodizing. Diagnostic port plugs before and after anodizing. Anodized cathode aperture.

The second condition reducing scatter created by the spot1 x-rays hitting the rod holder materials will be addressed by substituting existing rod holder materials with a materials having a lower Z component and by reducing the cross sectional area of the material. The existing rod holder assembly consists of 3 stainless steel pieces and a graphite holder which screws into the 3 piece stainless assembly. The stainless steel assembly (Z=26) has a 17 cm^3 cross sectional area. This stainless steel assembly will be replaced with a single Aluminum disk (Z=13) with a 2.35 cm^3 cross sectional area. The existing graphite rod holder and tungsten rod will be used for each case. The standard Tungsten rod is friction fit into the graphite rod holder. The components are shown in figure 5.





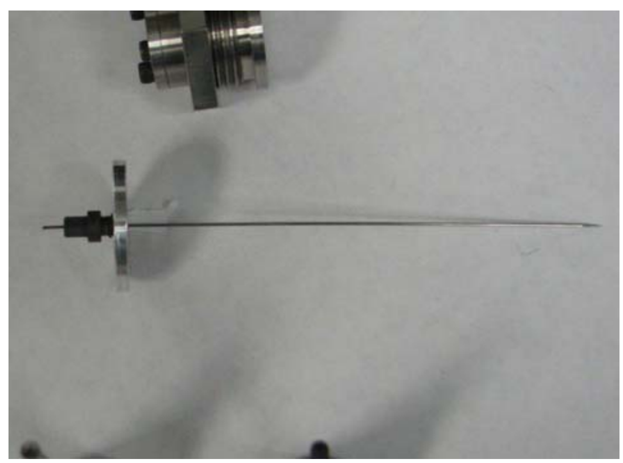


Figure 5. Four pictures of the components which make up the two different anode rod holder assemblies. (1) W rod friction fit into the graphite holder to be used with both the existing and modified holder assembly, the OD of the graphite holder is threaded. (2) W rod and graphite holder screwed into the 3 piece stainless steel rod holder assembly. (3) 3 piece stainless steel assembly broken out with attaching screws also shown W rod inserted into graphite holder. (4) W rod and graphite holder screwed into Al rod holder flush to the Dome. Not shown graphite holder sticking out.

Table 1 Experiment matrix

Test	No changes	Anodized cathode plate	Anodized B-dots	Anodized cathode aperture (anodized on the upstream side)	Anodized cathode aperture with (anodized and aperture radius on the upstream side)	3mm thick aluminum holder (graphite stick out)	3mm thick aluminum holder (graphite flush)
Baseline	X						
Mod1		X					
Mod2		X	X				
Mod3		X	X	X			
Mod4		X	X		X		
Mod5		X	X			X	
Mod6		X	X				X

III. EXPERIMENT OVERVIEW

It was desired to look at each condition individually to identify which condition has the greatest effect on the soft x-rays, but due to outside conditions the time allotted to the testing was reduced. This created a situation where a change to the original plan was necessary in order to accomplish the entire test series; therefore, some modifications were tested concurrently. An experiment matrix is shown in Table 1. The 1st column labeled test puts an identifier for each test. The 2nd column labeled No changes is defined as the shots done and radiographs taken before any changes where made. The 3rd column labeled anodized cathode plate is the test preformed with the cathode plate anodized. The 4th column label anodized b-dots is the test performed with the 3 b-dot current diagnostics mounted on the end plate housings anodized. This had do put in separately because anodized b-dots were not available for Cygnus2. The 5th column labeled anodized aperture (anodized on the upstream side) is the tests performed with the cathode aperture anodized on the upstream side. The 6th column labeled anodized aperture with (anodized and aperture radius on the upstream side) is the tests performed with the cathode aperture was radiused and anodized on the upstream side. The 7th column labeled 3 mm thick Aluminum holder (graphite stick out) is the tests performed using 3 mm x 3.175 cm aluminum holder with the graphite rod sub assembly mounted from the front which causes the graphite to rod junction to sticking out from the surface of the anode dome. The 8th column labeled 3 mm thick Aluminum holder (graphite flush) is the tests performed using 3 mm x 3.175 cm aluminum holder with the graphite rod sub assembly mounted from the back side where the graphite to rod junction to flush to the surface of the anode dome.

IV. EXPERIMENT DIAGNOSTIC

Hardware

The two pinhole cameras used for the diagnostics are designated by their color white or brass. The specifications for both are listed in table 2.

Table 2 Pinhole camera specifications

Camera	Aperture diameter/length	F length cm/“
White	1.2 mm	40.64 cm/16”
Brass	1.58 mm/5.1 mm	31.5 cm/12.4”

The white pinhole camera on Cygnus 1 was positioned at two different locations during the testing. The white camera’s position was essentially perpendicular to the rod of the Cygnus machine, with a field of view which includes the anode rod holder, cathode aperture, and end of the rod.

The brass camera was positioned 37 degrees off perpendicular of the rod and on the same horizontal plane 41.75 inches off the floor. The brass camera was positioned with a field of view which contains the entire rod and dome. The pinhole camera locations are summarized in Table3. To prevent saturating the image plate, a 1.25 cm thick piece of tungsten was rigged to the front of the window mount on the cathode cover of Cygnus2. A 1.25 cm thick solid piece of tungsten was later made to the dimensions of the cathode cover window frame. This window is used to align the rod needle during rebuild. After the rod is aligned, nylon screws are used to mount the tungsten shield in place of the aluminum window frame. This tungsten piece provided shielding as well as a fiducial via its dimensions and the locations of the mounting holes. The view of the brass camera allows for an even intensity comparison of the spot1 and spot2 locations. This view allows for the same attenuation (Al cathode plate with exception of the ½ inches of W on the window) this is an improvement over the white pinhole cameras view which is tainted by the different diameters, thicknesses and angles between the camera and the areas of interest. For the intent of this experiment both cameras views provide useful information A top view along with example radiographs are displayed in Figures 6&7..

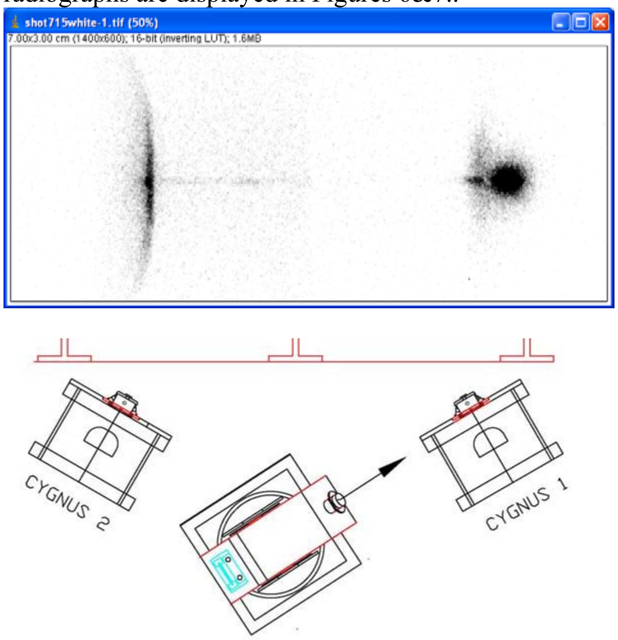


Figure 6. White camera radiograph showing the rod pinch area (spot1) and the rod holder area (spot2).

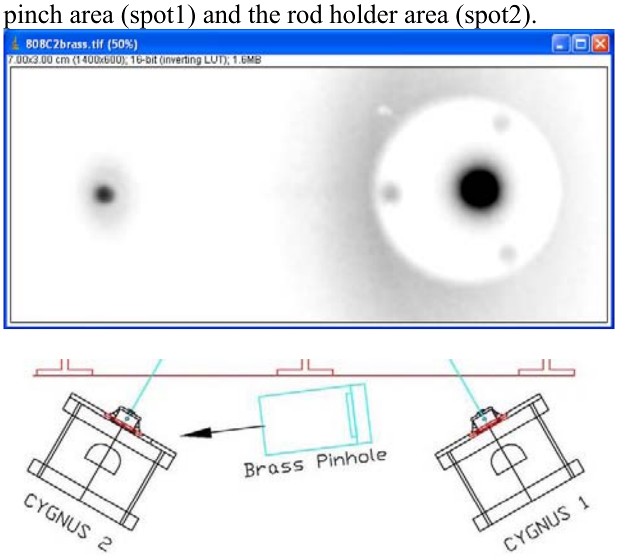


Figure 7. Brass camera radiograph showing 1.25cm thick tungsten window mount filtering the x-rays from the rod pinch (spot1) allowing the viewing of both the pinch and the holder area (spot2) and acts as a fiducial.

Table 3. Pinhole cameras orientations.

Machine	Pinhole camera	Position degrees off normal	Angle in degrees
Cygnus1	White	1º	27.3º
Cygnus1	White	3º	32º
Cygnus2	White	3º	32º
Cygnus2	Brass	37º	0º

Analysis System

The images from the pinhole cameras are recorded onto Fujifilm imaging plates (IP) model number BAS MS. An IP is a radiation energy memory type two-dimensional sensor, which has an image recording layer consisting of polyester base material densely coated with accelerated phosphorescent fluorescent material of fine crystals. An IP accumulates and stores radiation energy while it is exposed.

The Fujifilm FLA7000 fluorescent image analyzing system was used to read the IPs. The recording surface of an exposed IP is scanned with a laser beam inside the FLA-7000 and emits fluorescent light according to the exposure level.

A photo-multiplier tube (PMT) detects the fluorescent light and converts it into electric signals. A radiation image recorded on the IP during exposure is read as digital image information at the maximum resolution of 25 µm per pixel (40 pixels/ mm) and recorded in the analyzer unit.

The settings used during the IP readings on the Fujifilm FLA7000 Fluorescent Image Analyzing system are as follow:

- Sensitivity: s4000–Voltage levels to the photo multiplier tubes which controls reading sensitivity.
- Pixel size: 50um – Scanner resolution
- Latitude:L5–Dynamic range (2 ranges available L5=16-bit or L4=8-bit)

Analysis software

NIH image is a public domain image processing and analysis program for the Macintosh. It was developed by the research services branch of the national institute of mental health (NIMH), part of the national institute of health (NIH). ImageJ, also in the public domain, is a Java program inspired by Image that runs anywhere. ImageJ version 1.410 software was used to analyze the pinhole images. The imageJ software can be downloaded @ http://rsb.info.nih.gov/ij/

V. RESULTS

Image data

The scanned image is cropped using a rectangle (7.00 cm wide by 3.00 cm high), which is defined in a macro. This defined rectangle saved in a macro is used on every subsequent image establishing consistency when determining the areas of interest. The new image is smoothed using the Gaussian Blur filtering routine with a Sigma radius of 4.00. Various filtering methods were evaluated and this particular filter demonstrated the best results with the least amount of over correction.

The maximum points were found using a find maximum feature. Inputting the noise tolerance parameter to a threshold where the rod pinch and rod holder would only be identified. These points were recorded with the analyzed\measure tool. Macros for each of the areas of interest, spot1 (end of rod) and spot2 (rod holder), were run and each rectangle was centered about their respective area using the maximum point locations recorded in the previous section. This establishes consistency of the measurement by using a defined area centered about the location of the maximum point of each area. The mean of these areas are recorded using the analyzed\measure tool, which records the values in a spreadsheet. The cropped and filtered image is saved and the maximum points and intensity mean of the area are saved.

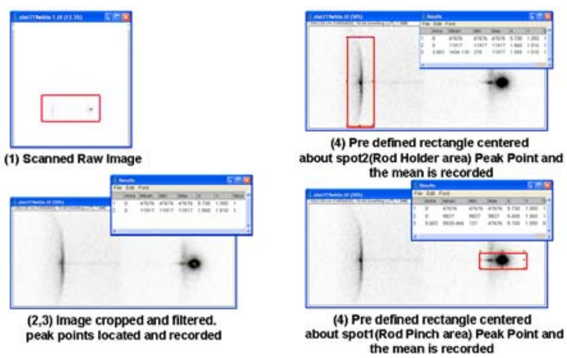


Figure 9. Steps utilizing ImageJ software to make consistent measurements for the modification comparison.

Image analysis

The data processed in ImageJ is analyzed comparing the average intensity of each area spot1 and spot2. A figure of merit (FOM) is calculated as the ratio of spot1 (rod end) to spot2 (rod holder). The data is plotted using Microsoft Excel and is shown in figures 10-13. The average FOM for each condition is recorded in Table 4.

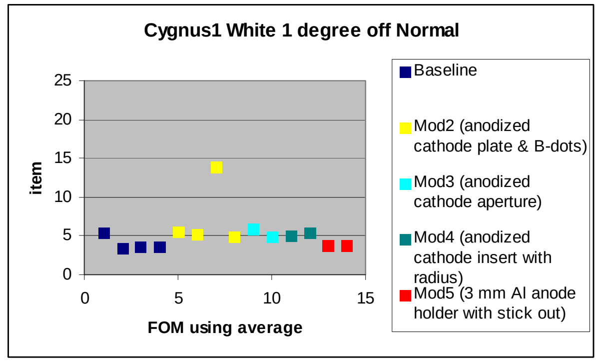


Figure 10. White pinhole 1° off normal viewing Cygnus1

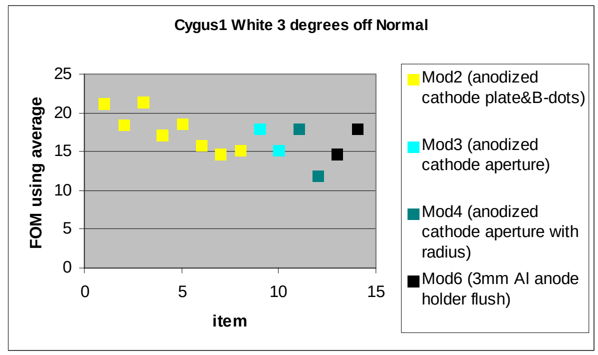


Figure 11. White pinhole 3° off normal viewing Cygnus1

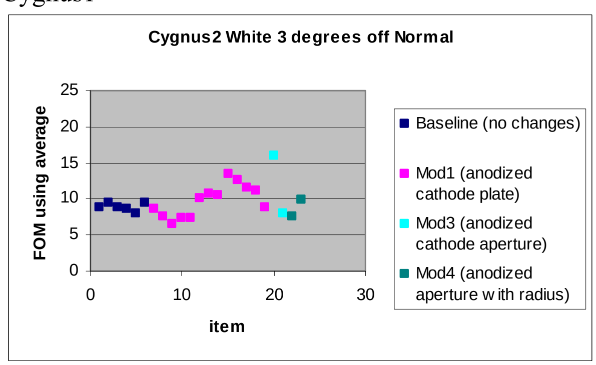


Figure 12. White pinhole 3° off normal viewing Cygnus2

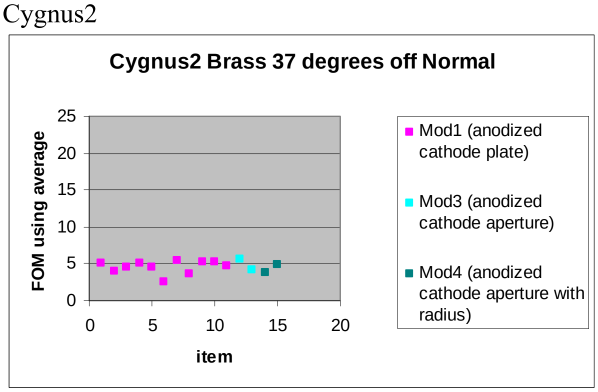


Figure 13. Brass pinhole 37° off normal viewing Cygnus2

Table 4. FOM average for each condition.

Test	Cygnus1 White 1º	Cygnus1 White 3º	Cygnus2 White 3º	Cygnus2 Brass 37º
Baseline (no changes)	**4**	**na**	**9**	**na**
Mod1 (anodized cathode plate)	**na**	**na**	**10**	**5**
Mod2 (anodized cathode plate& b-dots)	**7**	**18**	**na**	**na**
Mod3 (anodized aperture)	**5**	**17**	**12**	**5**
Mod4 (anodized aperture with radius)	**5**	**15**	**9**	**4**
Mod5 (Al holder with stick out)	**4**	**na**	**na**	**na**
Mod6 (Al holder flush)	**na**	**16**	**na**	**na**

VI. SUMMARY, CURRENT and FUTURE WORK

When it was observed that there is an apparent second source of x-rays at the rod holder and the attempts to eliminate or reduce them were had little effect, a second set of tests were conducted where the geometry of the rod holder was changed to move the junction of the rod to rod holder closer to the aperture. This shape resembles a Hershey kiss. There were only two tests conducted with this geometry one holder was made of graphite and the second was made of aluminum. The main x-ray emission at the spot2 location did move with the holder rod junction. (See figures 14, 15 and 16).

Although changing the material and surface finish (anodization) showed little effect on the FOM, the results cultivated new direction for future experiments After demonstrating that the x-rays at the rod holder moved with the extension of the interface, a third set of tests are planned which will extend the rod holder junction through the aperture.

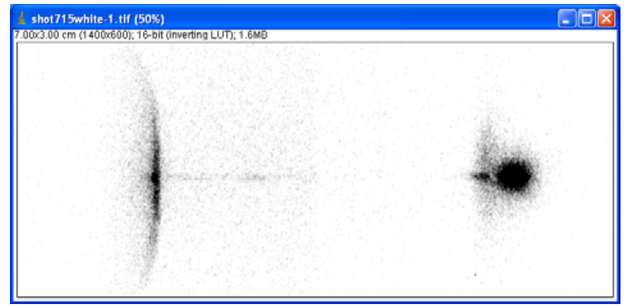


Figure 14. Cygnus1 white pinhole camera using the standard stainless steel holder with graphite section of holder assembly flush.

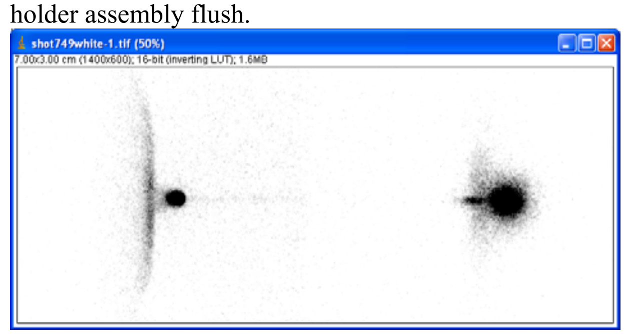


Figure 15. Cygnus1 white pinhole camera using the 3mm Al holder with graphite section of holder assembly sticking out.

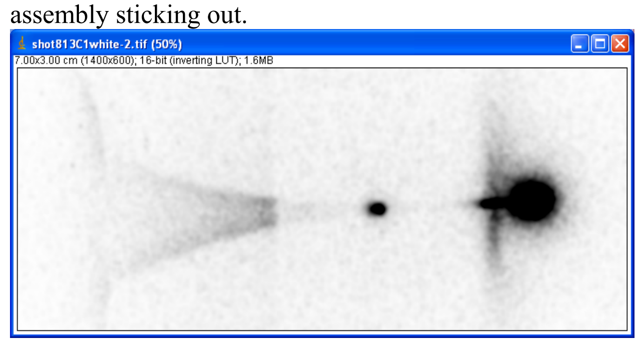


Figure 16. Cygnus1 white pinhole camera using an aluminum Hershey kiss holder. Note the bright spot at the rod to rod holder interface in the middle of the radiograph.

The rod holder will resemble a straw and the rod will be shortened. This design will consist of a low Z hollow tube where different materials (ie Au, Pt, W, etc.)5mm long will insert into the tip. See figure 17.

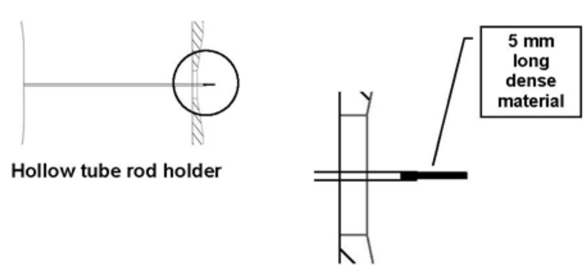


Figure 17. Hollow tube rod holder geometry

A pinhole camera dedicated to Cygnus is being constructed and this diagnostic should become a permanent part of the Cygnus diagnostic suite. The images will be utilized both as Cygnus source verification as well as a tool to explain image anomalies.

Other groups are also addressing the undesired second source of x-rays. Successful rod pinch shots on RITS have demonstrated a bent anode rod which allows emissions at the holder to be off the line of sight. This will reduce the intensity of the secondary x-rays down the line of sight to the imaging cameras.

VII. REFERENCES

UPDATE

[1] P.R.Menge et al., "Rod Pinch radiography source optimization at 2.3MV,"???? in Proceedings of the 13th IEEE International Pulsed Power Conference, IEEE Cat. No. 01CH37251, 2001, pp. 591-595.

[1] D.Weidenheimer et al., "Design of a driver for the Cygnus x-ray source," in Proceedings of the 13th IEEE International Pulsed Power Conference, IEEE Cat. No. 01CH37251, 2001, pp. 591-595.

[2] J.R. Smith et al., "Performance of the Cygnus x-ray source," in Proceedings of the 14th International Conference on High Power Particle Beams, ISBN 0-7354-0107-1, 2002, pp. 135-138.

[3] V. Carboni et al., "Pulse power performance of the Cygnus 1 and 2 radiographic sources," in Proceedings of the 14th IEEE International Pulsed Power Conference, IEEE Cat. No. 03CH37472, 2003, pp. 905-908.