

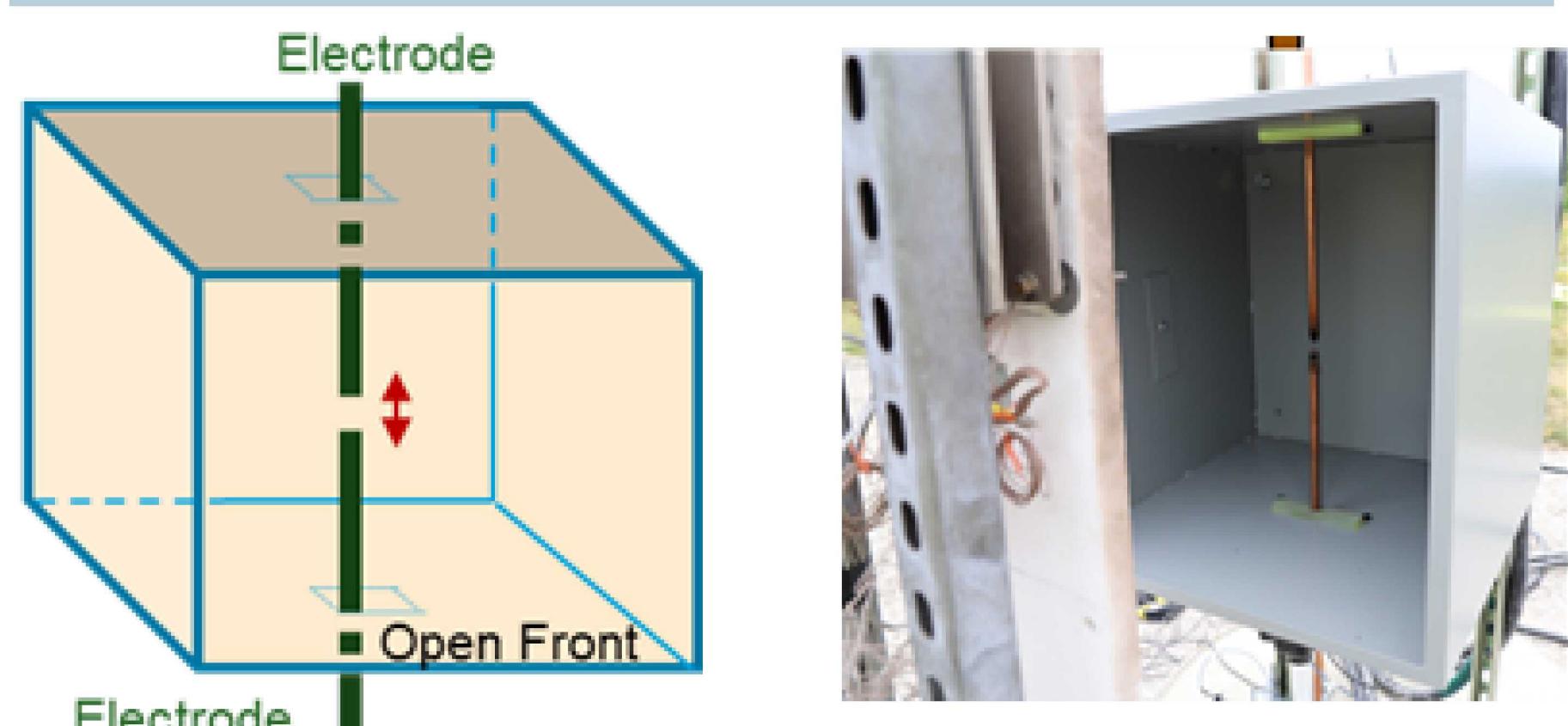


Characterization of DC Arc-Plasmas Generated by High-Voltage Photovoltaic Power Systems

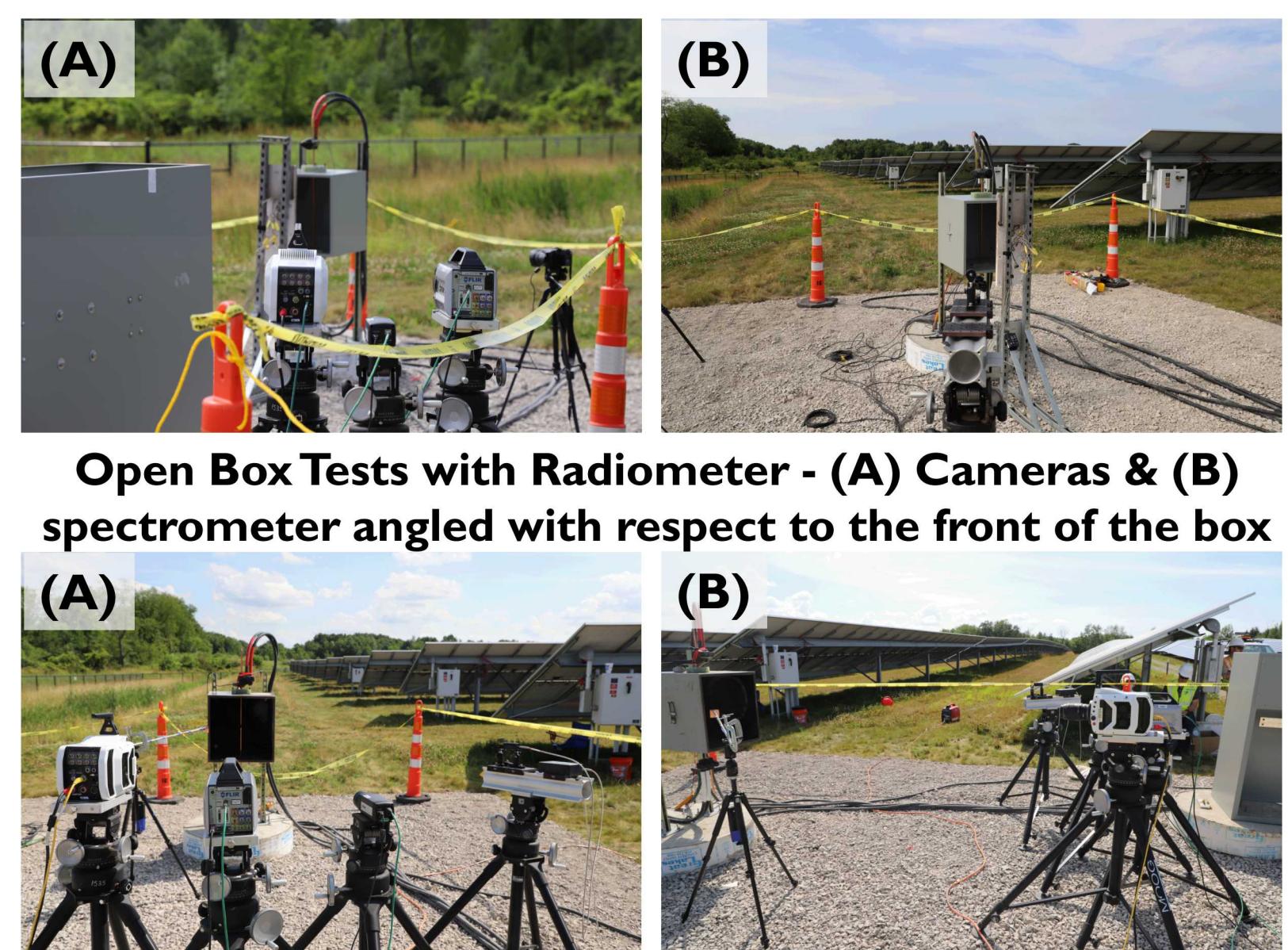
Caroline Winters, Alvaro Cruz-Cabrera, Ray Martinez, and Kenneth Armijo

- A DC arc fault is triggered by air breakdown and is sustained by unabated, continuous current flow
- Energy is released through spectral radiation, thermal emission, material phase change, and reaction kinetics [Augspurger Komm Engineering Inc., 2011]
- Infrared (IR) thermal imaging and optical emission spectroscopy (OES) facilitated plasma/environment interaction studies
- The copper electrode arcs sustained temperatures of $T_{arc} > 6000$ K, while the surrounding environment was maintained at $T_{IR} \approx 1500$ K
- Thermal irradiance from the IR images was compared to calorimeter data to generate a “Zone of Influence” affected by the arc

Experimental Set-up



Schematic and image of arc configuration



Open Box Tests w/out Radiometer - Spectrometer & cameras placed in front of the arc; (A) front view & (B) side view

Optical Emission Spectroscopy (OES)

Boltzmann relation between state populations

$$\ln\left(\frac{I\lambda}{gA}\right) = \frac{-E_u}{kT} - l \ln\left(\frac{4\pi Z}{hcN_0}\right)$$

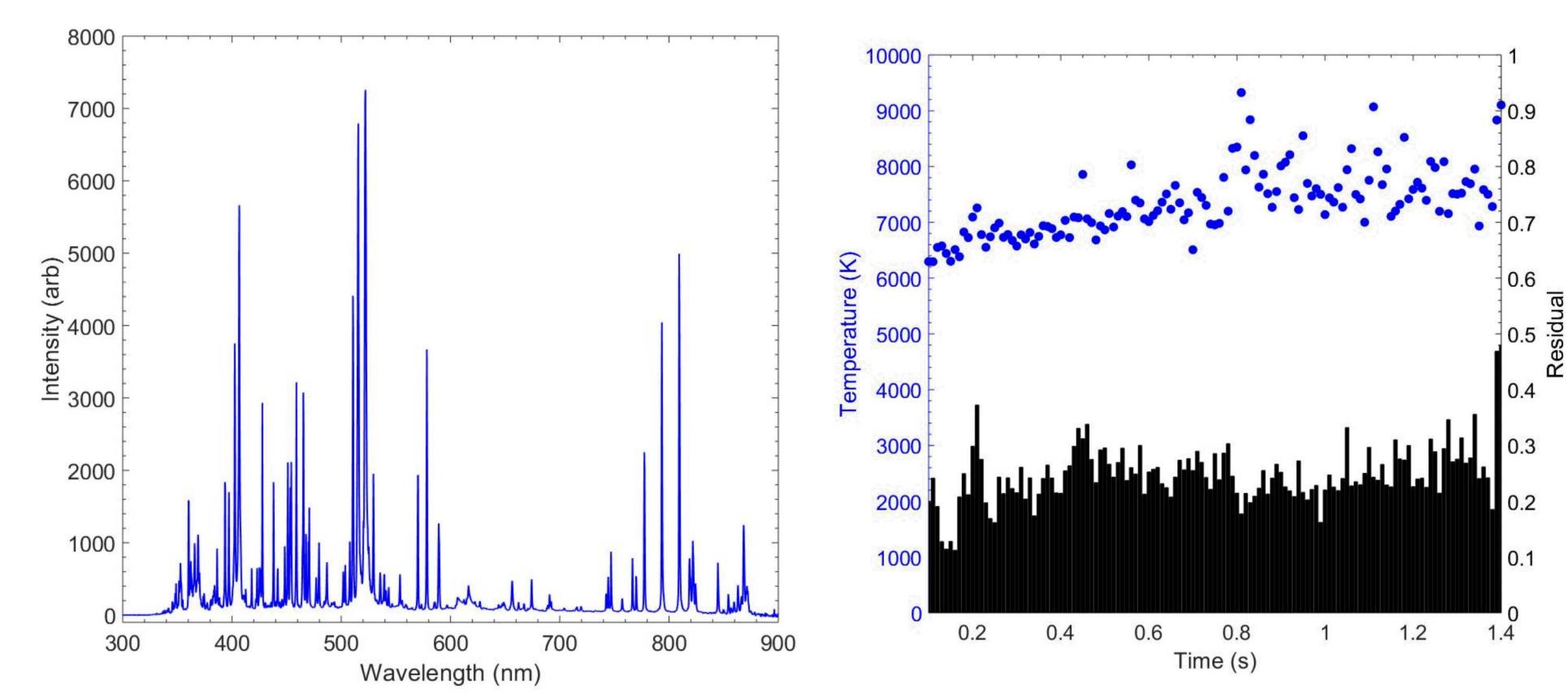
Line intensity, I
Wavelength, λ
Temperature, T
Boltzmann constant, k
Upper state energy, E_u

Cu (I) Transitions & Spectroscopic Constants

Wavelength (nm)	g_u	E_b (cm $^{-1}$)	E_w (cm $^{-1}$)
570	12	13,245	30,784
578	6	13,245	30,535
793	6	30,535	43,137
809	6	30,784	43,137

Arc Temperature Inference

Air-Cu arc with applied voltage, $V = 774$ V_{DC}, and gap spacing, $G = 12.7$ mm

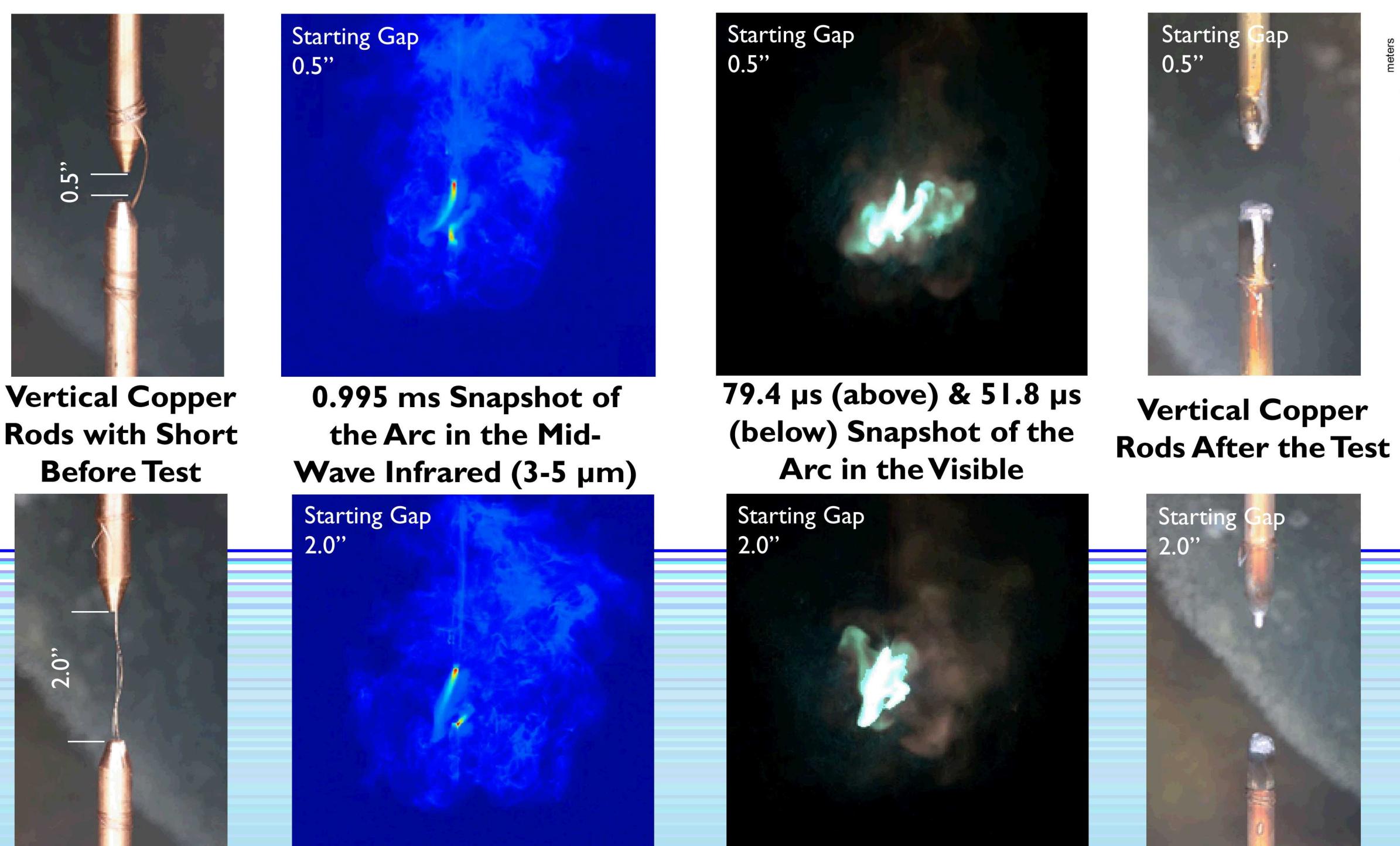


Arc Temperatures

Electrode Orientation	Gap (in)	Applied Energy (kJ)	Mean Arc Temperature (K)	Std. Dev. (K)
Vertical, pin-to-pin	0.5	40	7349	605
Vertical, pin-to-pin	2.0	50	8013	658

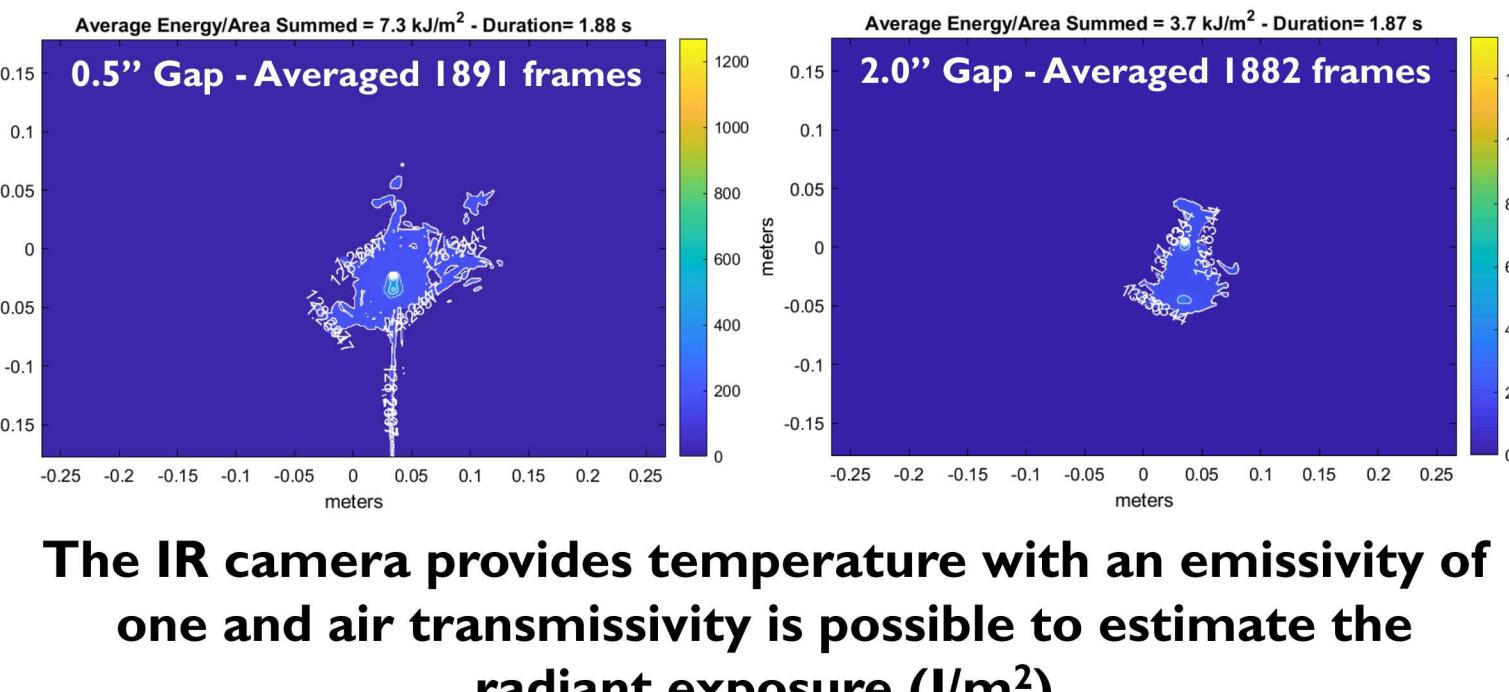
- OES measures the temperature of the copper atoms held within the DC arc
- These atoms were released from the vaporization of the copper electrodes
- Four transitions were identified to generate Boltzmann plots and infer temperature
- The vertical, pin-to-pin electrode configuration produced a more stable arc than other geometries
- This is the first time OES has been demonstrated to measure arc temperatures during field testing

IR & High Speed Imaging

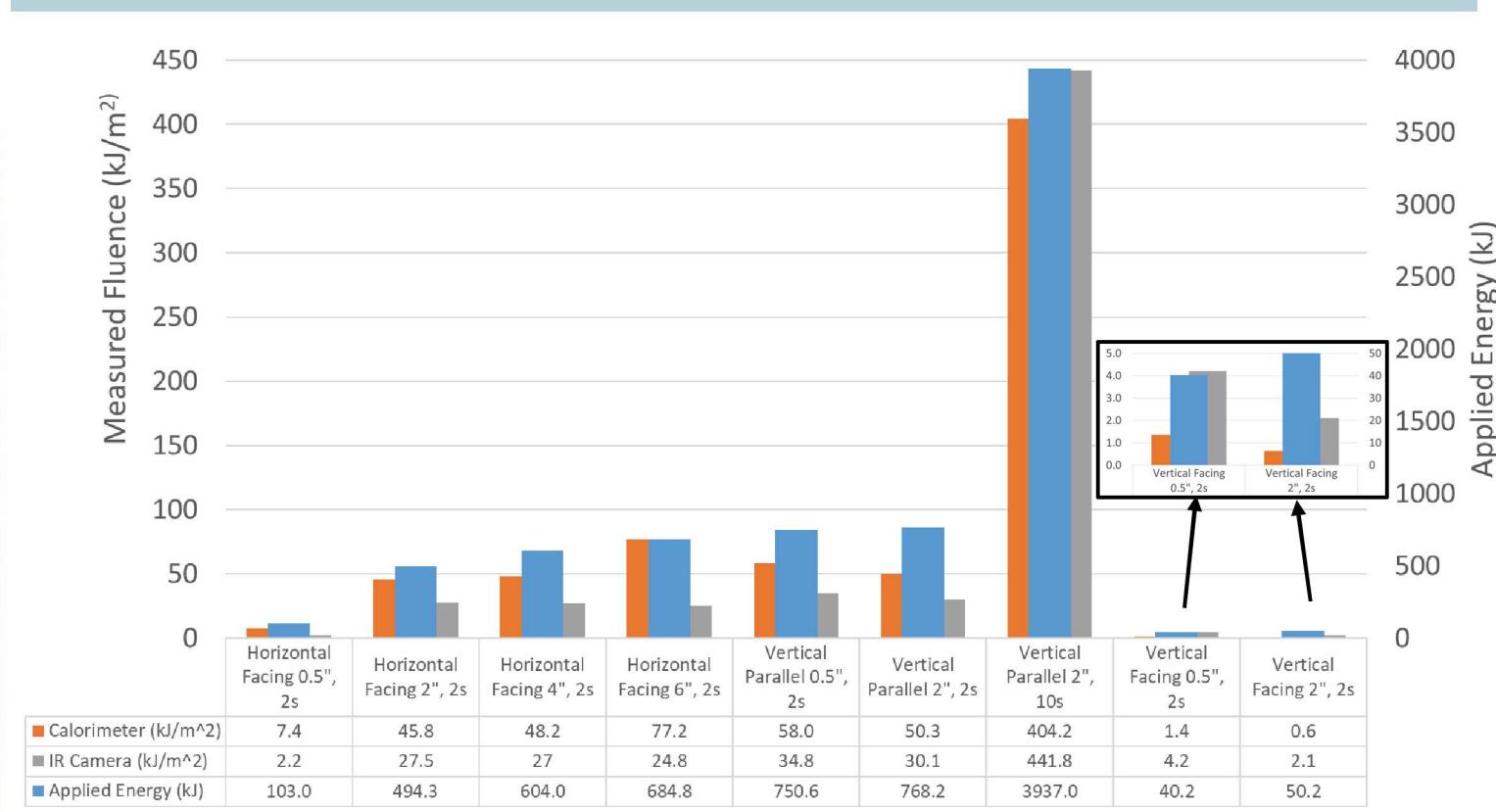


- Infrared Imaging (3-5 μm) using high speed (1004 fps) calibrated cameras
- Related to traditional collection methods using calorimeters
- Radiance exposure estimated from a black body assumption
- Zone of influence estimated from average radiance exposure & experimental data to tissue damage by EM radiation exposure

Averaging Infrared Frames

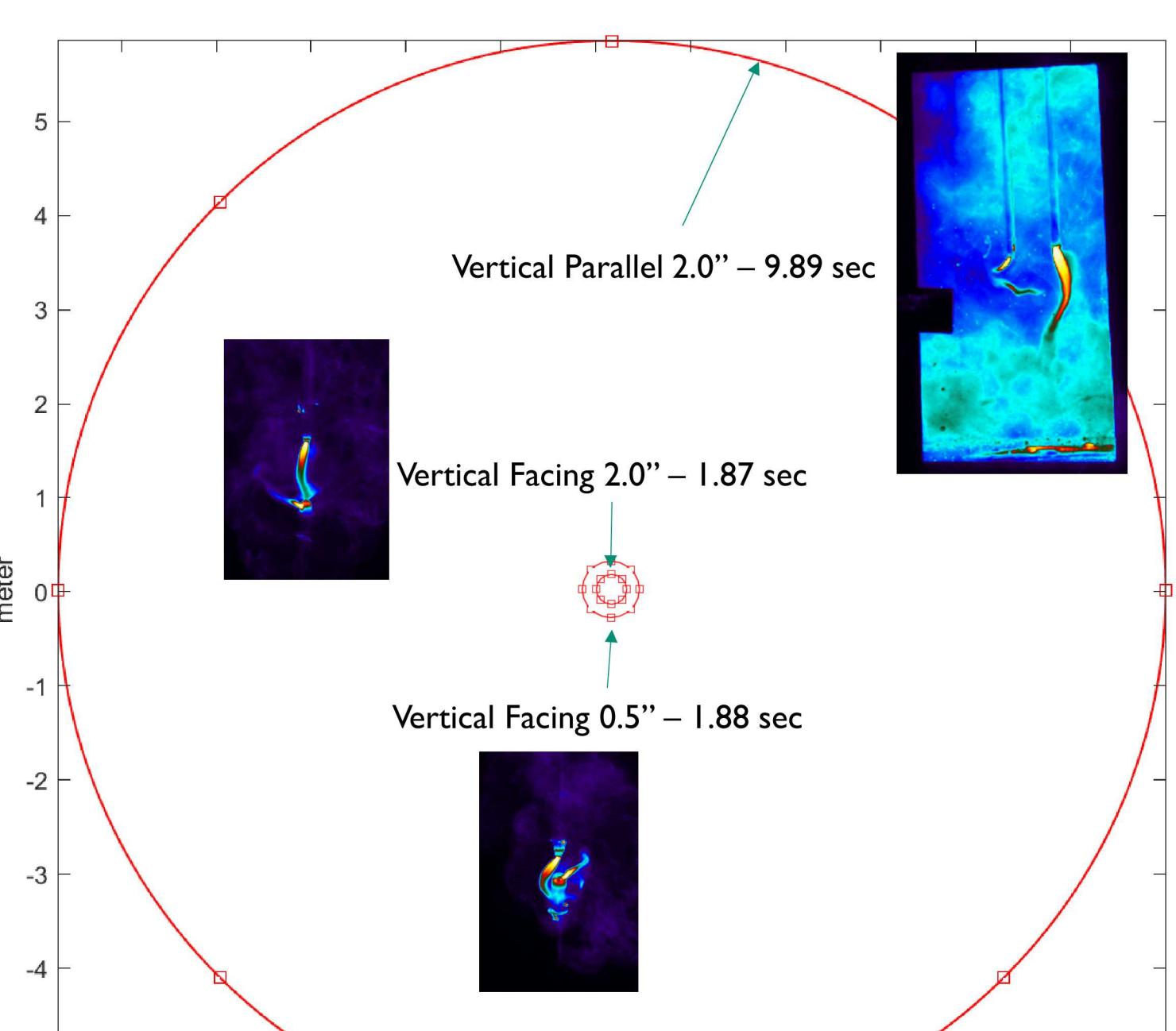


Applied Energy & Measured Fluence



Trends

Zone of Influence



The red circles are the minimum distance of unbearable pain for three different tests (geometry, gap, duration and applied energy)

²[Kramida, et al.]