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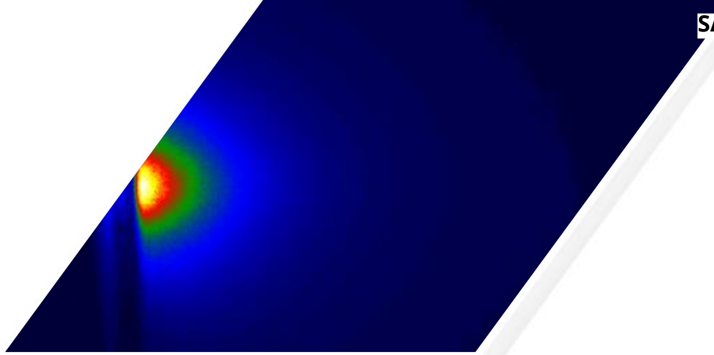

USING SPHINX ACCELERATOR TO MEASURE HEAT TRANSFER IN METAL FOILS

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ABSTRACT

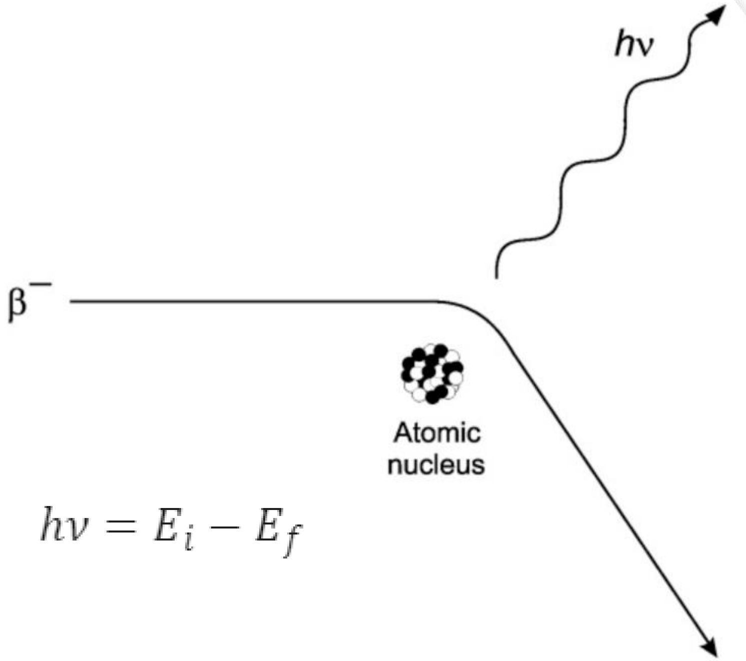
Experiments on the SPHINX accelerator at Sandia National Laboratories (SNL) looked at electron beam heating of metal foils used in Bremsstrahlung flash x-ray production. Titanium and tantalum foils were exposed to electron beam energies of up to 2MeV to determine surface heating. As part of the experiment, the x-ray dose profiles were characterized using a scintillating panel (EJ-230) placed both perpendicular and parallel to the photon beam. This was followed by direct electron beam imaging using a fast-gated ICCD camera and a fused silica Cherenkov witness plate. Once characterized, the foil was directly measured using a mid-wave (3-5 micron) infrared camera (MWIR) to determine the peak surface temperatures and spatially-resolved thermal profiles. Additionally, an IR pyrometer was used in a single wavelength mode (2.3 μm) to determine localized surface temperatures as well. Results are compared with calculations of surface temperatures obtained from e-beam energy depositions combined with the specific heats of the foils. This is the first attempt to directly measure the surface temperature profile on a short-pulse (10 nanoseconds) flash x-ray source using MWIR imaging. These data are directly relevant for Monte Carlo/Integrated Tiger Series electron/photon transport code results being used in the design of future Bremsstrahlung sources such as CREST.

MISSION

- Using the SPHINX linear particle accelerator, we conducted a series of shots to characterize foil heating (Titanium foil, 4 mil/101.6 microns and Tantalum foil, 5mil/127 microns) from an electron beam.
- We want to determine if we produce enough temperature to stimulate ion emission (~400^{0} C), which can cause beam focusing, increase current density, and cause physical damage to the diode.
- We also want to define the methodology to measure the thermal properties of SPHINX. We hope to apply the methods used here to the future CREST accelerator as well as other accelerators like SATURN, HERMES III, and the Z Machine.
- We operated SPHINX in both Bremsstrahlung (BREMS) and electron-beam mode.
  - BREMS – Refers to the use of a high-Z material in the beam path in order to produce X-ray radiation.
  - E-Beam – Allows electron beam to propagate through a thin foil (typically titanium). E-beam produces little X-ray radiation.

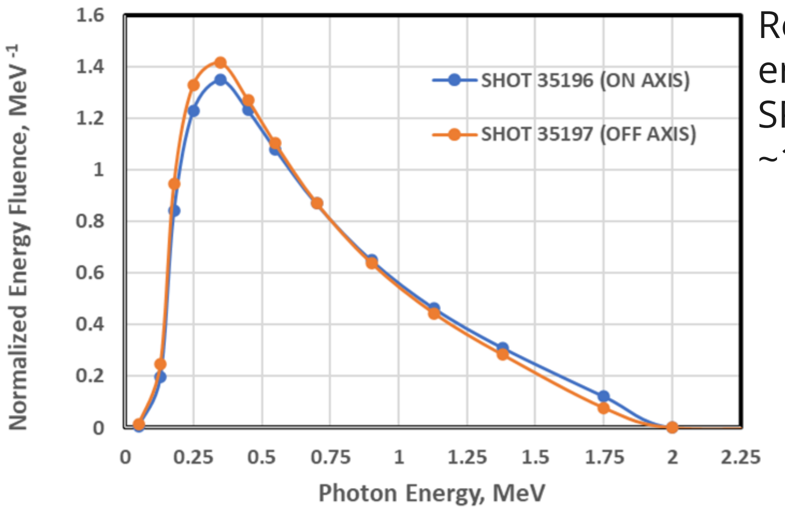
BREMSSTRAHLUNG RADIATION

- Bremsstrahlung radiation (BREMS for short) is a phenomenon that occurs during the interaction of a high-energy electron beam with a high-Z material (Tantalum in our case).
- Because the material has a high Z (atomic number), it has more protons in its nucleus, leading to a greater force of attraction between the traveling electrons and the nucleus.
- Energetic electrons are shot through the high-Z material. The electrons interact with atoms of the material and are deflected, losing velocity in the process.
- This loss of velocity (and therefore kinetic energy) is released as an X-ray.



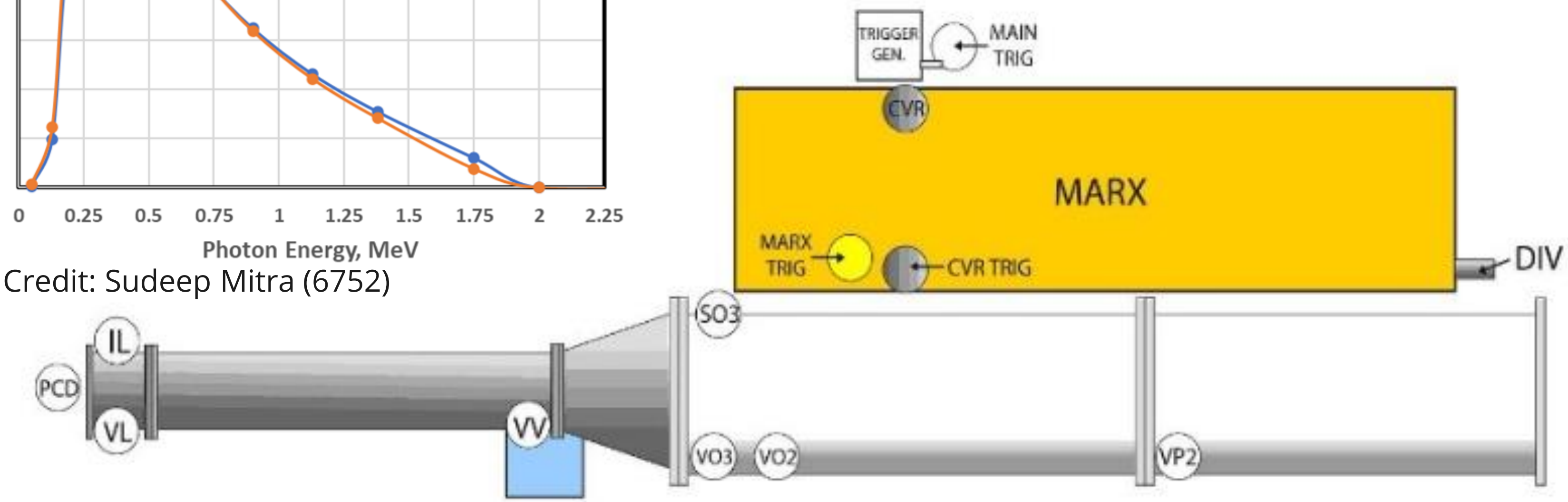
SPHINX

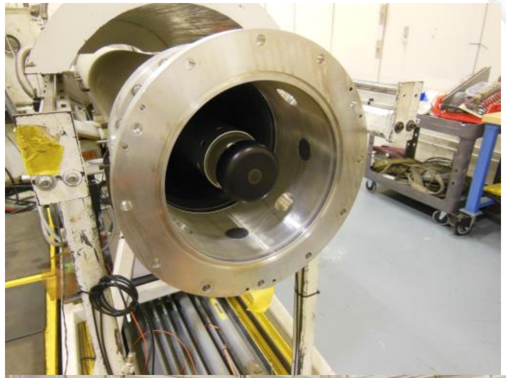
- Short Pulse High Intensity Nanoscale X-Radiator
- SPHINX – Pulsed Power accelerator that has a ~2.0 MeV endpoint energy. It produces about 100 GW of power within a 10 nanosecond pulse time.
- Uses a large Marx Bank, an oil transmission line (white), and a coaxial vacuum line (gray) to deliver energy to a diode load.

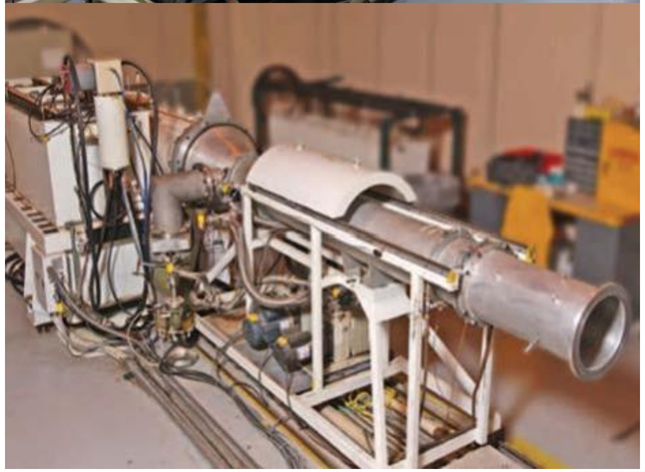


Representative photon energy spectrum of SPHINX ranging from ~100kV to ~2MV.

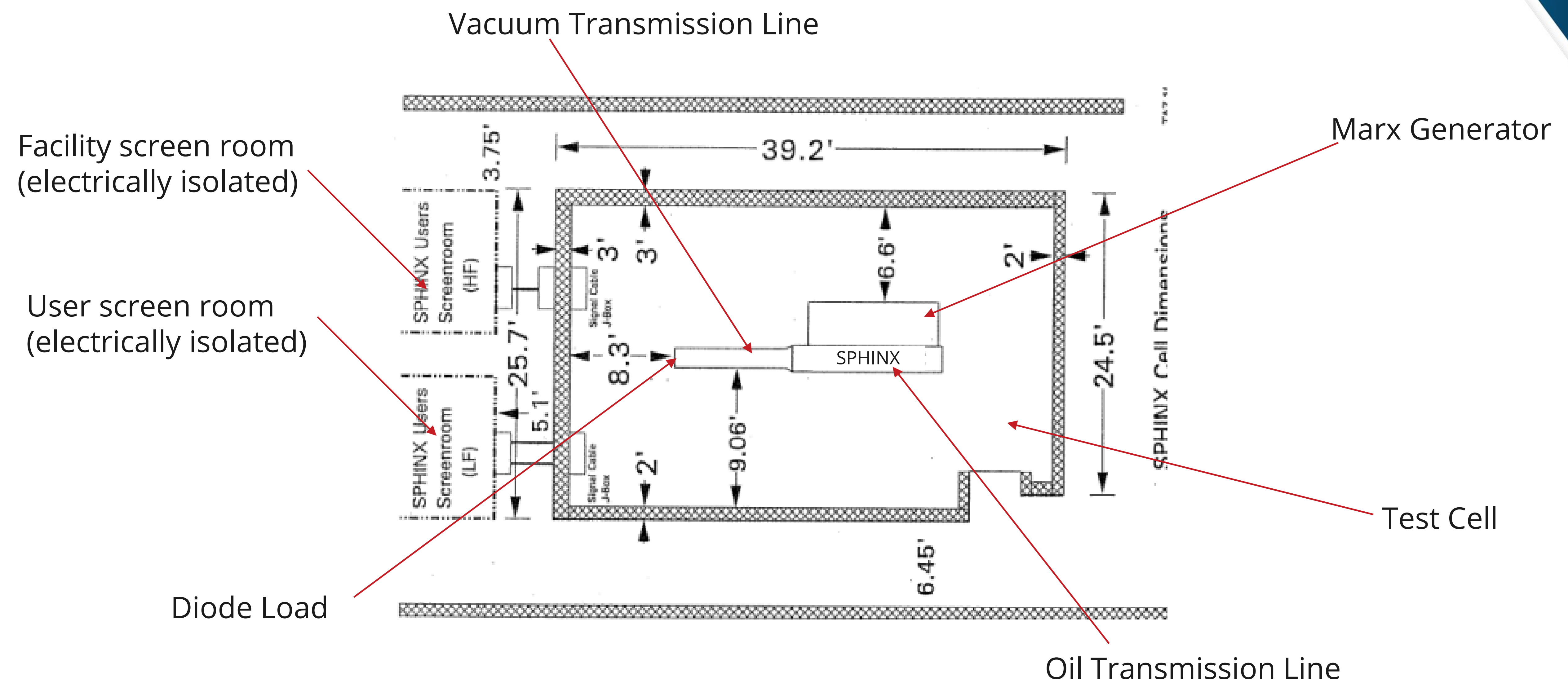
Credit: Sudeep Mitra (6752)





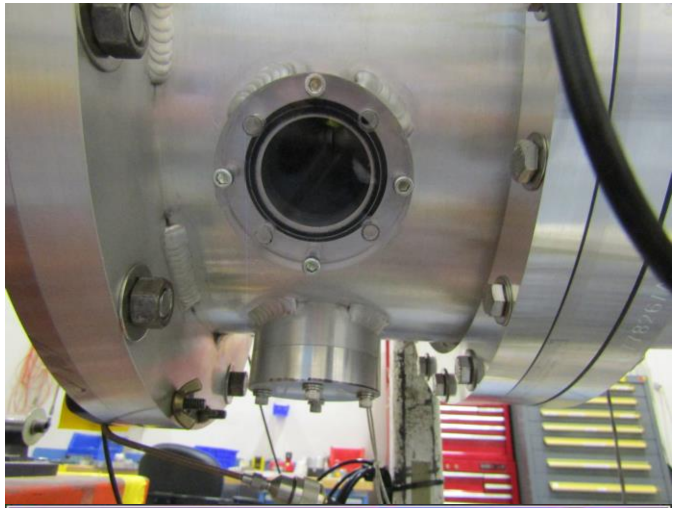


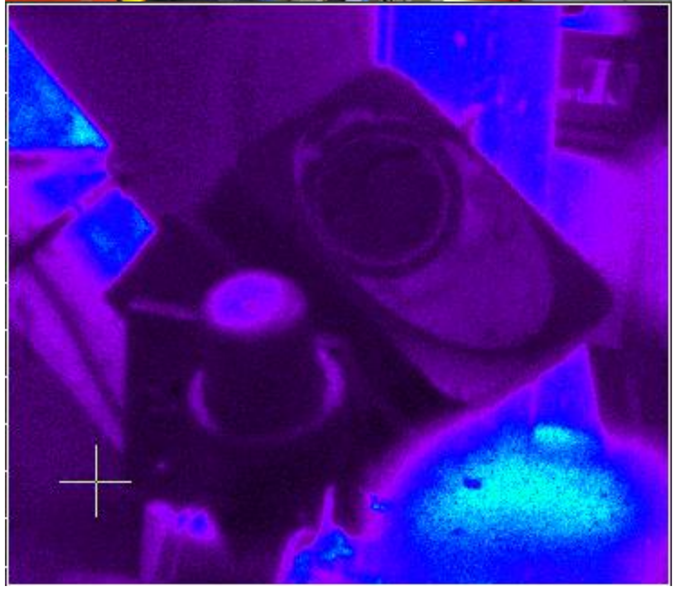
SPHINX FACILITY DIAGRAM



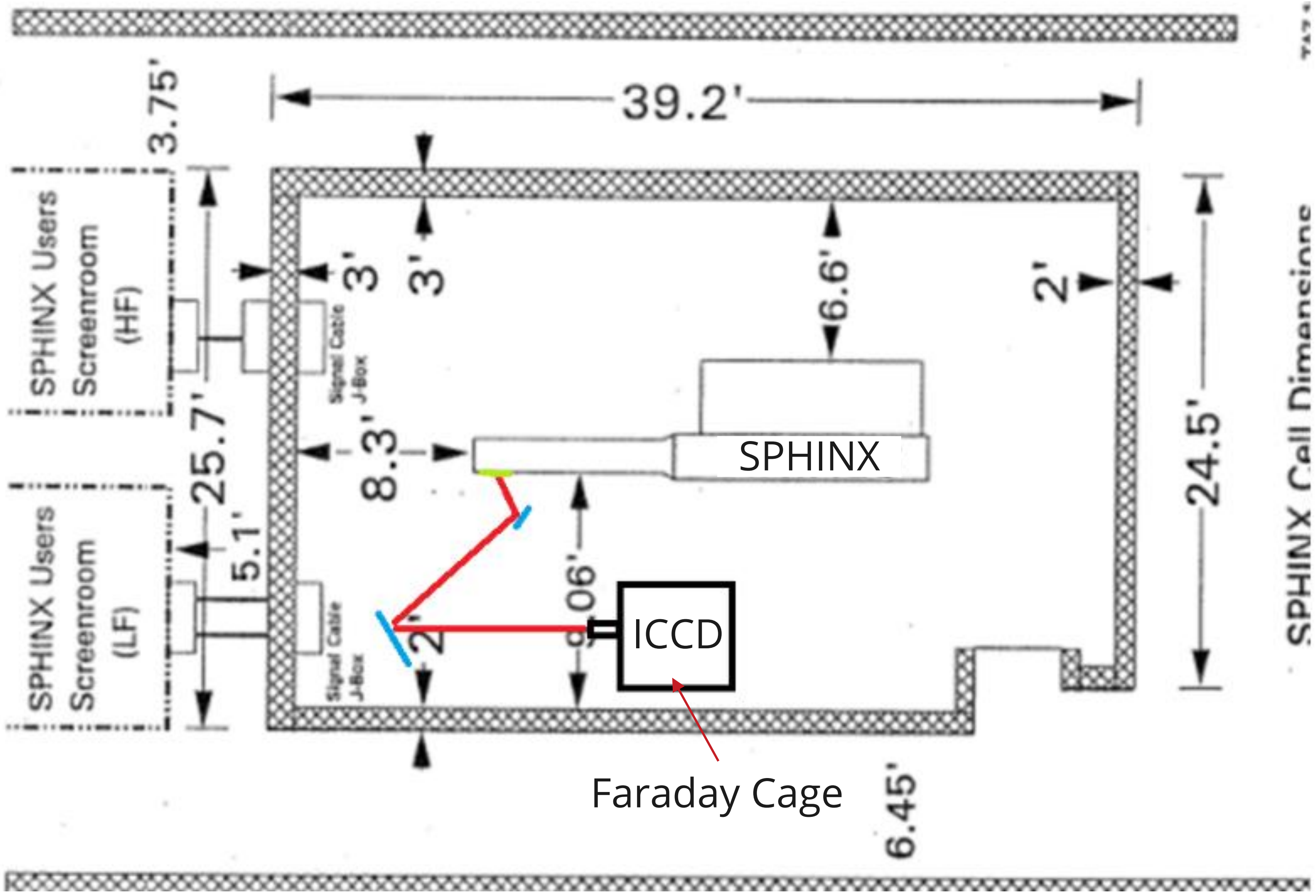
EXPERIMENTAL SETUP | PART I: CHERENKOV IMAGING

- SPHINX in BREMS mode.
- We used an Andor iStar Model DH334T18UE3 ICCD camera to view the side of the anode on the MITL. We used a series of mirrors to enable the ICCD camera to look into the accelerator through the viewport (bottom image).
- Through the viewport, we observed visible light emission.
- We believe this light is the result of Cherenkov Radiation at the viewport.
- Cherenkov radiation is an emission of photons as electrons move faster than the speed of light in a particular medium.
- We did see some X-rays hitting the camera's image intensifier, producing a background speckle pattern in the images.





EXPERIMENTAL SETUP DIAGRAM 1 (VACUUM WINDOW ORIENTATION)



CHERENKOV RADIATION

- Cherenkov Radiation is a phenomenon that occurs when electrons, or more generally, charged particles move faster than the speed of light in a medium.
- How can particles travel faster than the speed of light?
  - The speed of light in a medium is reduced.
  - Particles can travel faster than the speed of light in a *medium* (the absolute speed limit is speed of light in a *vacuum*).
- The equation seen on the bottom right is used to calculate the number of photons of Cherenkov radiation emitted in a selected wavelength range (λ_L and λ_H).
  - This number is proportional to the intensity (counts) measured in this experiment using the ICCD camera.

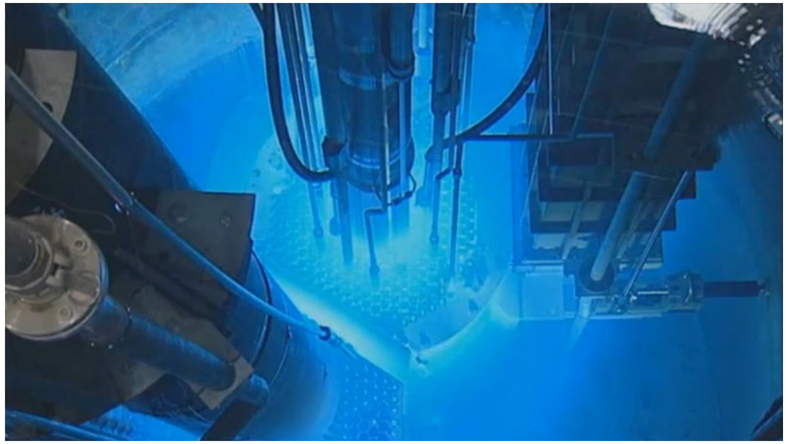
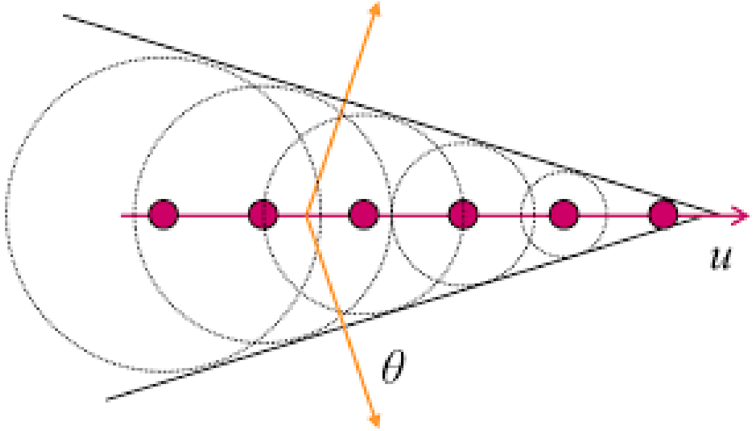


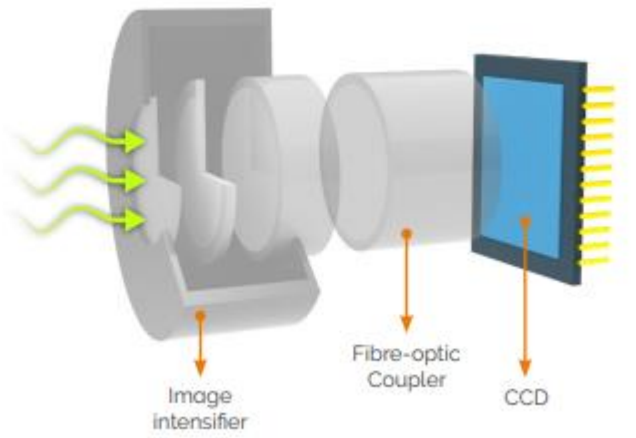
Photo of Sandia's ACRR Reactor. The blue glow is Cherenkov Radiation.

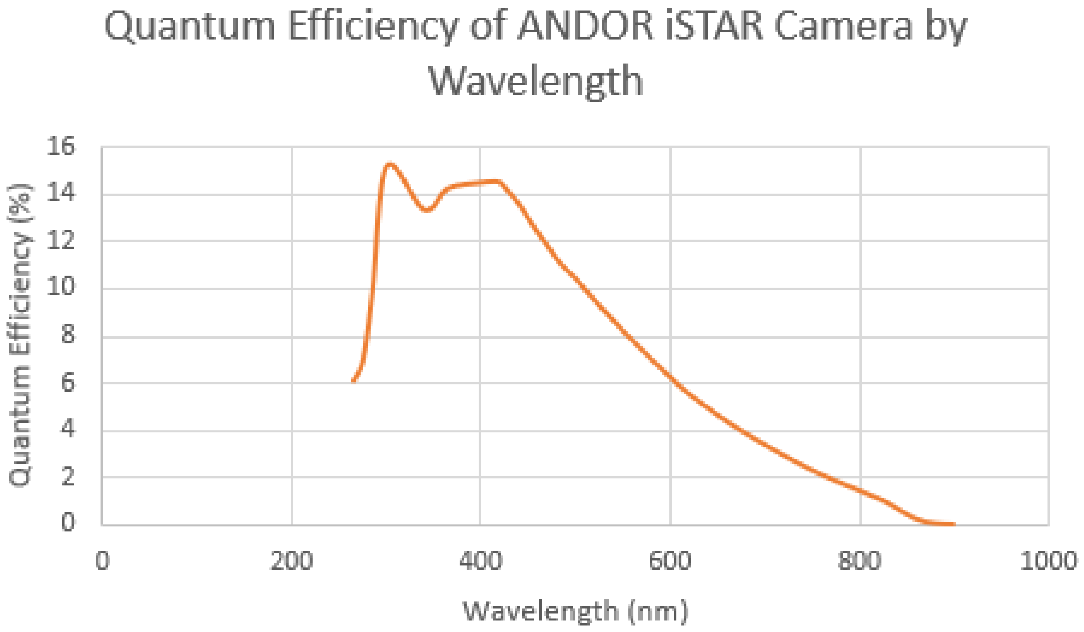


$$\frac{\partial N}{\partial x} = 2\pi\alpha\,(1-1/\beta^2 n^2)\,(1/\lambda_L - 1/\lambda_H)$$

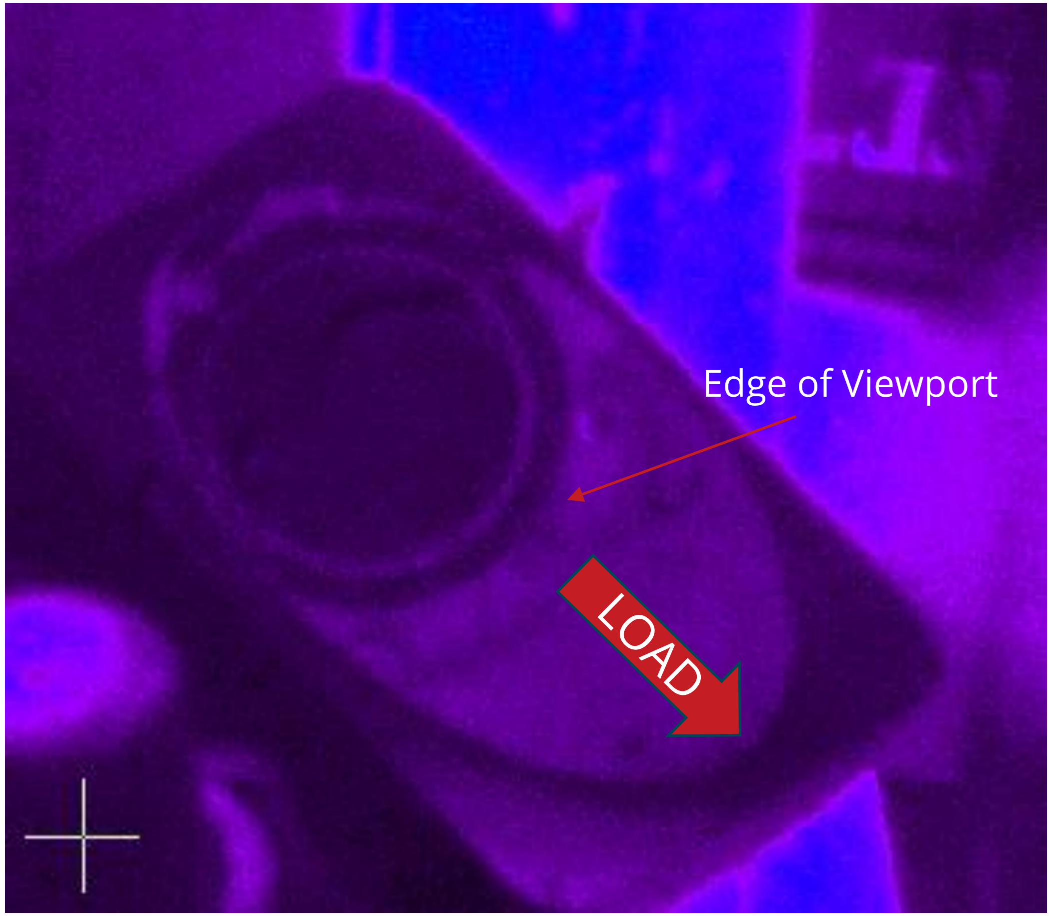
DIAGNOSTICS

- Camera: Andor iStar Model DH334T18UE3.
- The camera uses an intensifier and a CCD sensor, making it an ICCD camera
- 16 bit output.
- 1024x1024 resolution.
- We can directly control the camera's gate time with the software.
- Controlling the gate means that we can time the camera with SPHINX's ~10 nanosecond pulse.

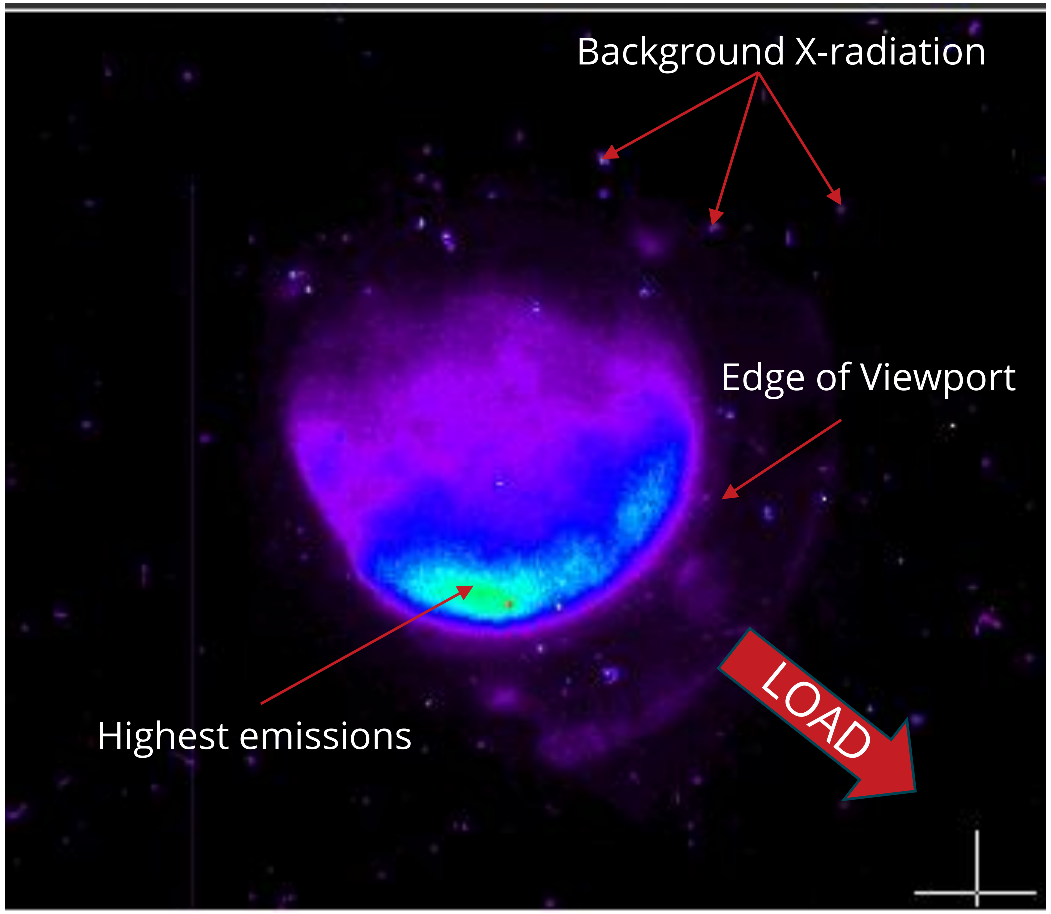




EXAMPLE SHOT (CHERENKOV RADIATION)



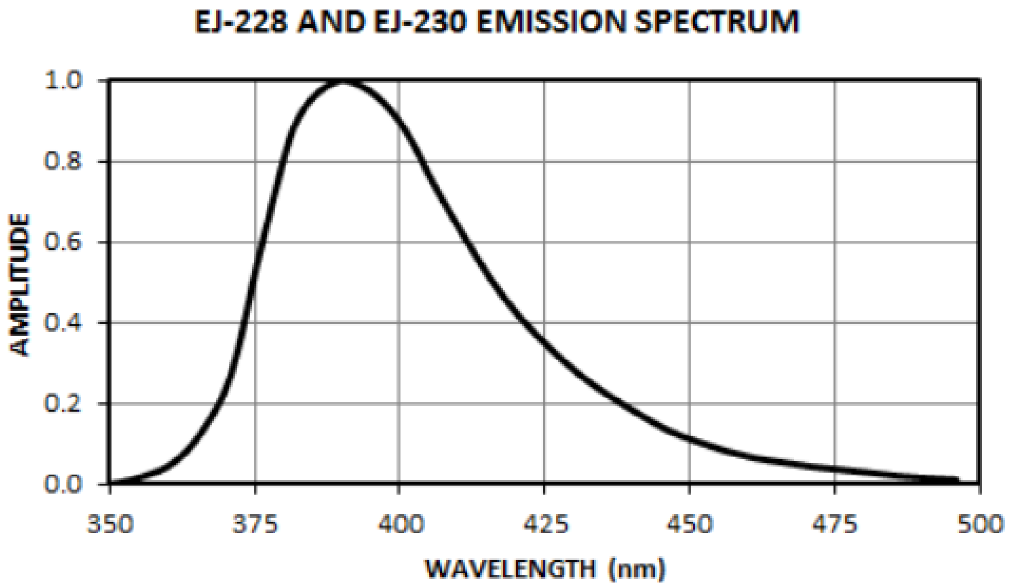
Context Image 35196
(Image of setup before a shot).



Shot 35196

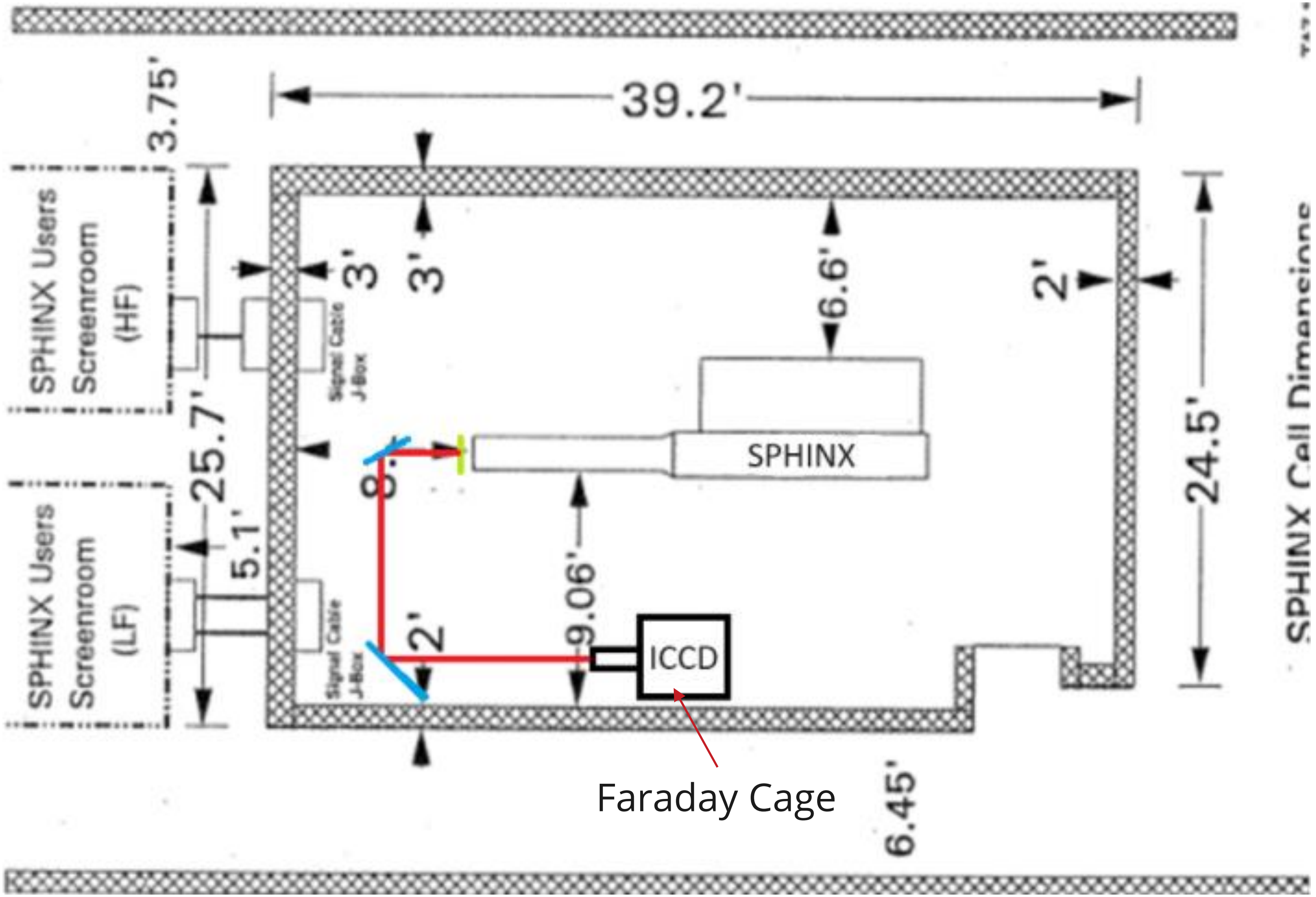
EXPERIMENTAL SETUP | PART II: X-RAY DOSE PROFILE IMAGING

- SPHINX in BREMS mode.
- We transitioned to using a polyvinyltoluene-based scintillator (EJ-230).
- The EJ-230 material scintillates at ~385nm.
- The scintillator measures 10mm x 508mm x 508mm.
- This scintillator allows us to visually see the x-ray profile emitted from SPHINX.

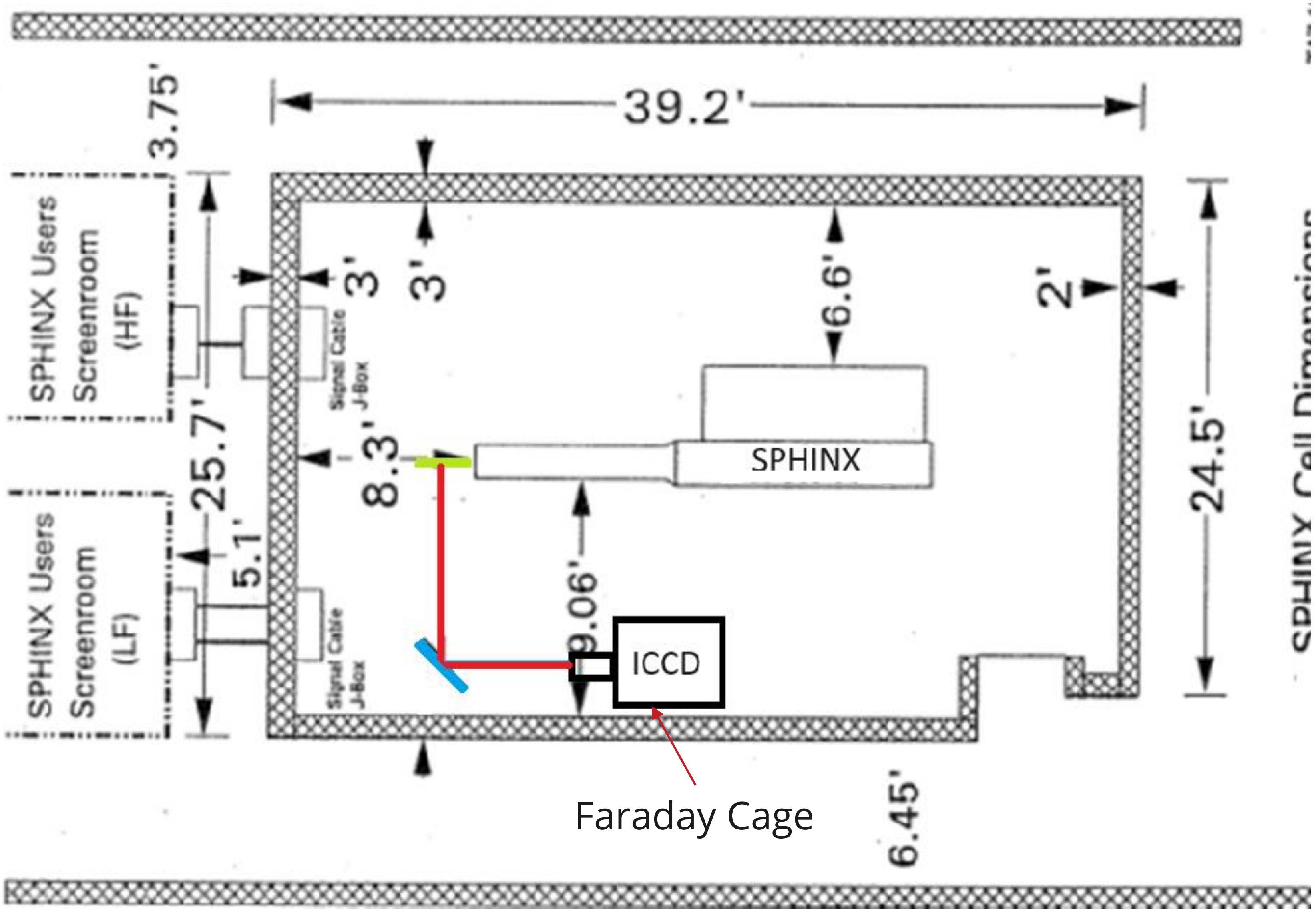


https://eljentechnology.com/images/products/data_sheets/EJ-228_EJ-230.pdf

EXPERIMENTAL SETUP DIAGRAM 2 (FRONT ORIENTATION)



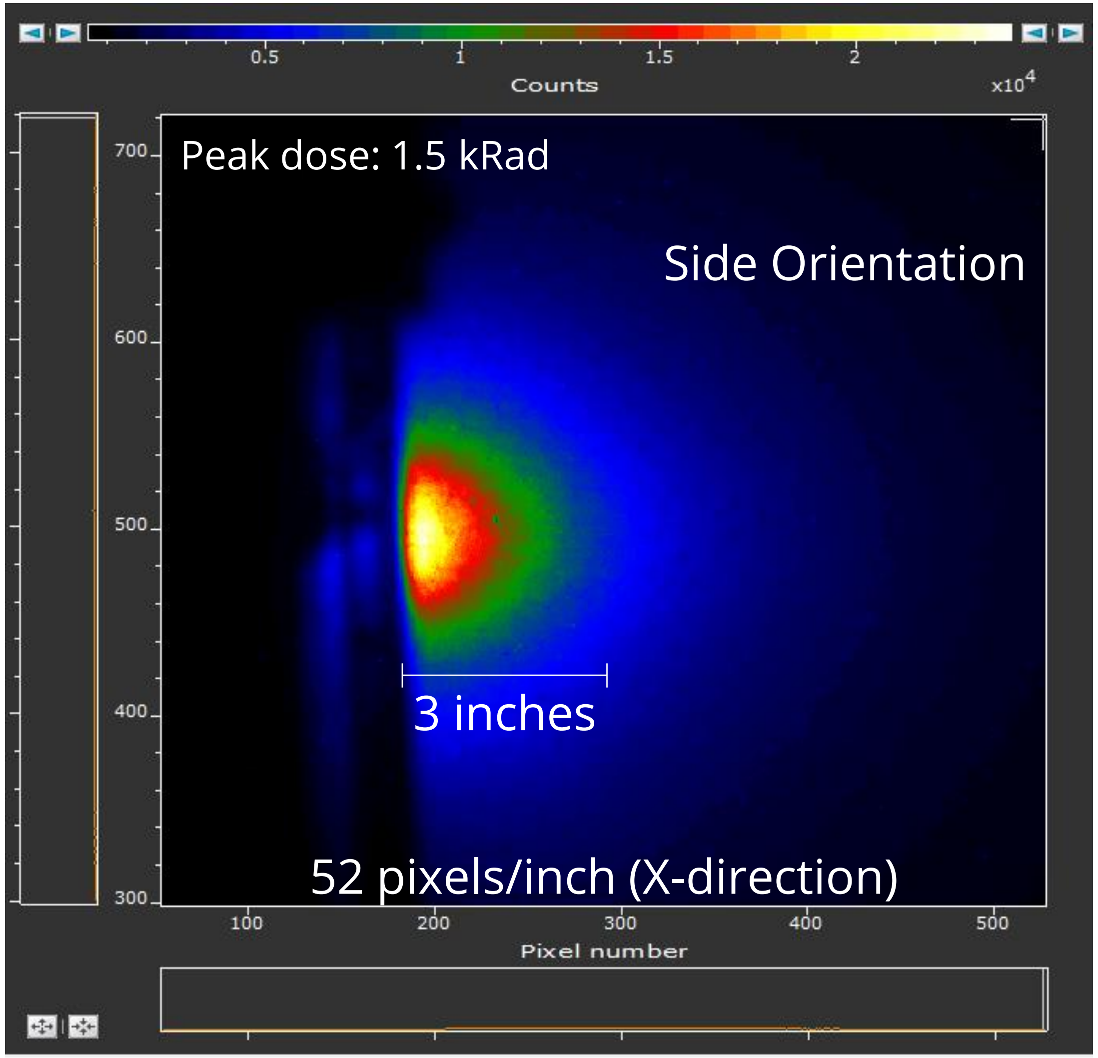
EXPERIMENTAL SETUP DIAGRAM 2 (SIDE ORIENTATION)

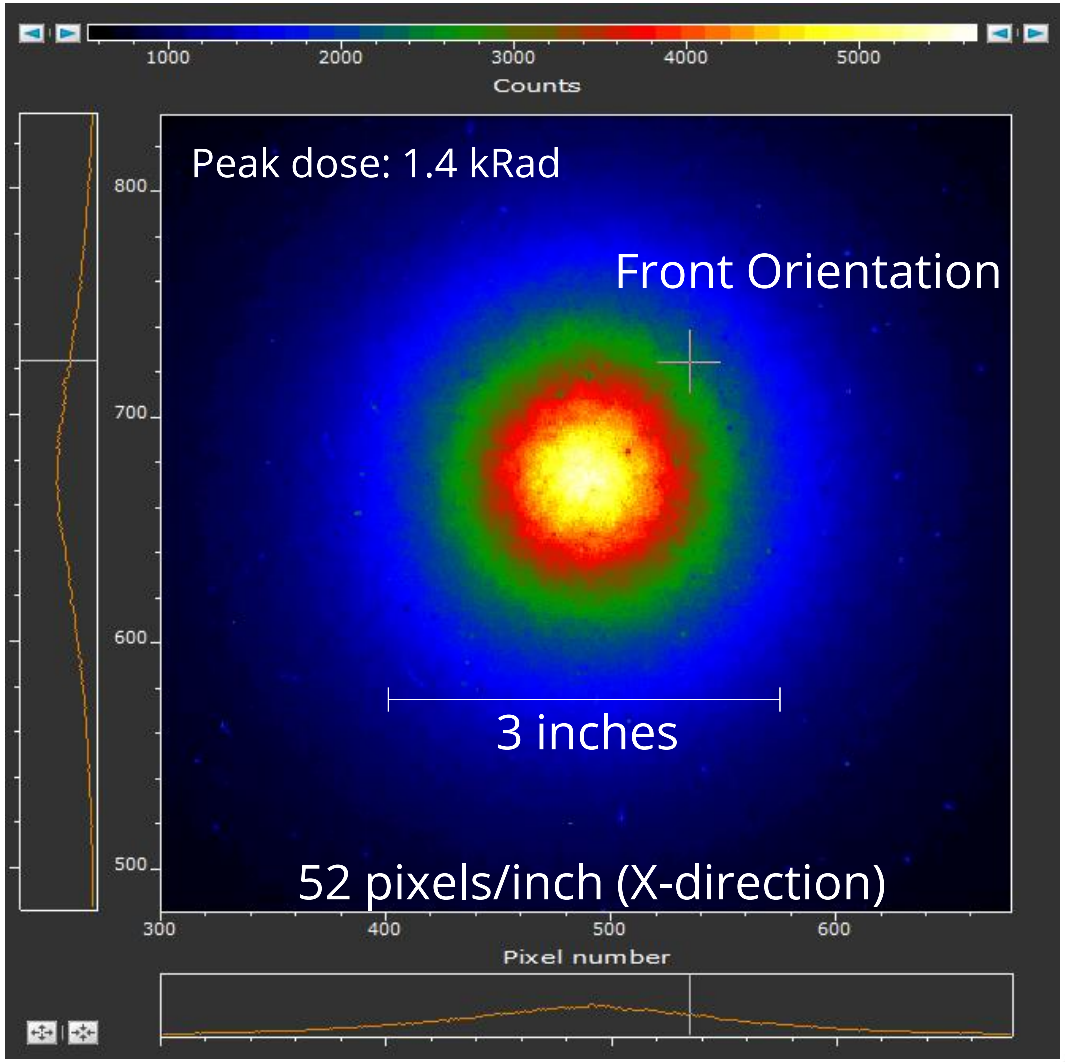


SCINTILLATOR IMAGES

*EJ-230 Scintillation Efficiency: 9700 photons/1 MeV e^-

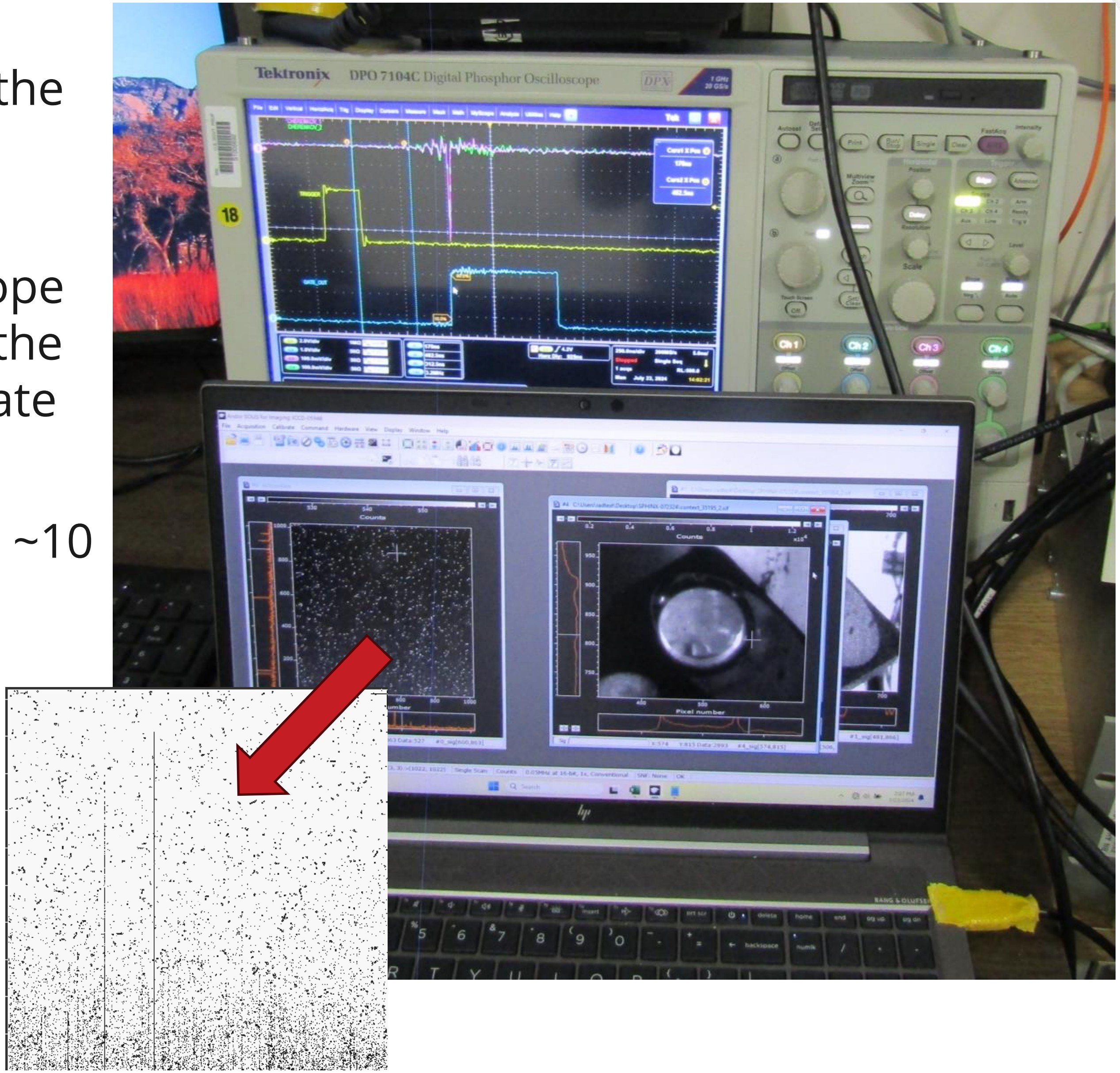
- Taken using the Andor iStar ICCD camera, these images show the distribution in intensity of the X rays produced by SPHINX (intensity is proportional to the total X-Ray dose; ~10cts=1rad).





MEASUREMENT CHALLENGES: ICCD CAMERA

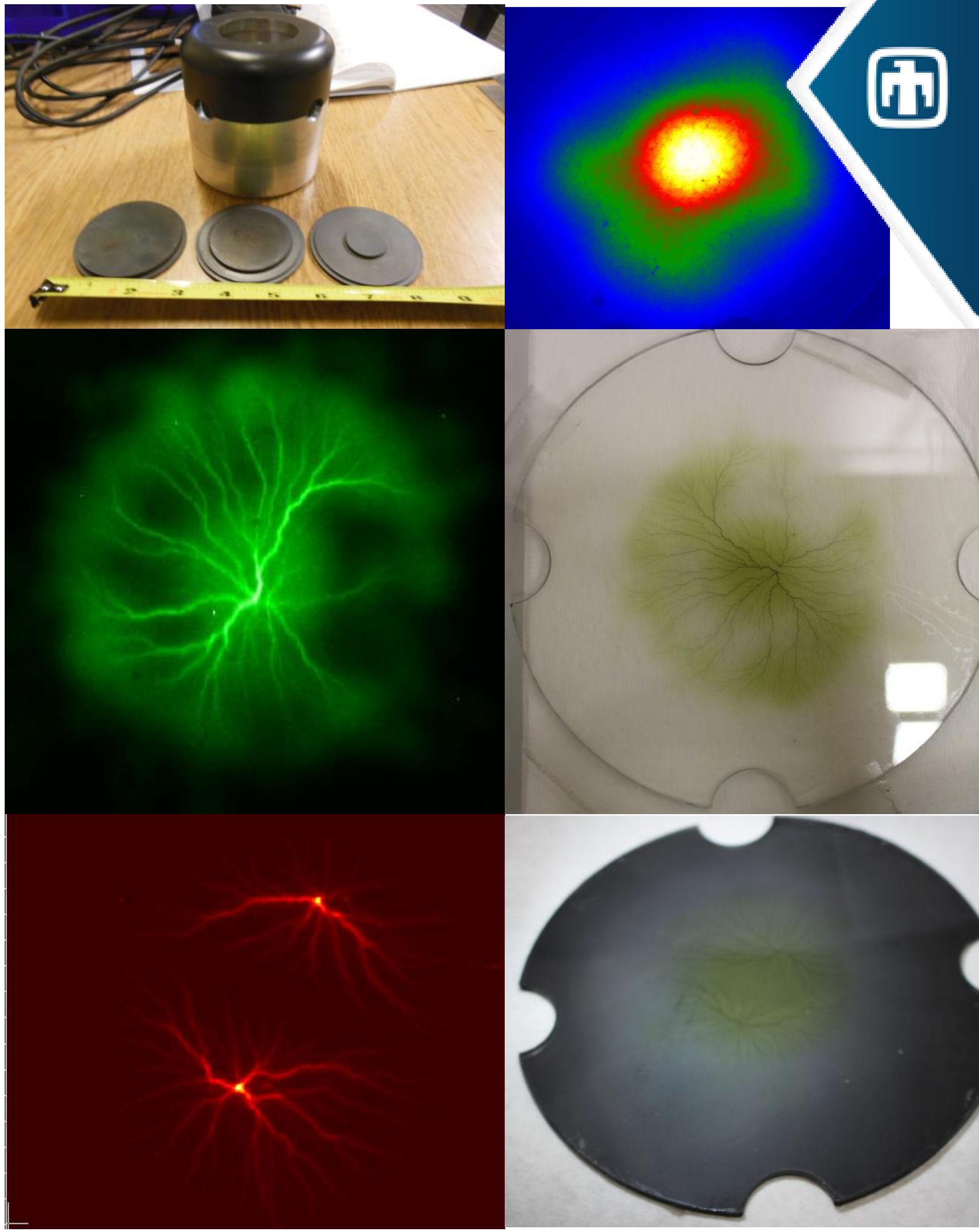
- One of the hardest parts of working with the ICCD Camera was timing the camera gate properly in order to get a measurement.
- We used a Tektronix DPO7104C oscilloscope to measure the timing and magnitude of the SPHINX shots and adjusted our camera gate times accordingly.
- In the first couple of shots, we missed the ~10 nanosecond pulse because of these gate timing issues.



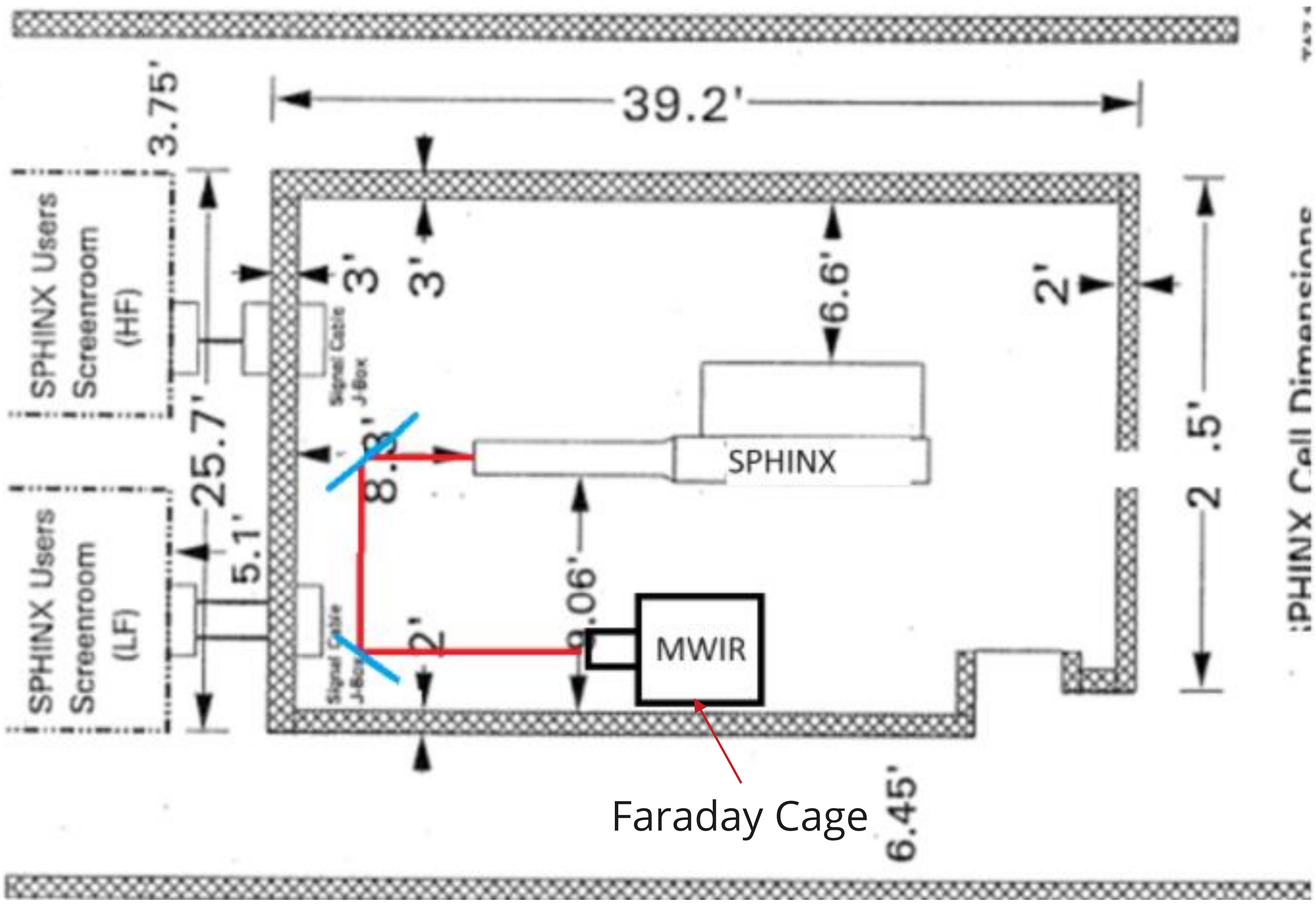
Right: An example of a shot with poor timing.

EXPERIMENTAL SETUP | PART III: E-BEAM IMAGING

- SPHINX transitioned to E-Beam mode.
- We used different pieces of Lexan (a polymer), glass, and quartz to show the electron beam profile
- Different materials yielded different results.
- Materials such as Lexan and glass, we saw permanent darkening left by the electron beam.
- Quartz/Fused Silica showed resistance to the darkening left by the electron beam (less color centers).
- We changed the AK Gap and the cathode diameter in order to see variations in the electron beam profiles.
- After these final experiments using the ANDOR camera, we transitioned to thermal imaging.

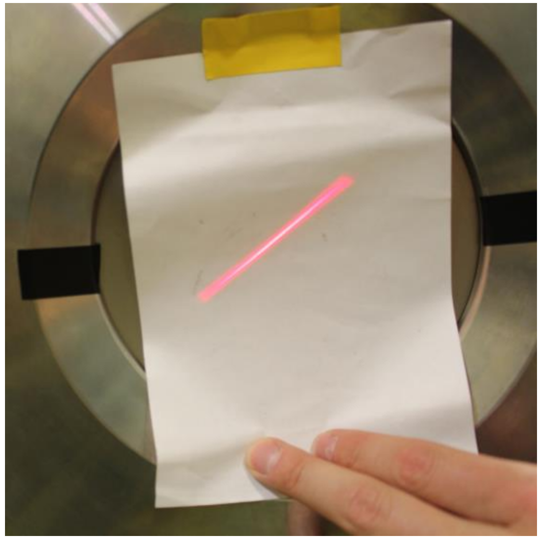


EXPERIMENTAL SETUP DIAGRAM 3 (MWIR CAMERA)



DIAGNOSTICS (THERMAL IMAGING)

- FLIR MWIR Camera Model X6901
- We used this camera to capture multiple frames of the foil. This measurement directly shows the heat distribution on the foil surface.
- It has a spectral range of 3.0 - 5.0 µm.
- It has an accuracy of ±1-2% of the reading at our selected temperature ranges.
- A pyrometer (Advanced Energy IMPAC IGAR 6 Advanced) was also used for this portion of the experiment
- The measurement area of the pyrometer was too large for our needs, averaging in a line across the foil rather than in a circular spot at the center.



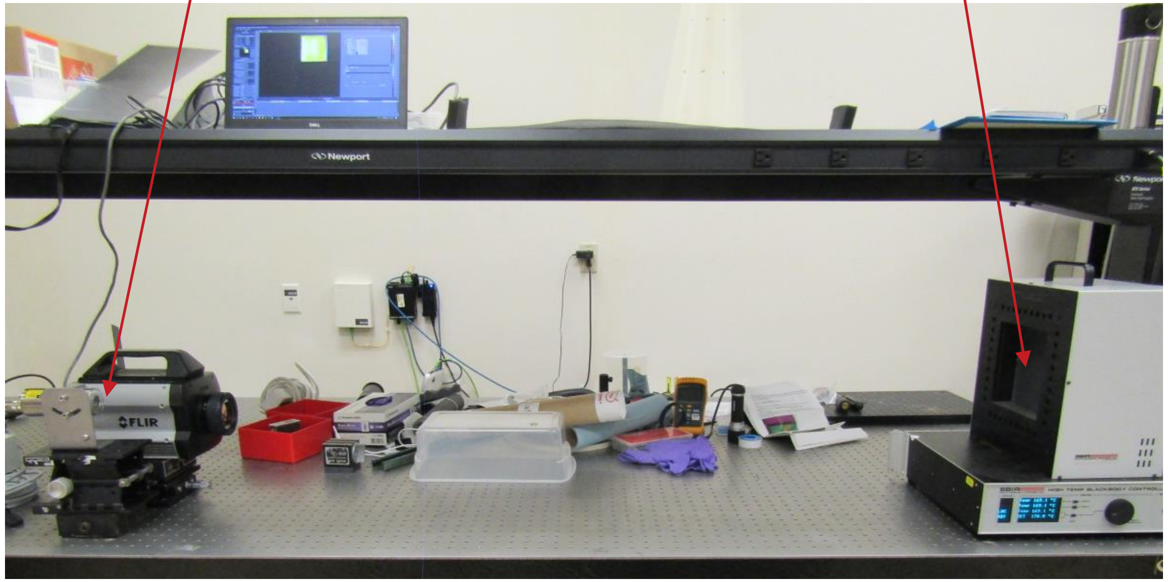
Laser line showing the measurement area of the pyrometer

MWIR CAMERA CALIBRATION

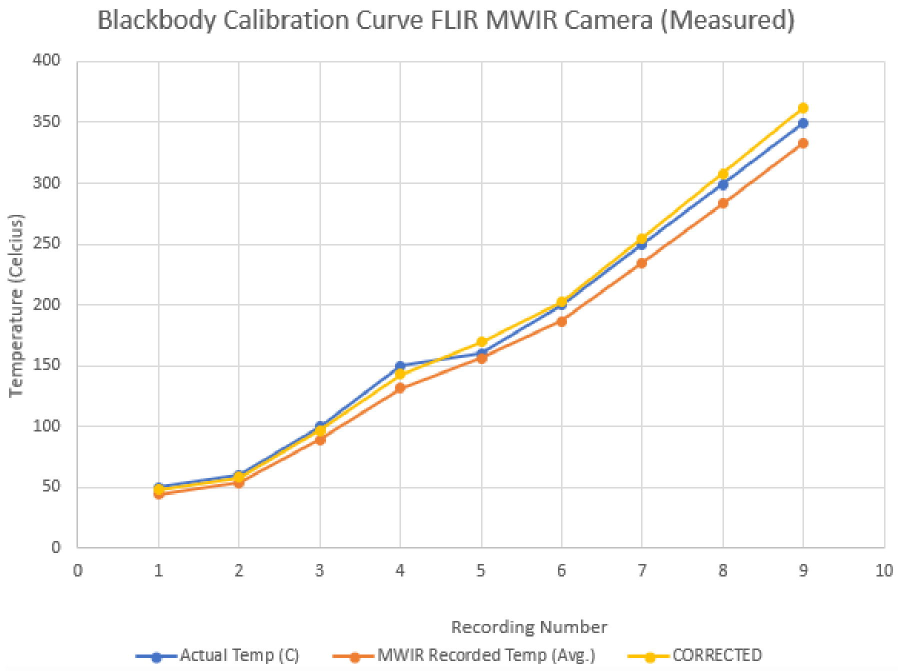
- We calibrated the FLIR Camera using a known blackbody Source.
- Calculated average correction factor = 1.09

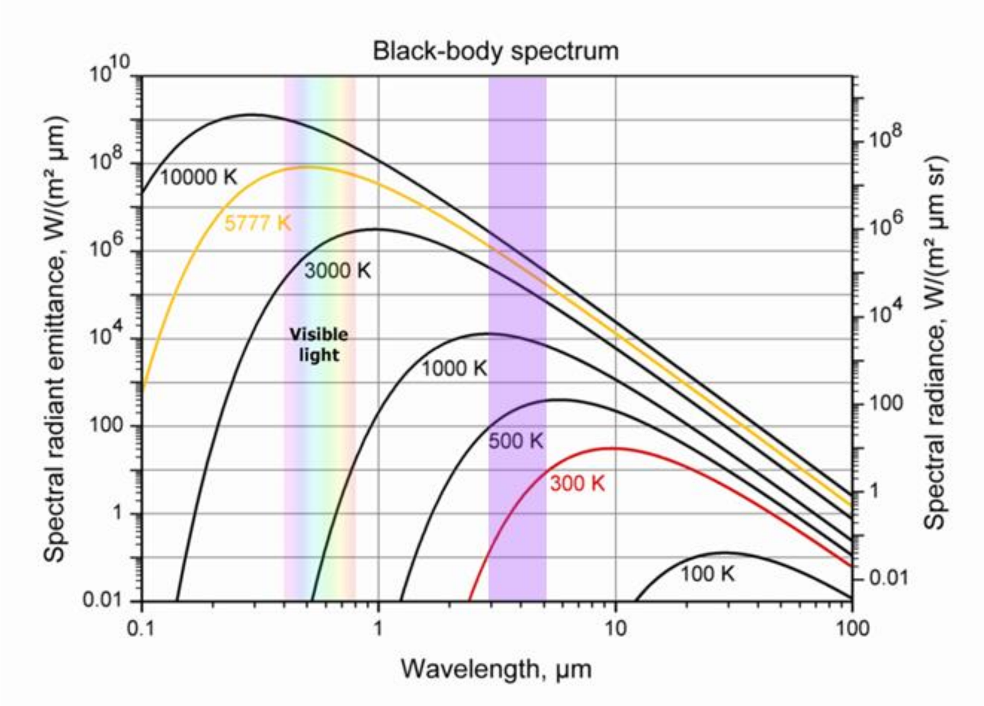
MWIR Camera and Pyrometer

Known Blackbody Source (Emissivity = 0.97)

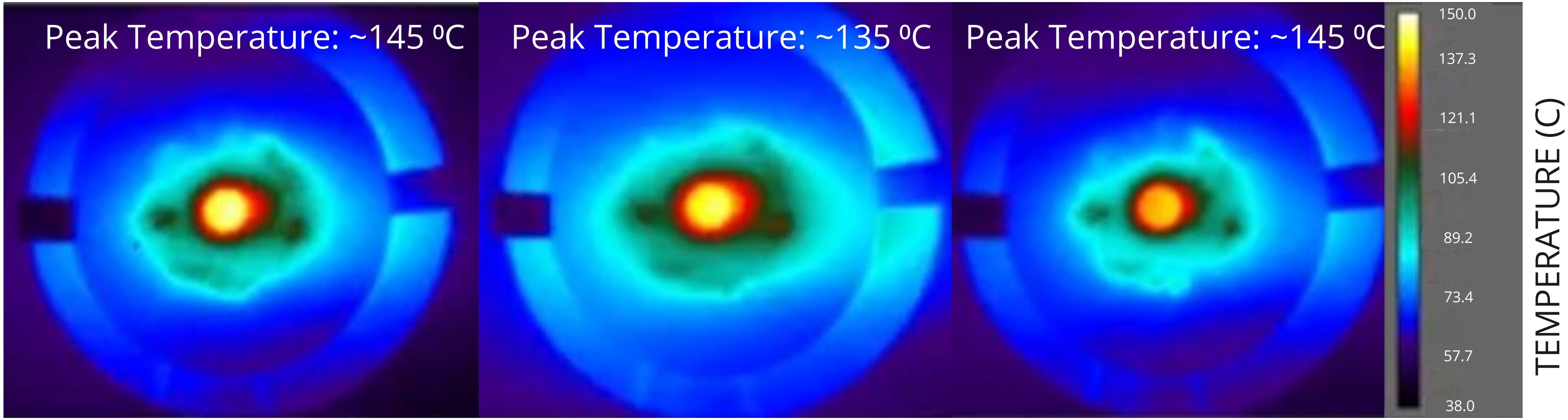


Setup for calibrating both the FLIR MWIR Camera and the IMPAC IGAR 6 Advanced Pyrometer





RESULTS



SPHINX Shot 35252

Cathode Diameter: 1”

AK Gap Size: 0.75”

Material: Titanium Foil

SPHINX Shot 35253

Cathode Diameter: 1”

AK Gap Size: 0.75”

Material: Titanium Foil

SPHINX 35254

Cathode Diameter: 1”

AK Gap Size: 0.75”

Material: Titanium Foil

*This configuration should yield the highest temperatures (highest current density). We did not come close to our limit of 400 degrees Celsius.

MEASUREMENT CHALLENGES

- With the FLIR camera, we often saw a cooler first frame and a hotter second frame.
- The reason for this is because we were not able to control the clock pulse of the FLIR camera. Once the camera is on, it generates its own clock pulse.
- Because the camera integrates its temperature measurements over the whole gate time (450μs) for each frame, the first frame appears cooler than the others (see diagram below).

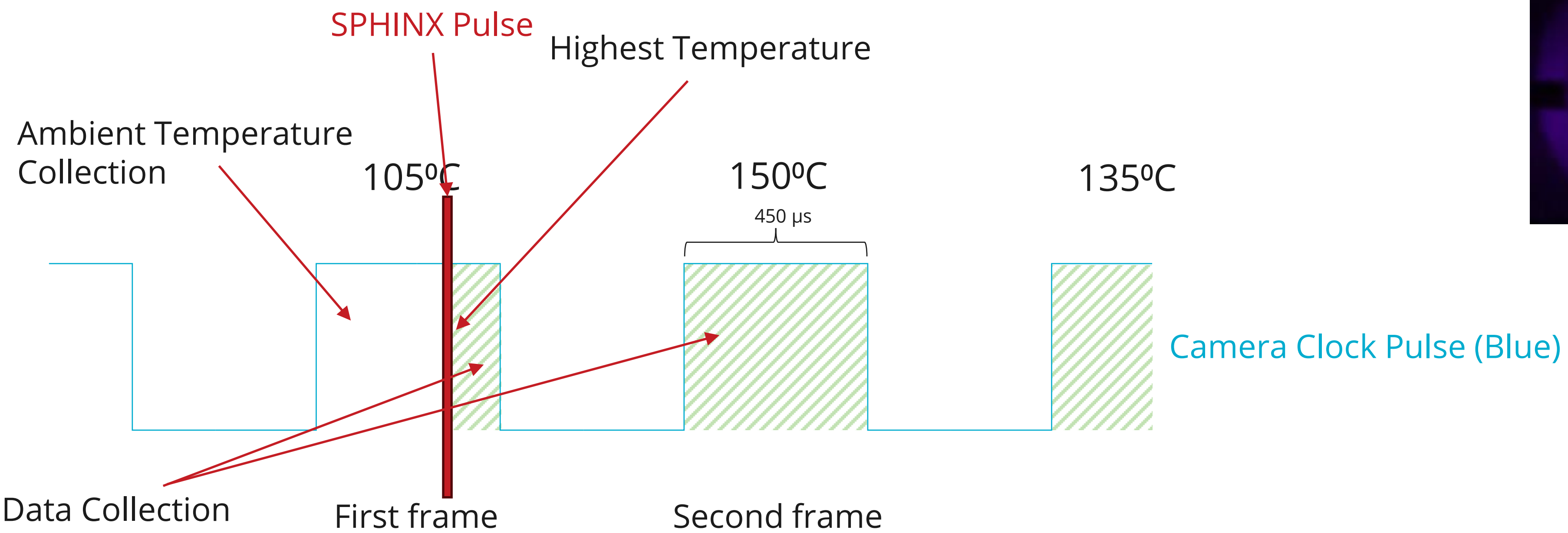
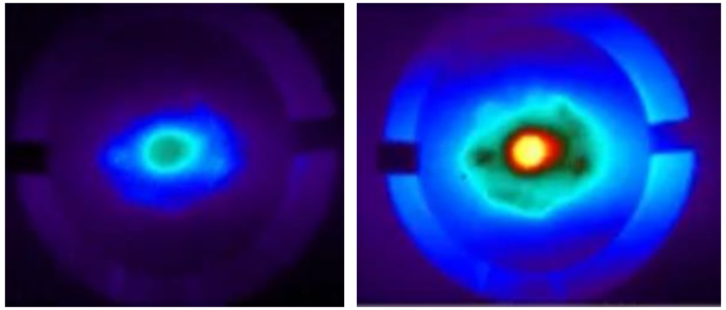


Diagram not to scale



First Frame (35252)

Second Frame (35252)

SUMMARY/FUTURE WORK

- We found that we did not come close to reaching the 400^0C mark with the Titanium foil.
- With higher-Z (Tantalum) foil, we found that we were getting close to or exceeding 400^0 C
- The reason that a higher-Z material was heated more is because it is absorbing most of the electron beam's energy.
- Titanium foil has a lower Z number, so less of the beam is absorbed by the foil.
- In the future, we would like to add a frequency generator to the FLIR camera so that we can control its clock signal.
- We will focus the pyrometer on the center of the foil rather than the entire foil surface.
- We will collect more data by taking more shots.
- We will calibrate our equipment with a blackbody (Ti foil is a poor blackbody with an emissivity of only 0.2).

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QUESTIONS?