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Absolute Calibration Method For Nanosecond-Resolved, Time-Streaked, Fiber Optic Light Collection, Spectroscopy Systems

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Abstract

Presented is a convenient method to calibrate fast (<1ns resolution) streaked, fiber optic light collection, spectroscopy systems. Such a system is used to collect spectral data on plasmas generated in the vacuum gap of electron beam diodes fielded on the RITS-6 accelerator (8-12MV, 140-200kA). On RITS, plasma light is collected through a small diameter optical fiber and recorded on a fast streak camera at the output of 1m Czerny-Turner monochromator. To calibrate such a system, it is necessary to efficiently couple light from a spectral lamp into the small diameter fiber, split it into its spectral components (10 Angstroms or less resolution), and record it on a streak camera with 1ns or less temporal resolution. One method of doing this is with a DC short arc lamp. For this paper, a 300W xenon arc lamp was used. Since the radiance of the xenon arc varies from the cathode to the anode, just the area around the tip of the cathode ("hotspot") was imaged onto the fiber, producing the highest intensity output. To compensate for chromatic aberrations, the signal was optimized at each wavelength measured. Output power at each wavelength was measured using 10nm bandpass interference filters and a calibrated photodetector. These measurements give power at discrete wavelengths across the spectrum, and when linearly interpolated, provide a calibration curve for the lamp. The fiber is then attached to the entrance of the monochromator and a spectrum is taken. The shape of the spectrum is determined by the collective responsivity of the optics, monochromator, and streak tube across the spectral region of interest. The ratio of this curve to the measured bandpass filter curve at each wavelength produces a correction factor (Q) curve. This curve is then applied to the experimental data and the resultant spectra are given in absolute intensity units (photons/sec/cm^2/steradian/nm). Error analysis shows this method to be accurate to within +/-20%.

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Outline

•RITS-6 accelerator at Sandia National Laboratories (SNL)

•Electron Beam Diodes for Flash X-ray Radiography

•Optical Diagnostic Layout on RITS

•Plasmas in Electron Beam Diodes

•Requirements for a Spectral Calibration Source

•Absolute Intensity Measurements

•Imaging Optics

•Streaked Spectra and Applied Intensity Calibrations

•Focal Issues with Lens and Fiber Optics

•Errors

•Summary and Conclusions

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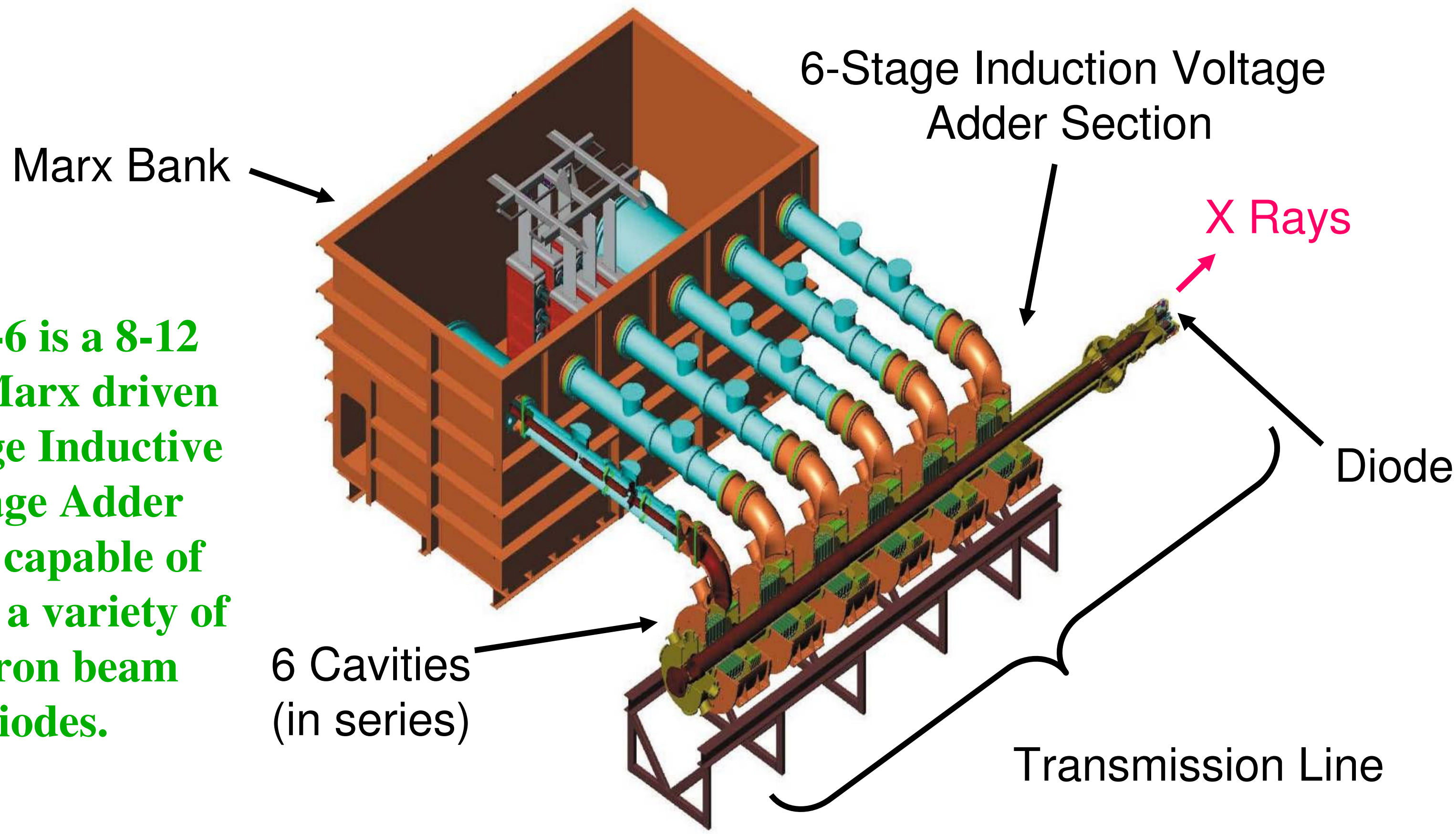
RITS-6 Accelerator at Sandia National Laboratories

RITS-6 is a 8-12 MeV Marx driven six-stage Inductive Voltage Adder (IVA) capable of driving a variety of electron beam diodes.



[1] D. Johnson, et al., *Proc. 15th IEEE Int. Pulsed Power Conf* (IEEE, Jun. 13-17, 2005) pp. 314–317.

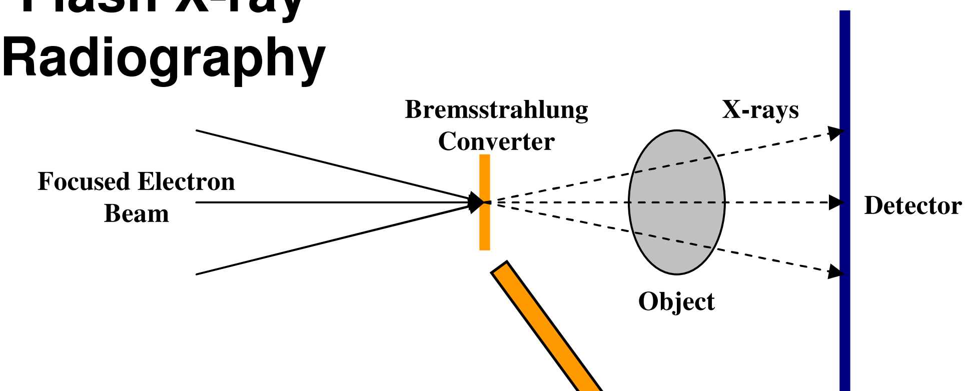
Electron Beam Diodes for Flash X-ray Radiography

Sandia National Laboratories is conducting research and development in pulsed-power driven electron beam x-ray sources for flash x-ray radiography.

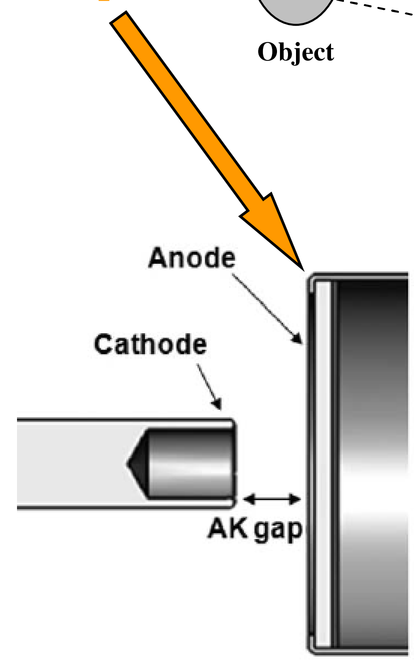
SMP Diode Parameters

- 6-8.5 MV
- 150 kA (~15% ions)
- 50 Impedance
- 70ns Electrical Pulse
- 45ns Radiation Pulse
- > 350 Rads @ 1 meter
- < 3 mm focal spot size

Flash X-ray Radiography



Self-Magnetic Pinch Diode



[2] K. Hahn, et. al., *IEEE TRANSACTIONS ON PLASMA SCIENCE*, VOL. 38, NO. 10, OCTOBER 2010, pp.2652-62.

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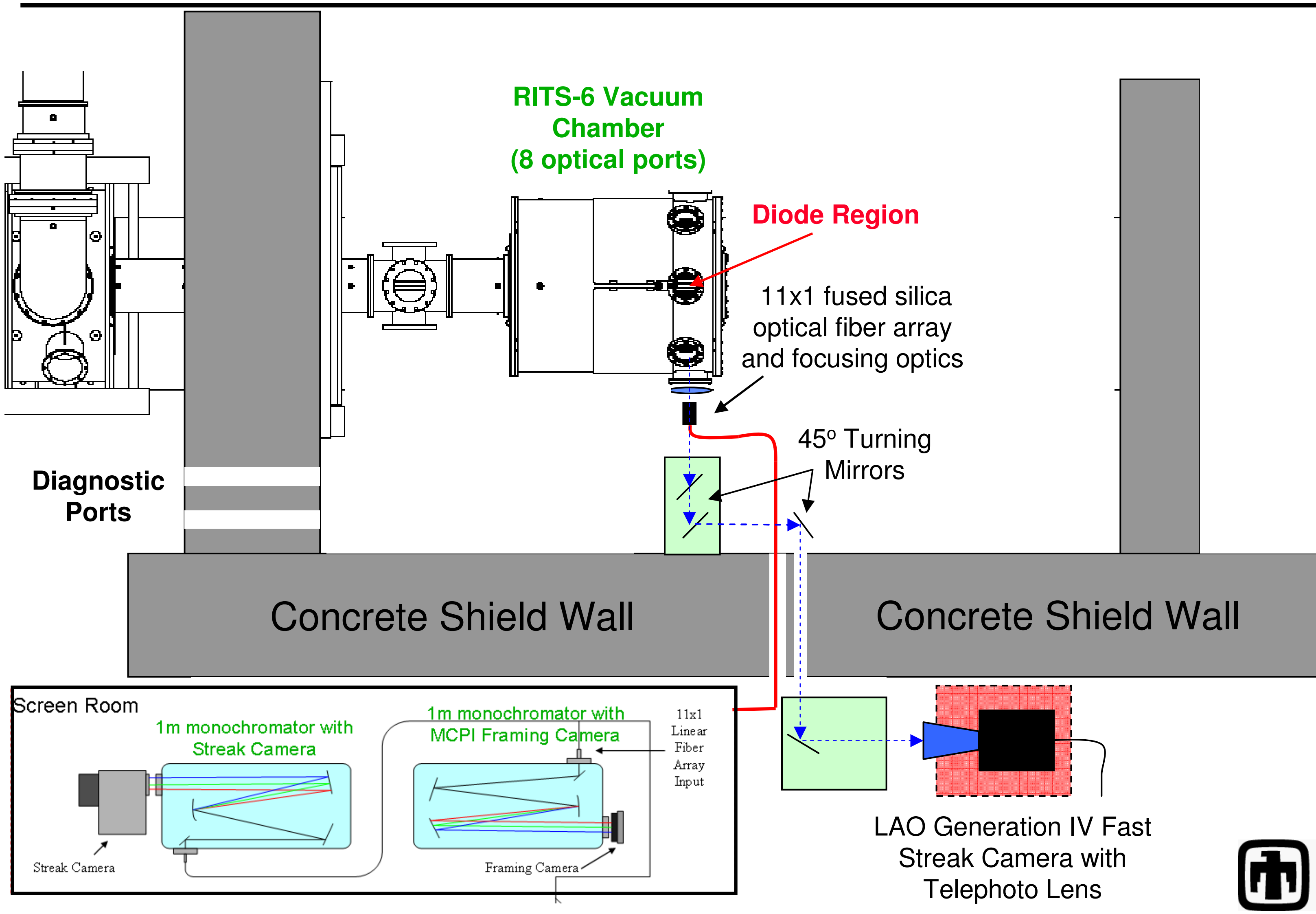
Optical Diagnostics on the RITS-6 Accelerator



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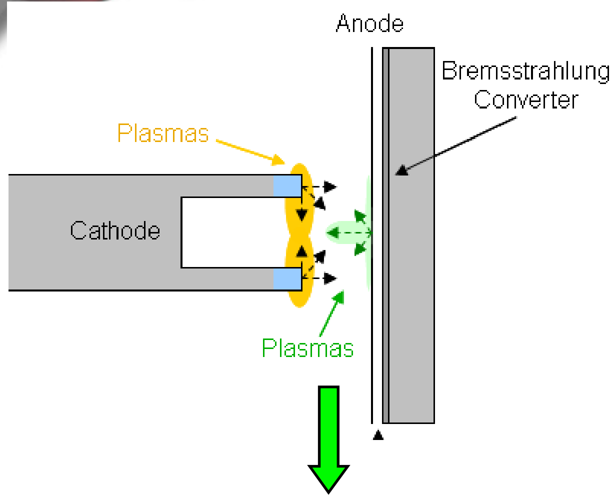
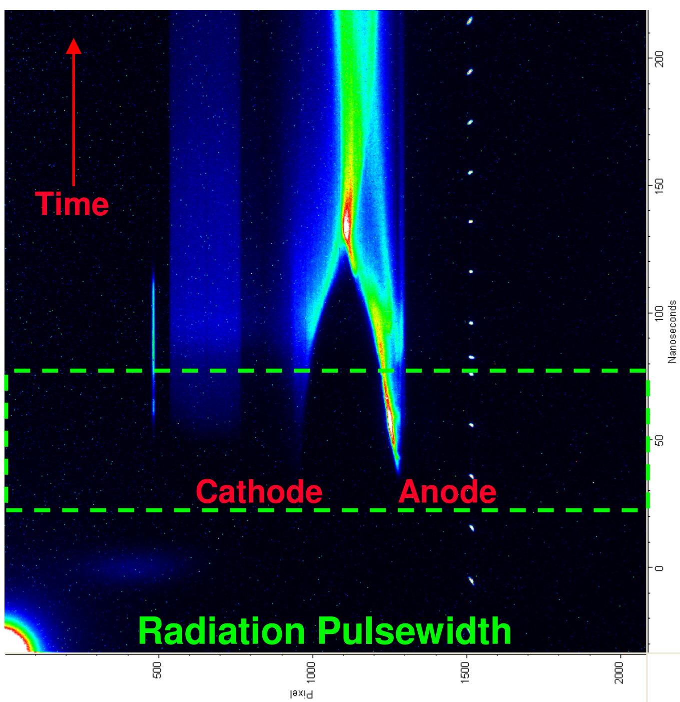
Motivation for Studying Plasmas

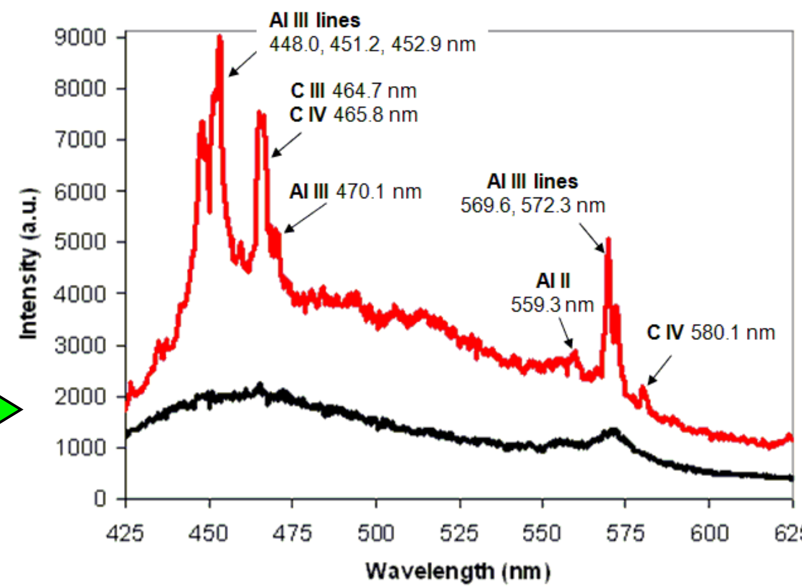


Plasmas generated from the rapid heating of electrode materials in the vacuum diode affect the electron beam dynamics causing changes to the voltage, x-ray spectrum, and pulse-width. Understanding these plasmas and being able to accurately model their behavior is a continuing research effort at Sandia.

Electrode Plasma Evolution



Electrode Plasma Spectra



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Requirements for a Suitable Calibration Source

•Very intense (high brightness) to duplicate experimental conditions.

•Small spatial extent to simulate experimental conditions and couple efficiently with small diameter fiber optics.

•Stable arc formation and low "wander."

•Spectrally flat throughout the visible wavelength region.

•Stable output over time, so multiple measurements can be taken and compared.

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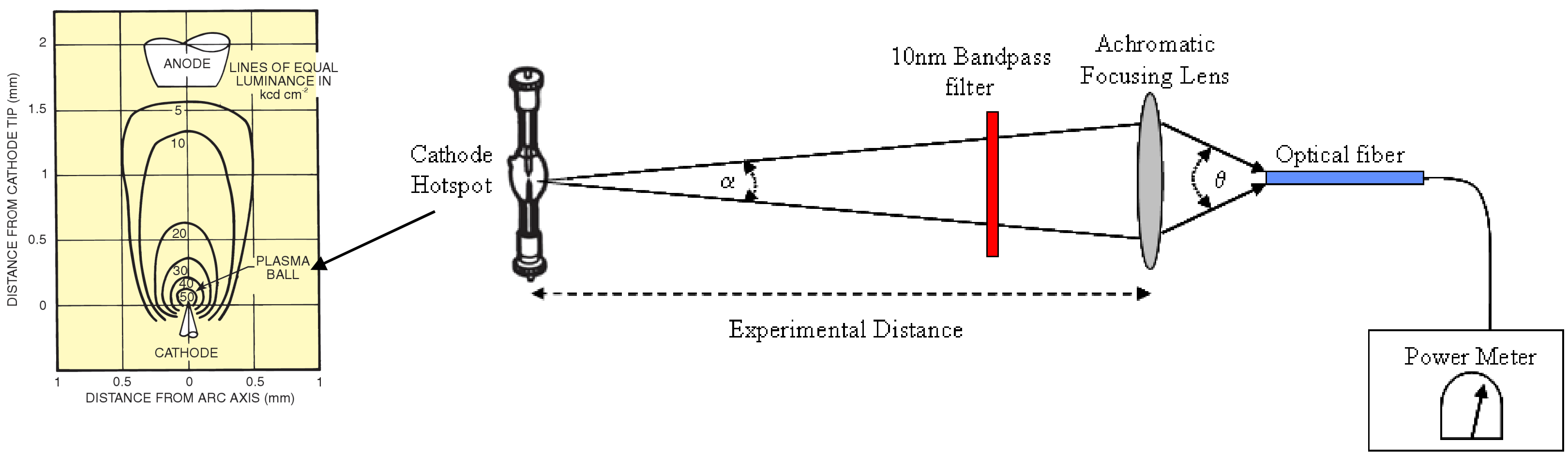
Spectral Calibrations

A 300W DC Xenon Arc Lamp is used as the Calibration Source.
It provides intense, stable, broadband emission across the visible spectrum.



Wavelength (nm)	Power (uW)	Bkgd. (μW)	Corrected Measurement (μW)	Peak Filter Trans. (%)	FWHM (nm)	Actual Power (μW)
400	25.30	0.02	25.28	0.472	9.3	5.758
450	35.60	0.02	35.58	0.493	10.5	6.874
500	39.00	0.02	38.98	0.589	10.6	6.244
550	40.60	0.02	40.59	0.609	10.2	6.534
600	43.50	0.01	43.49	0.744	9.8	5.964
650	36.70	0.01	36.69	0.544	10.8	6.232
700	32.00	0.01	31.99	0.663	11.7	4.124

Power is converted into units of Spectral Intensity (photons/sec/cm^2/steradian/wavelength)

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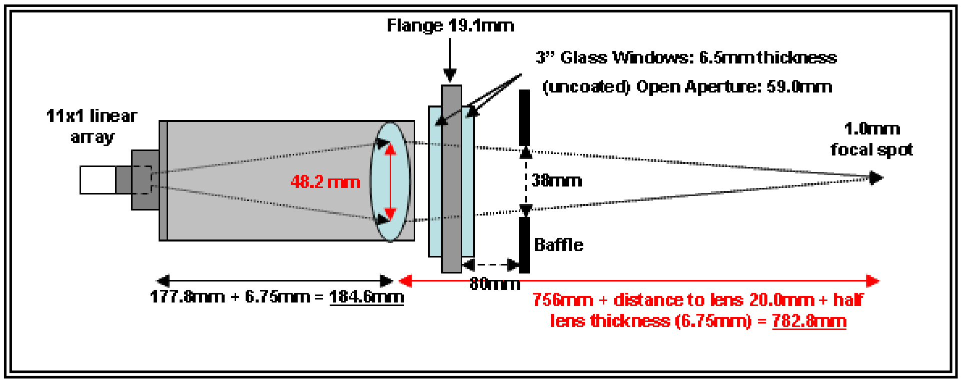
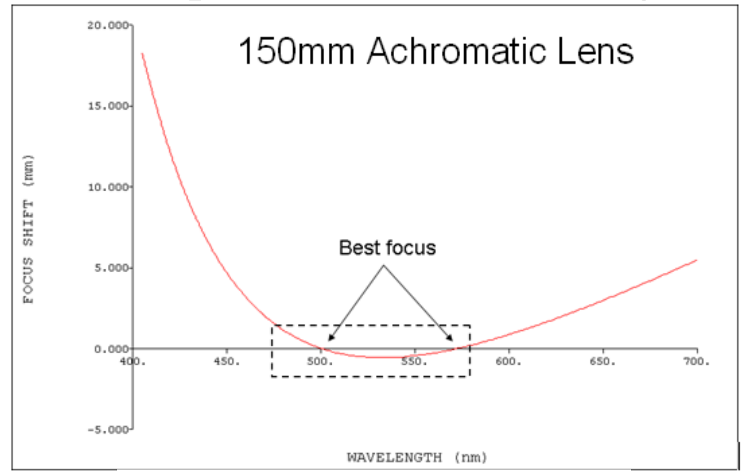
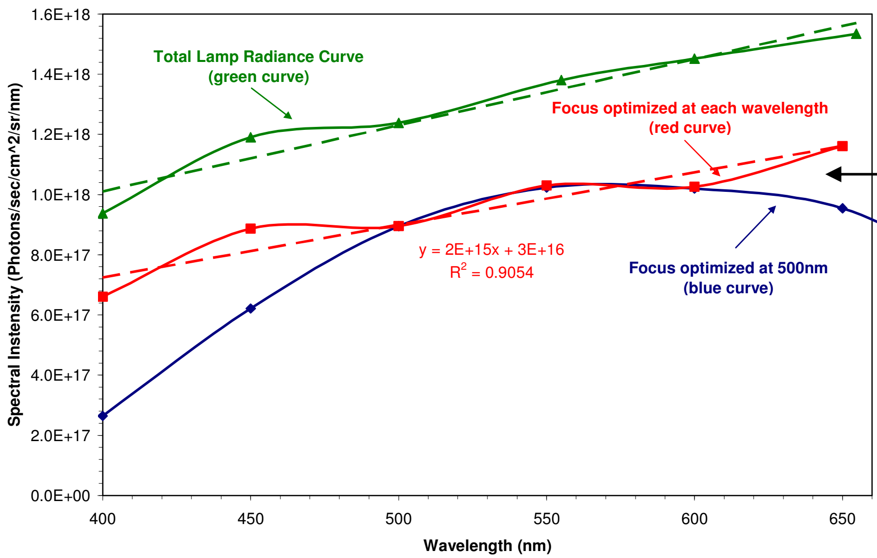
Imaging Optics

Fiber optic configuration



Focal Spot Position vs. Wavelength





Deviation of the blue curve from the red curve represents variations in the focal spot size and location with wavelength. The green curve is the total lamp radiance.

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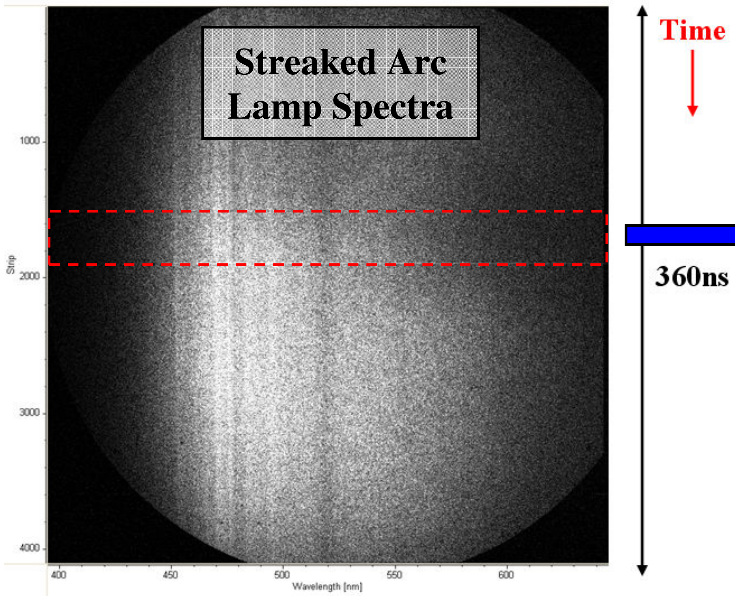
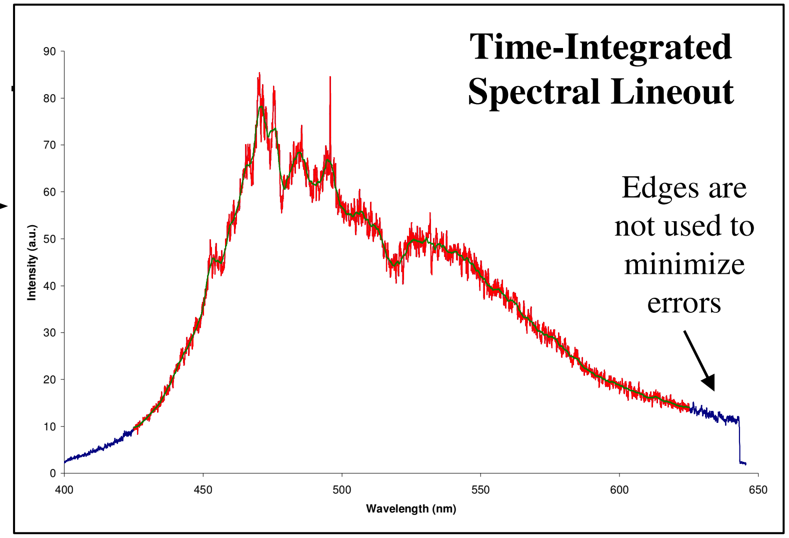
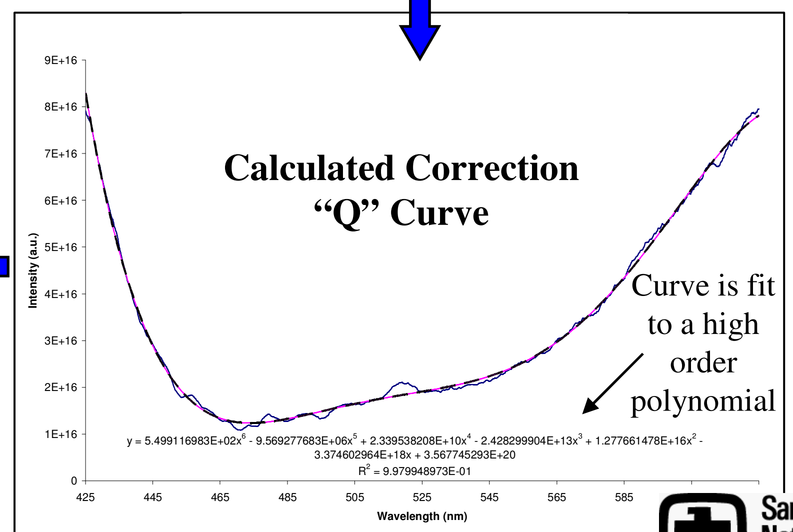
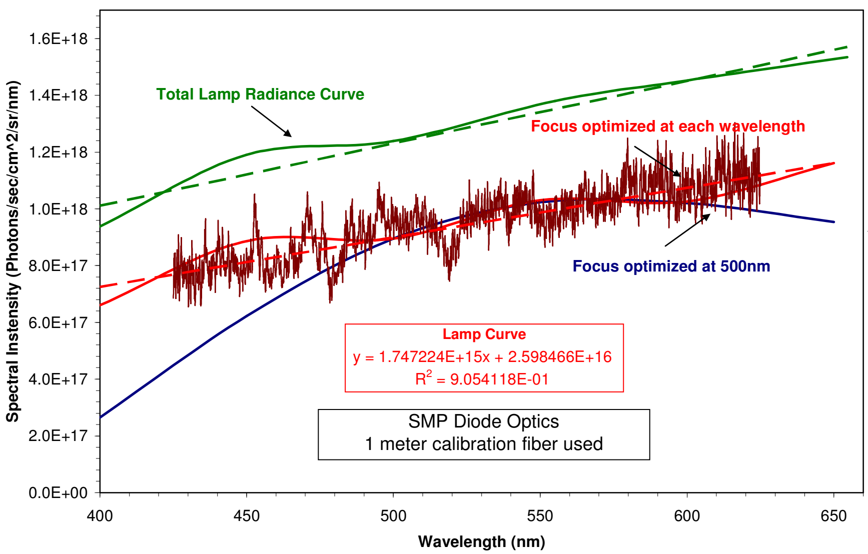
Obtaining Correction "Q" Curve from Streaked Arc Lamp Spectra







"Corrected" Arc Lamp Spectrum



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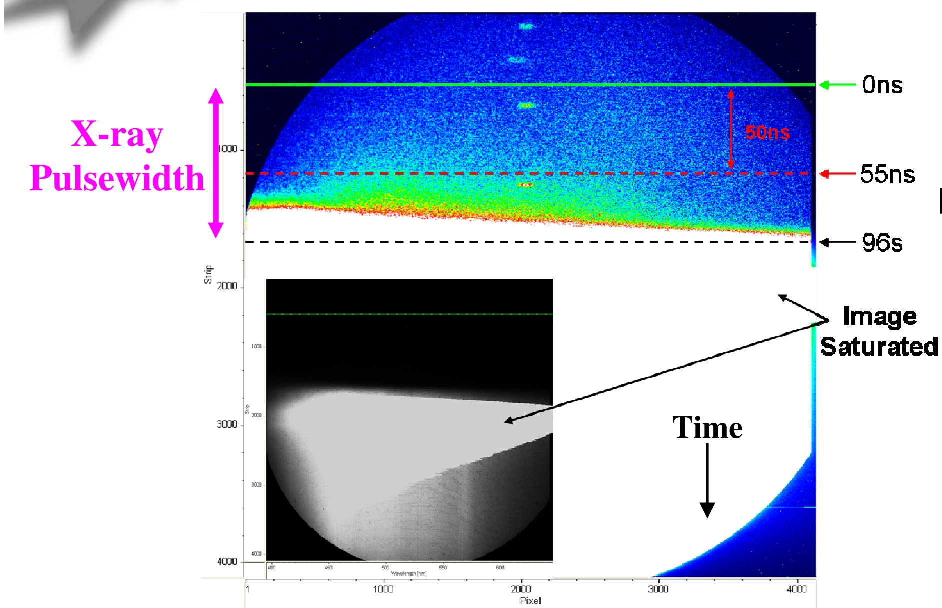
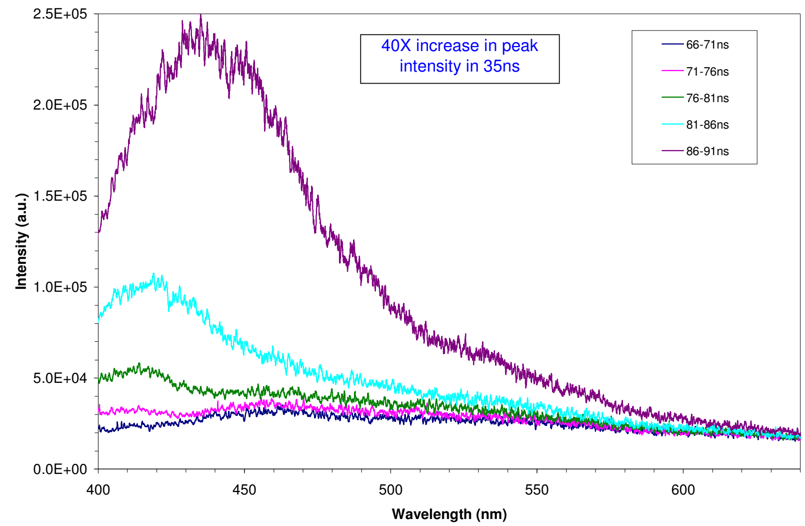
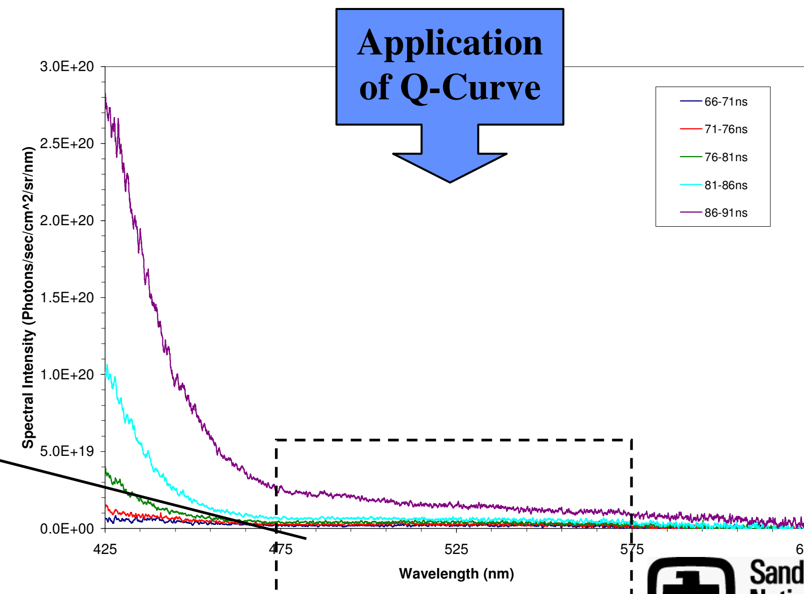
Application to RITS-6 Experimental Data

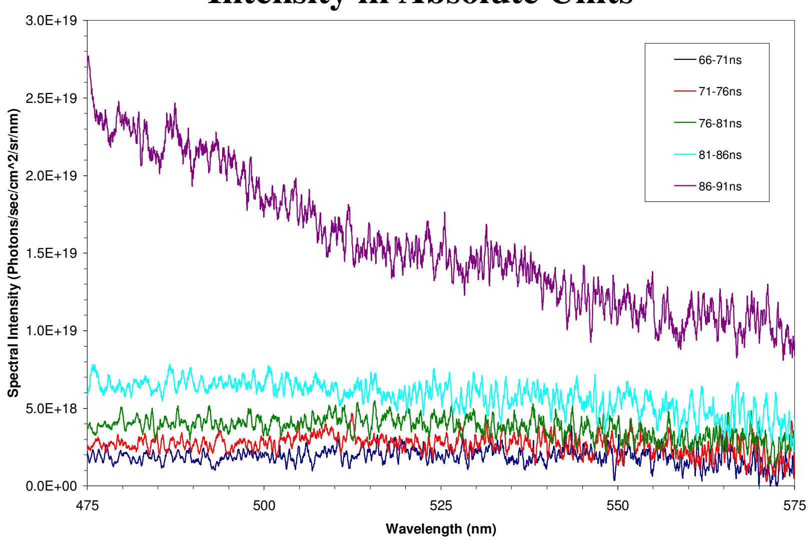


Intensity in Arbitrary Units





Intensity in Absolute Units



*Visible spectrum is dominated by the shorter wavelengths

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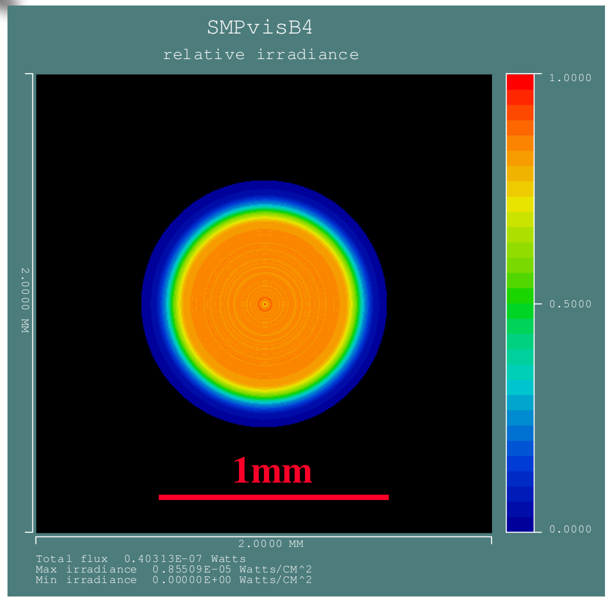
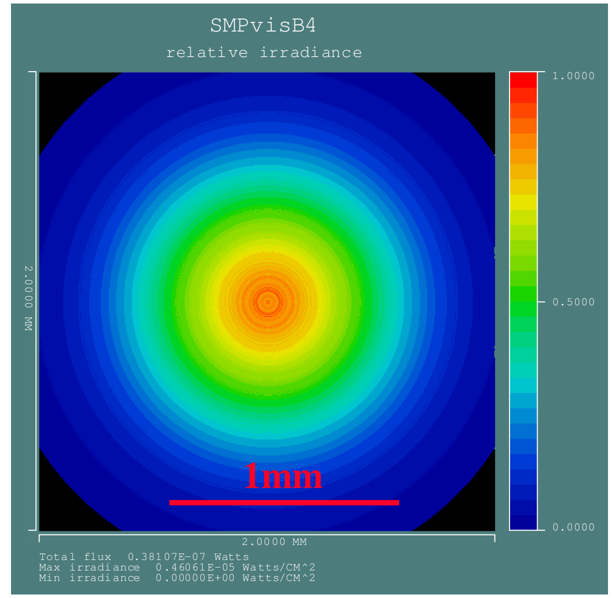
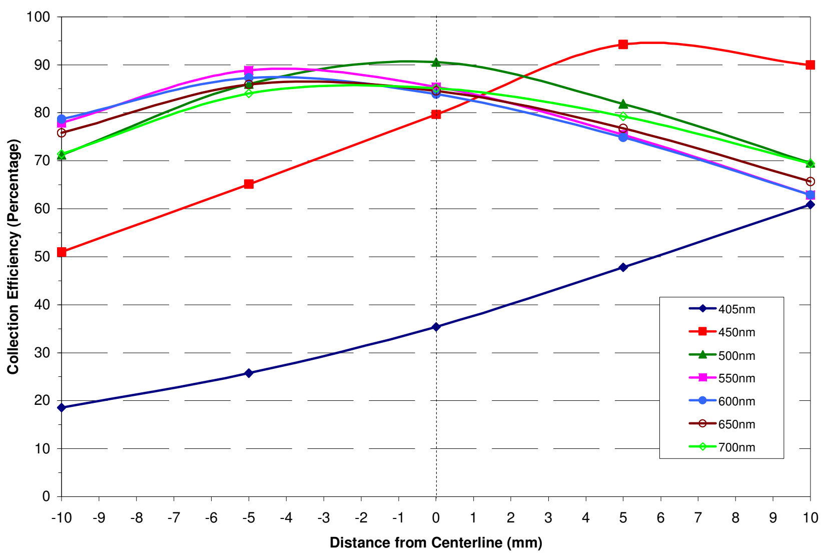
Important Issues Regarding the Optics



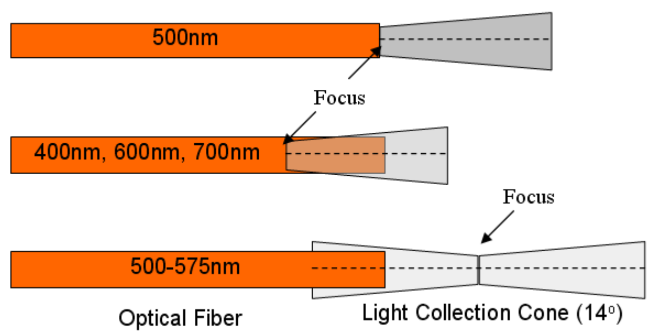
Focal Spot at 500nm*



Focal Spot at 405nm*



Collection Efficiency vs. Wavelength



Focusing Light into a small diameter optical fiber

*Simulations done using Code V Illumination Analysis

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Errors in Absolute Intensity Measurements

Component	Percent Error (+/-)
Power Meter	3.0
Bandpass Filter-Peak Transmission	2.5
Bandpass Filter-FWHM	20
Bandpass Filter-Central Wavelength	0.5
Arc Size Measurement	25
Solid Angle Measurements	2.0
Power/Irradiance Measurements	20
Radiance Measurements	30
Streak Camera Intensity	5.4
Focal Spot Size	15
Optical transmission	5

Total System Error: +/- 20%

***Obtained by propagation of errors method.**

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Summary and Conclusions

•A 300W DC Xenon Arc Lamp provides a suitable source for calibrating fast (<1 ns resolution), streaked, optical spectra like that collected on the RITS-6 accelerator.

•Calibrations are done by measuring the power output of the arc lamp's cathode "hotspot" through a set of calibrated bandpass filters using a NIST calibrated power meter through the experimental optics.

•Power measurements are converted to units of spectral intensity based on the solid angle of the optics and the fiber optic acceptance cone.

•The ratio of the streak camera lamp spectra to the bandpass calibration curve generates a correction "Q" curve. This curve is applied to the experimental data.

•Corrections for optical losses at all surfaces are included.

•Corrections for variations in the focal spot size and collection efficiency at different wavelengths are taken into account.

•Total combined error obtained by using this method is +/- 20%, which represents a high level of accuracy for plasma measurements in these environments.

***Also see talk IO6D-3: Load Impedance Dynamics in the RITS-6 Self-Magnetic-Pinch Diode.**