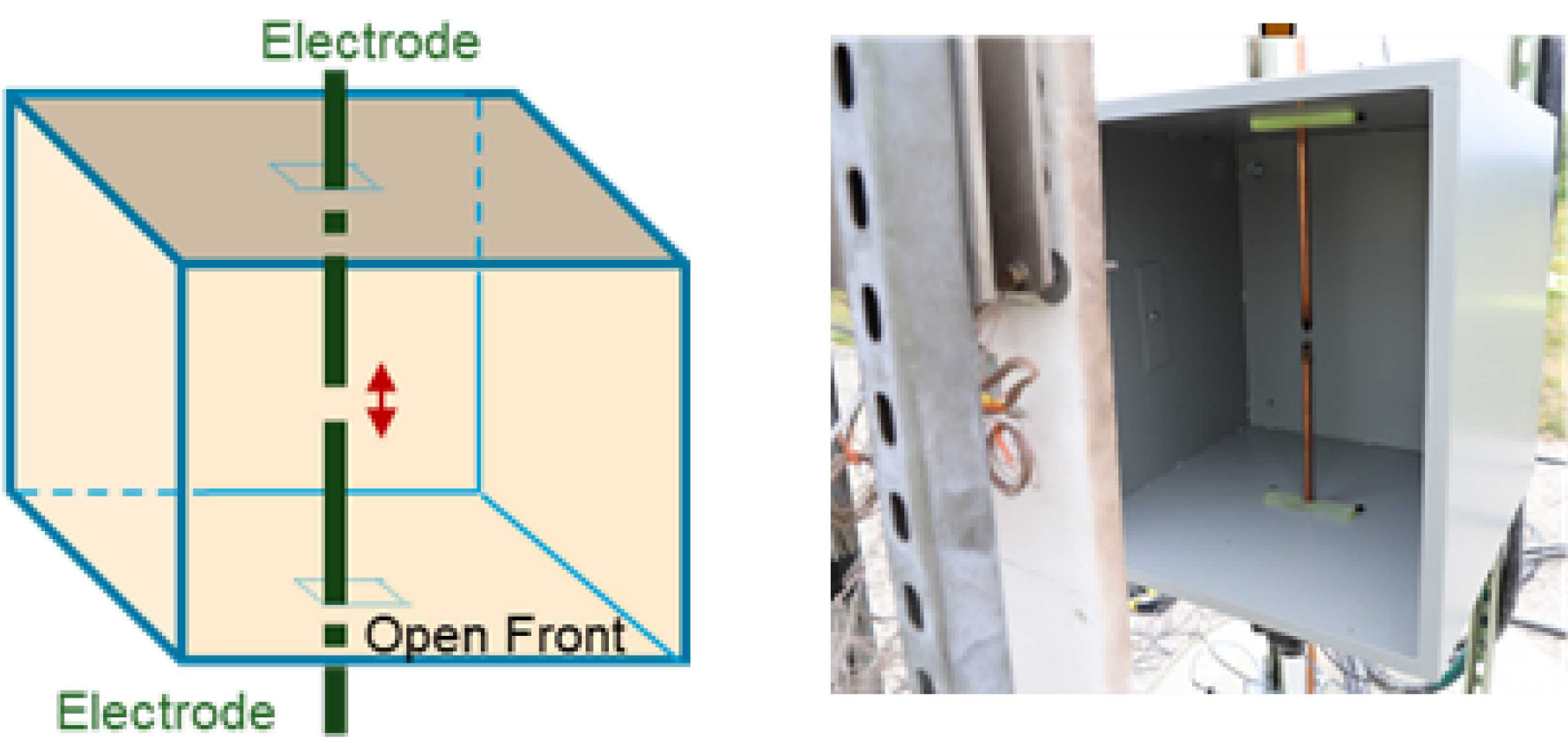


# Characterization of DC Arc-Plasmas Generated by High-Voltage Photovoltaic Power Systems

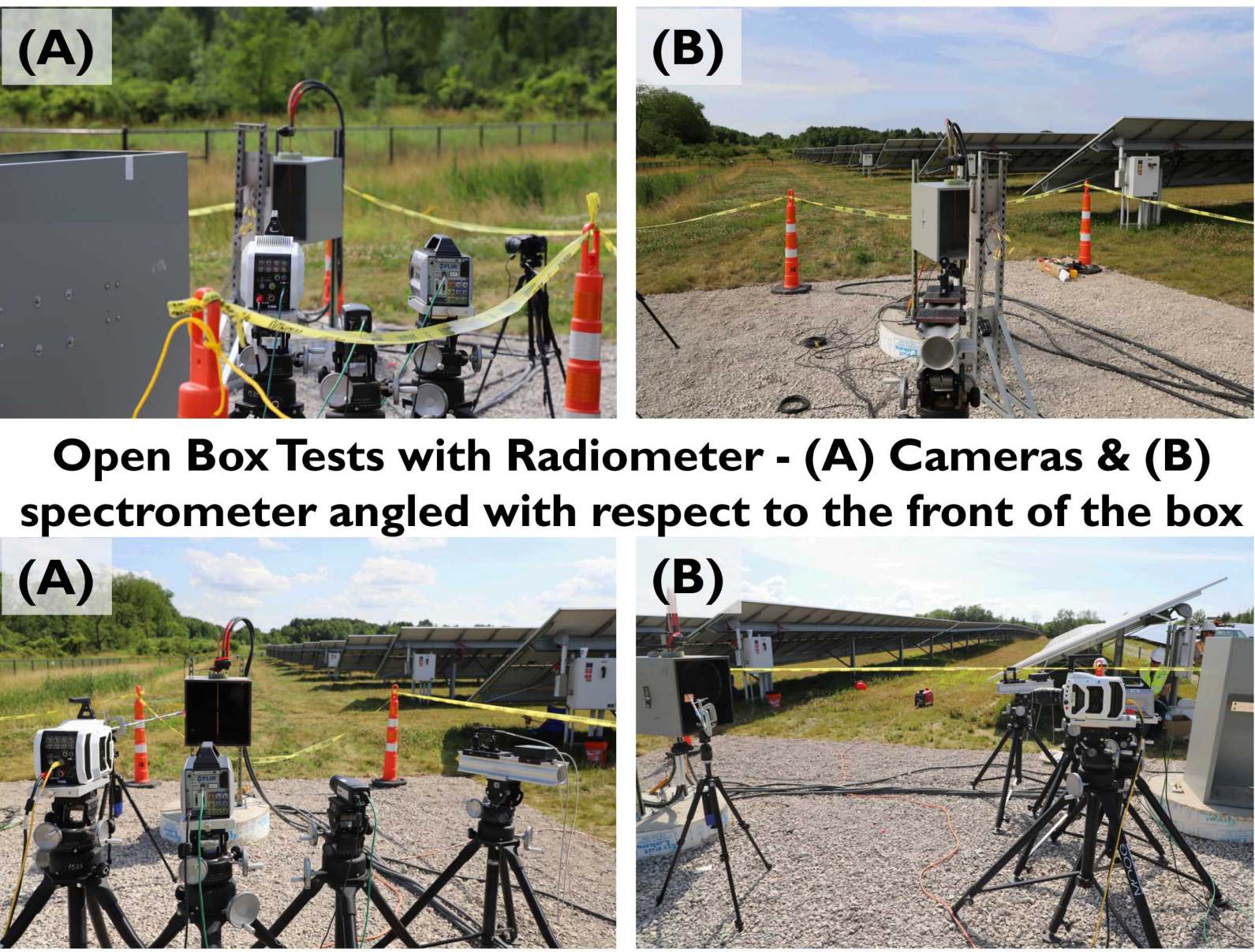
Caroline Winters, Alvaro Cruz-Cabrera, Ray Martinez, and Kenneth Armijo

- 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 [Augsburger 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

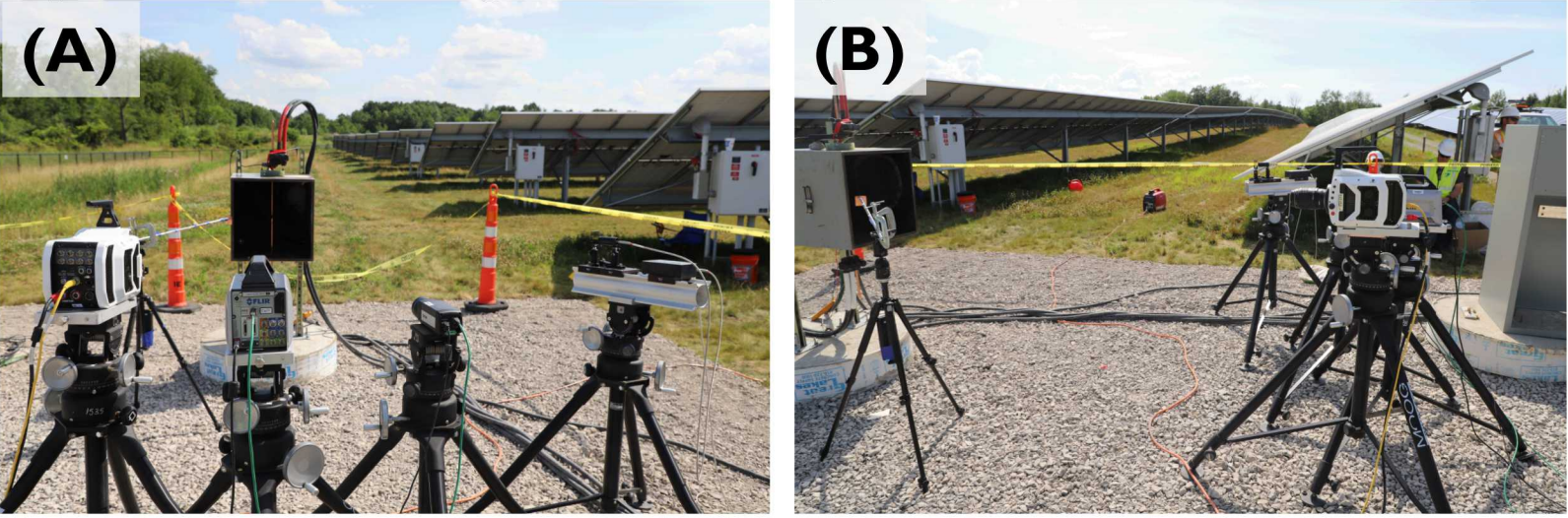
## Experimental Set-up



Schematic and image of arc configuration



Open Box Tests with Radiometer - (A) Cameras & (B) spectrometer angled with respect to the front of the box



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

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

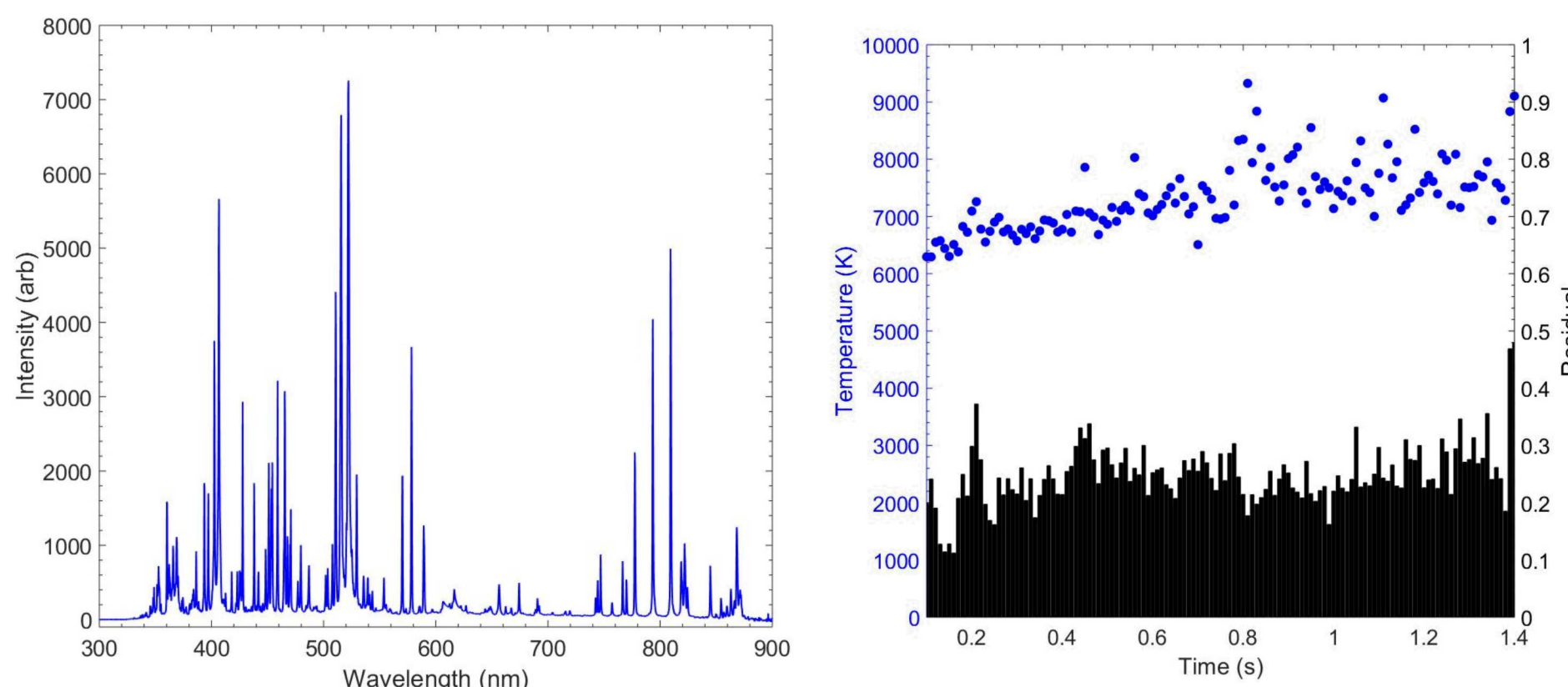
Line intensity,  $I$   
Wavelength,  $\lambda$   
Temperature,  $T$   
Upper state energy,  $E_u$   
Upper state degeneracy,  $g$   
Transition probability,  $A$   
Boltzmann constant,  $k$

## Cu (I) Transitions & Spectroscopic Constants

Wavelength (nm)	$g_u$	$E_p$ (cm <sup>-1</sup> )	$E_{\phi}$ (cm <sup>-1</sup> )
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<sub>DC</sub>, and gap spacing,  $G = 12.7$  mm

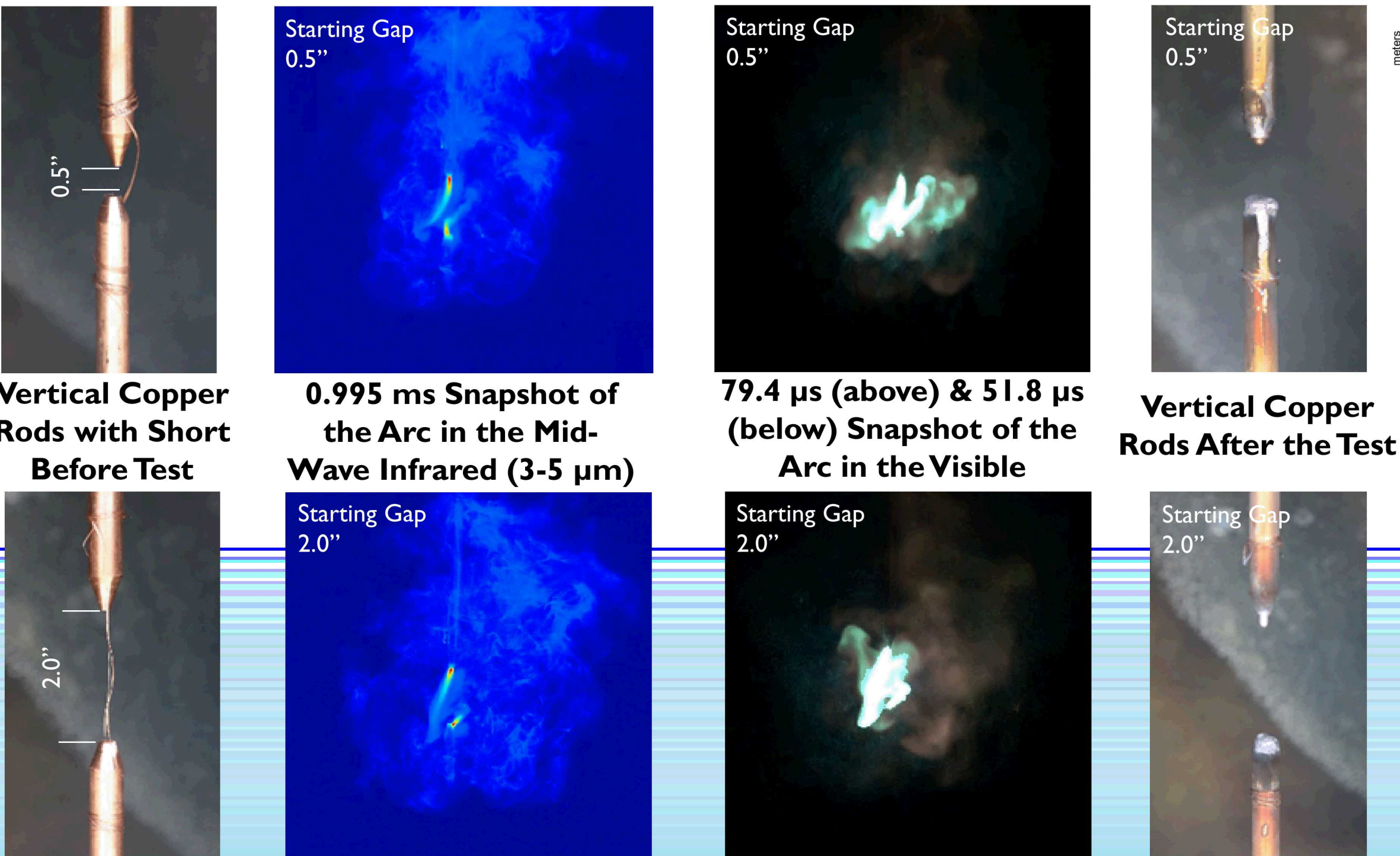


## Arc Temperatures

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

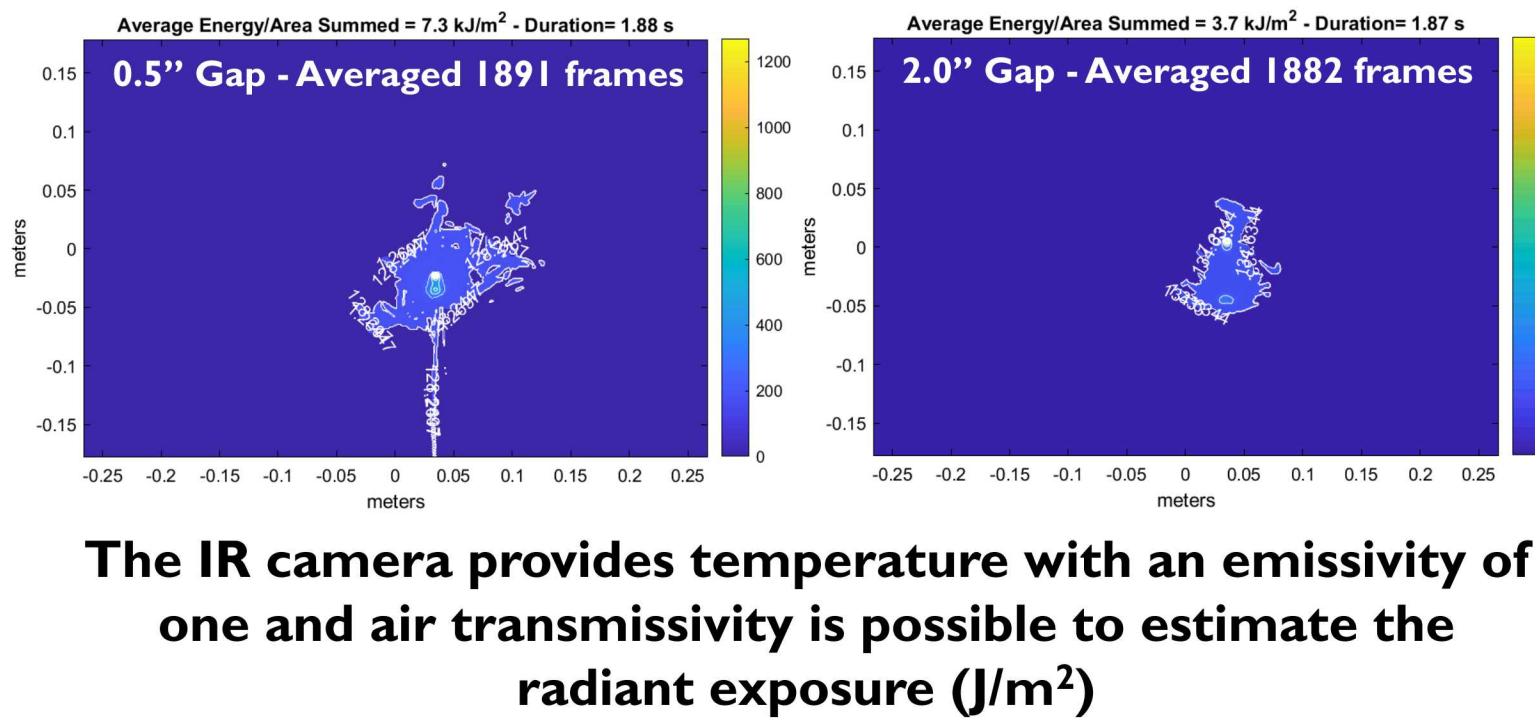
- OES measures the temperature of the copper atoms held within the DC arc
- These atoms were released from the vaporization of the copper electrodes
- Four transitions were identified to generate Boltzmann plots and infer temperature
- The vertical, pin-to-pin electrode configuration produced a more 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



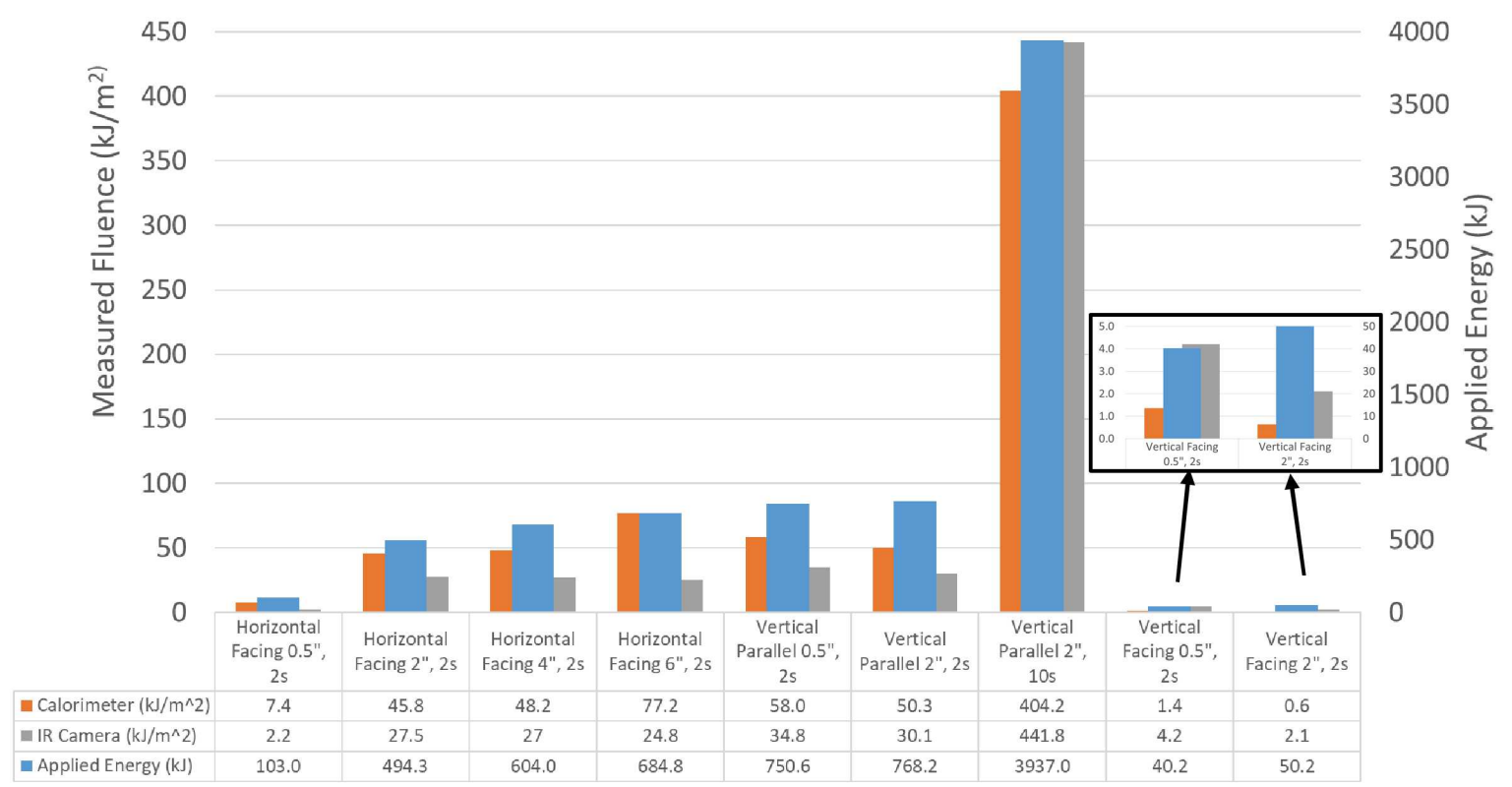
- Infrared Imaging (3-5μm) using high speed (1004 fps) calibrated cameras
- Related to traditional collection methods using calorimeters
- Radiance exposure estimated from a black body assumption
- Zone of influence estimated from average radiance exposure & experimental data to tissue damage by EM radiation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

## Averaging Infrared Frames

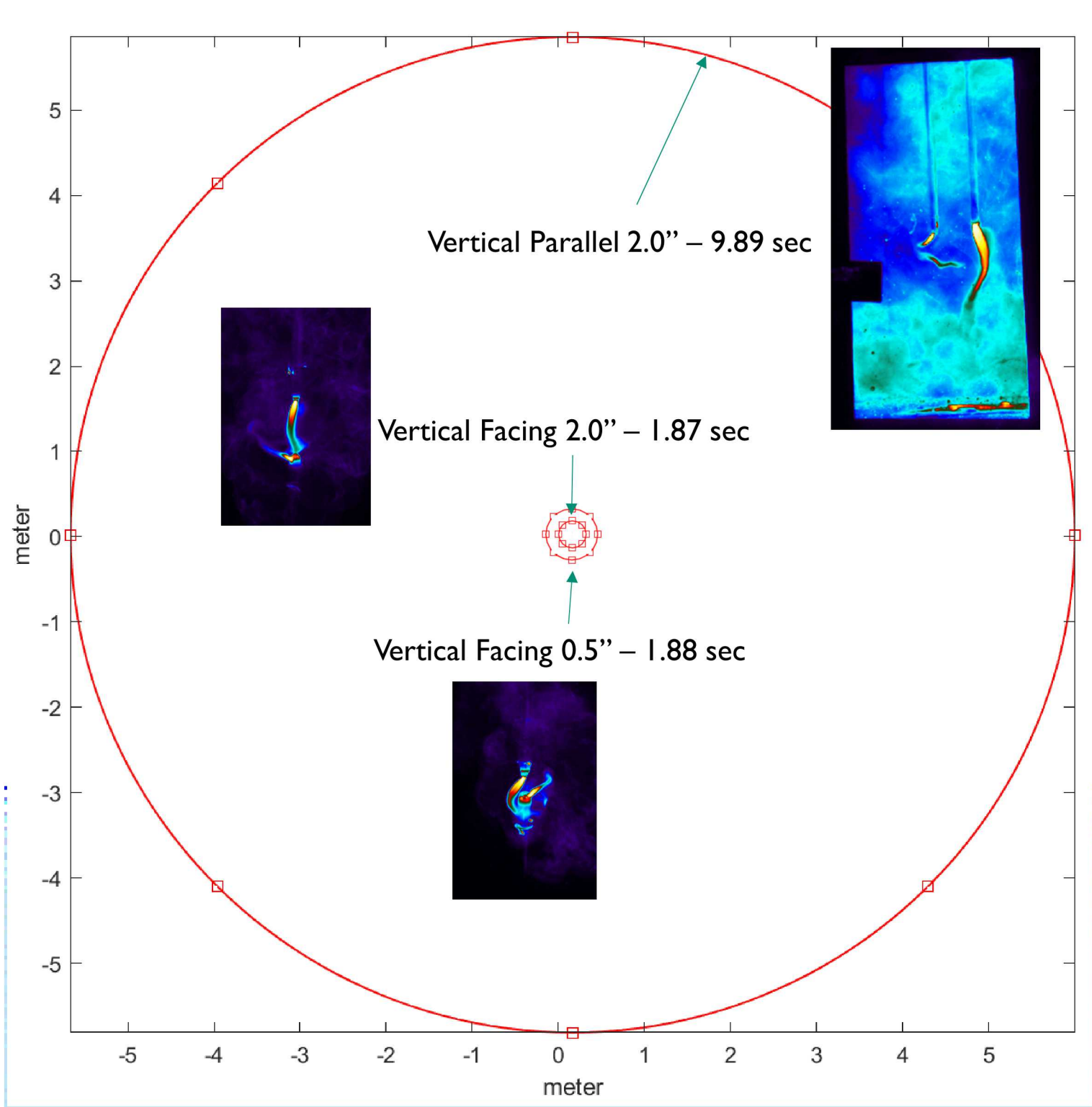


The IR camera provides temperature with an emissivity of one and air transmissivity is possible to estimate the radiant exposure (J/m²)

## Applied Energy & Measured Fluence



## Zone of Influence



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

- Trends

<sup>2</sup>[Kramida, et al.]