# Iso-Intensity Contour vs. ISO Laser Beam Representation *

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## ABSTRACT

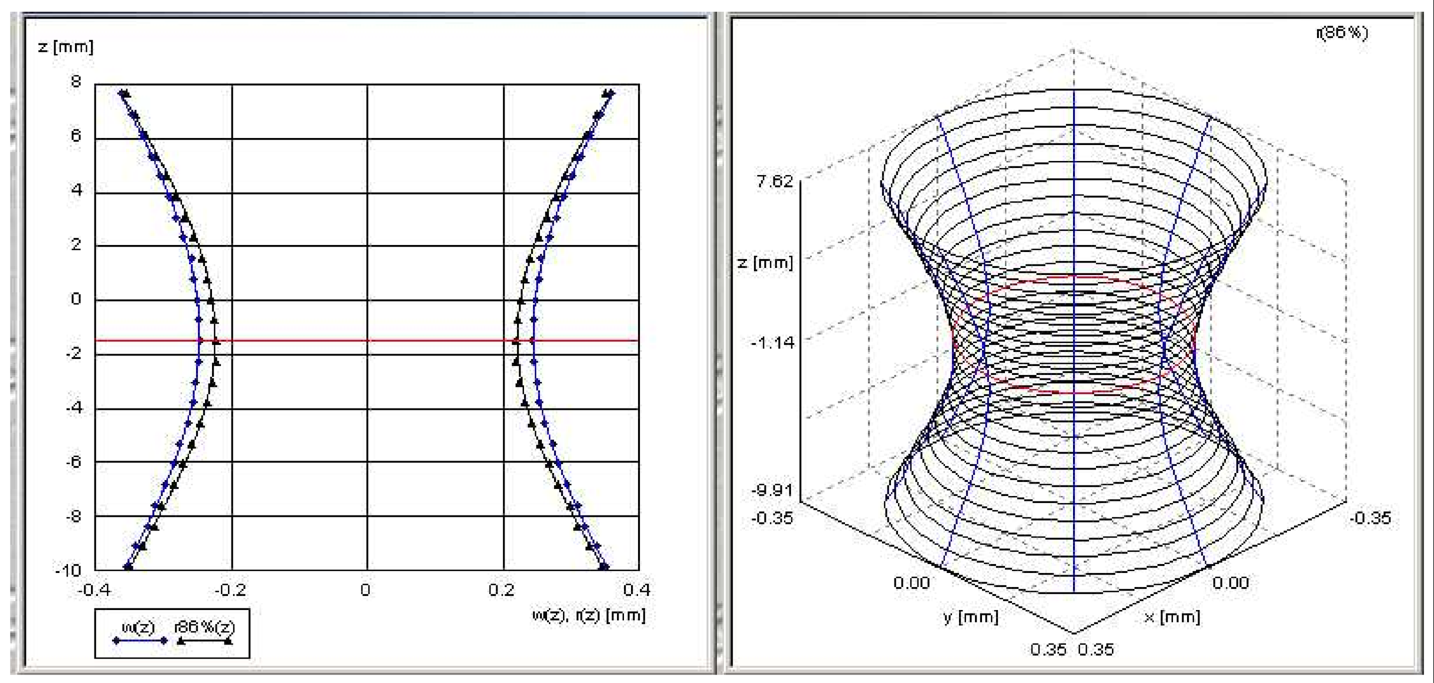
The ISO11146[1] laser beam characterization standard measures the $1/e^2$ peak power locus in planes normal to the beam propagation axis to quantify beam quality ($M^2$) and power density ($W/cm^2$) along the beam path. This analysis yields the minimum focal spot and position, giving an intuitive indication that the beam shape in the focal region is hyperbolic-like. However, we have found re-plotting the same measured information as onion-like iso-intensity contours gives a much better indication of the beam-intensity interaction zone.

## Standard ISO Beam Characterization Method

*Beam Propagation Equation*

$$\omega(z) = (\omega_0^2 + (M^2\lambda(z-z_0)/p\omega_0^2)^2)^{0.5}$$

### ISO beam caustic for a 350 W fiber laser (beam propagation axis vertical)




The ISO standard caustic along the beam propagation direction (BPD) defines the set of circles within which 86% of the beam's power is contained. This suggests the beam's hourglass shape. However, the caustic envelope is the collection of $1/e^2$ beam intensity ratio locations, and since the peak power along z varies strongly, the intensities at these locations are not held constant. *Since the interaction of the beam with the target (i.e. it's ability to heat a surface) depends upon the beam intensity at that location, an iso-intensity representation may be more useful, as shown in the following discussion.*

## Iso-Intensity Contour Beam Representation

For a Gaussian-distributed beam, peak intensity ($I_0$), the total power in the beam (P) and beam size ($\omega_0$) are related via[2]:

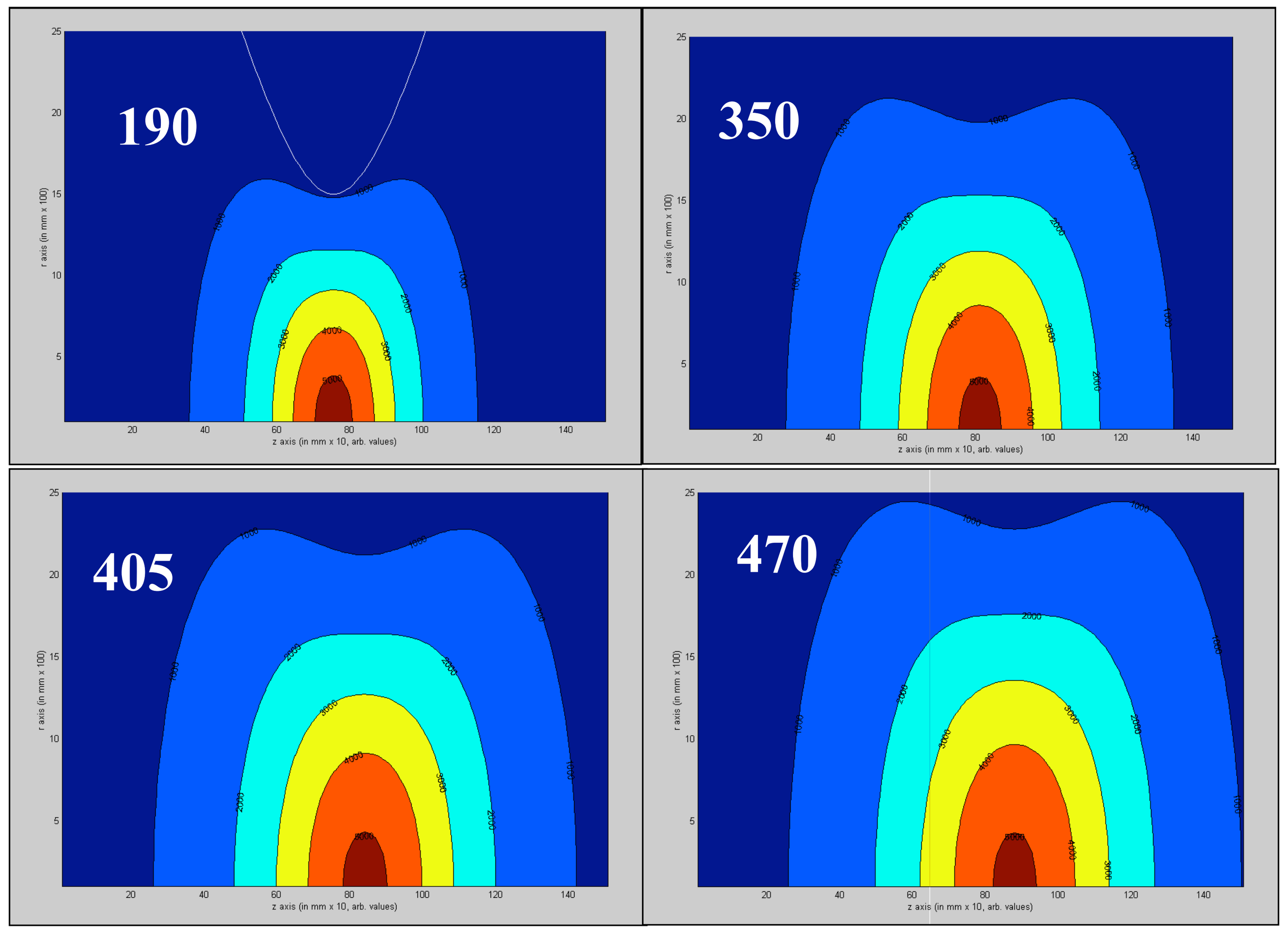
$$I_0(z) = 2P / \pi\omega(z)^2$$

The beam size $\omega(z)$ from the Beam Propagation Equation using experimentally-determined values $M^2$ and $\omega_o$ for a 500W maximum Nd:YAG laser was determined. Next, we calculated intensity versus radius r and position z from:

$$I(r,z) = I_0(z)\exp^{-2}(r/\omega)^2$$

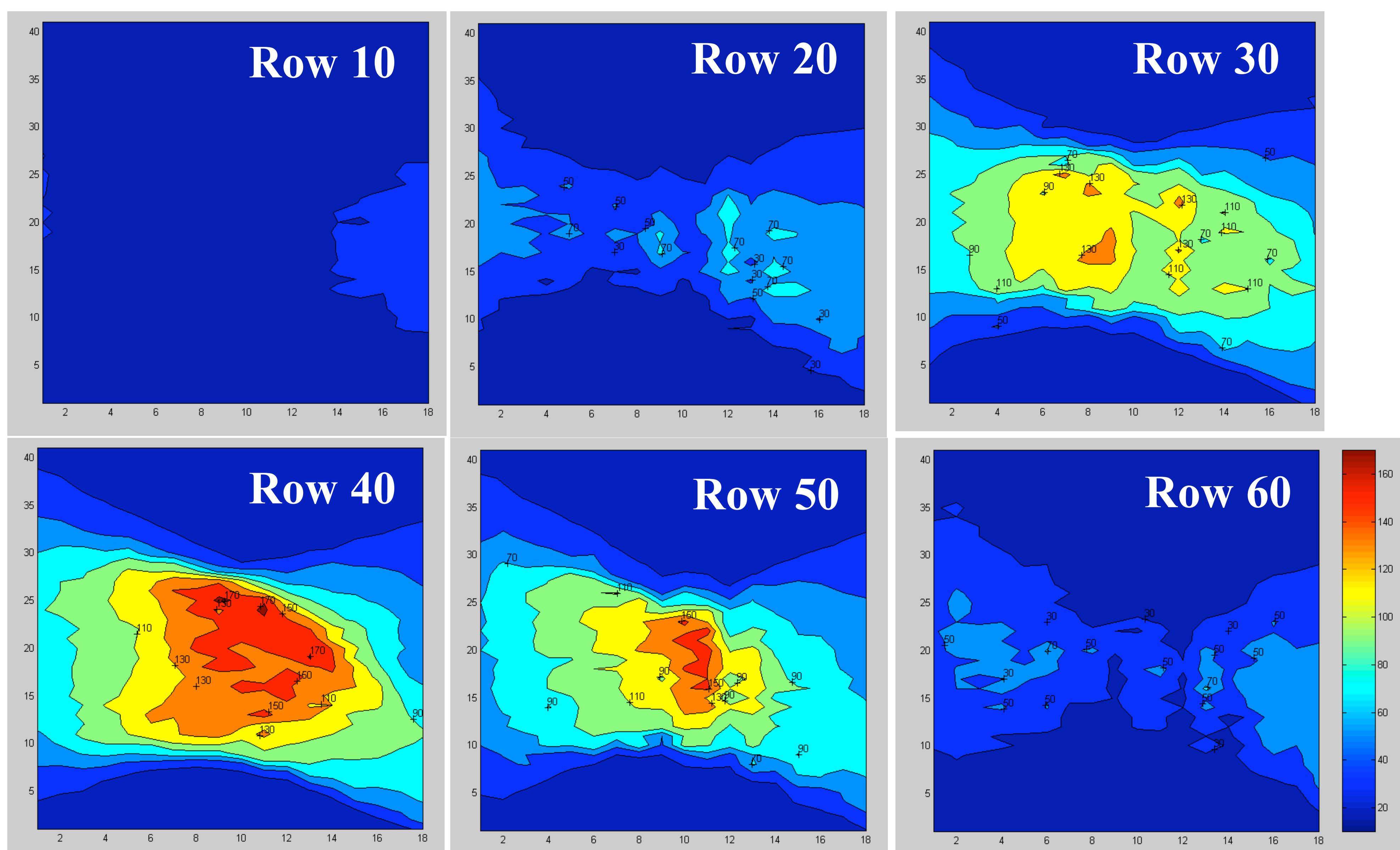
Standard MATLAB contour plots of I(r,z) are shown below, where the BPD is horizontal and because of symmetry only half of the beam is shown (note that the ISO caustic is shown as a light blue line in the 190W panel). It is interesting that for this specific laser, while the overall beam focal region grows with power level, the highest intensity contour size remains constant.

### Iso-intensity contours vs. power for a 500 W Nd:YAG laser




If one does not assume a Gaussian beam, the raw intensity data files obtained from a commercially-available flying-wire type beam profiler can be reformatted to provide a similar representation. The following shows slices parallel to the beam propagation direction for a different Nd:YAG laser (Row 40 is approximately on the beam centerline, units are arbitrary but consistent from panel to panel). This beam was not normal to the device's plane of wire rotation, and shows evidence of asymmetry and hot spotting.

### Beam intensity contours in planes parallel to the BPD




Finally, the practical importance of intensity contour profiling can be seen in the following, where weld penetration vs. defocus data is compared with iso-intensity contour data for a $CO_2$ laser.

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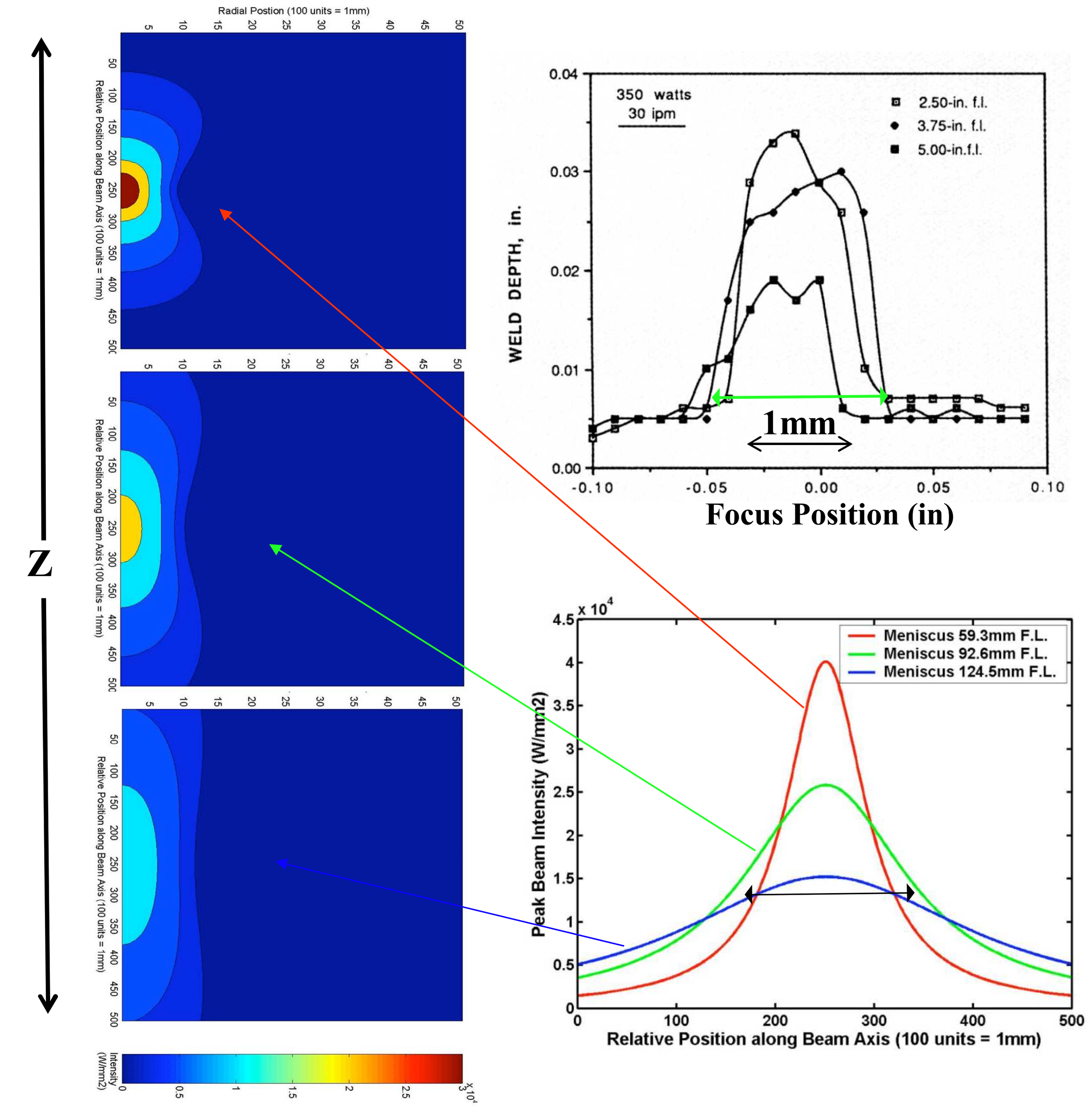
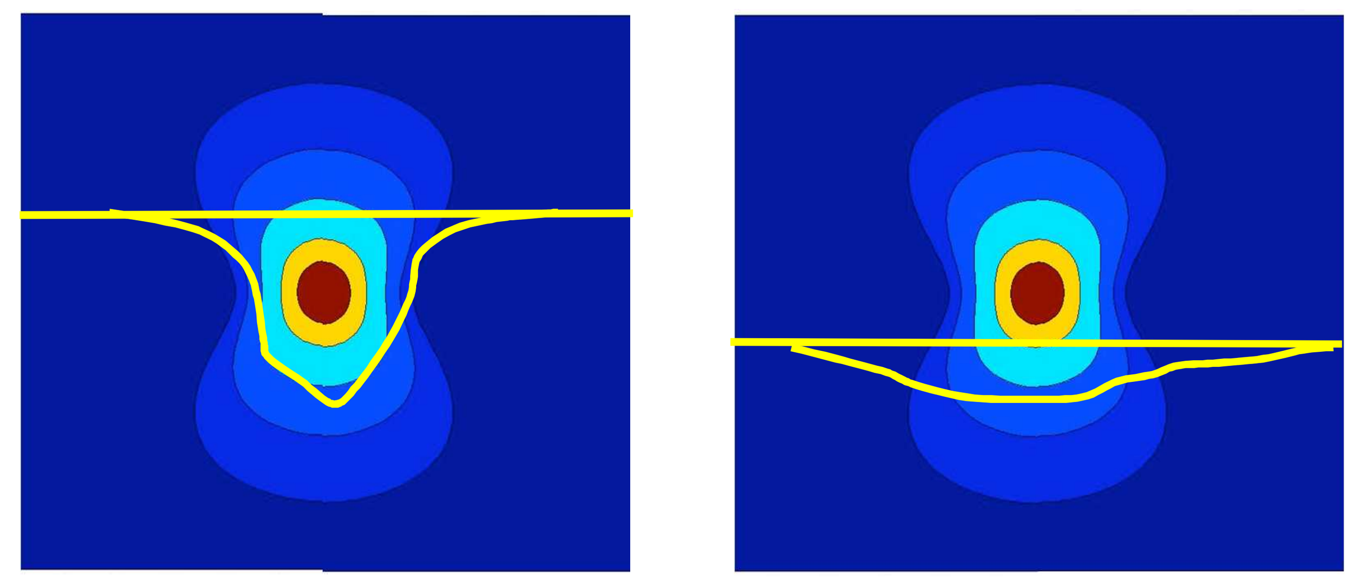
### Intensity contours & weld penetration depth for three meniscus-type lenses[3,4]

Top, 59.3mm (~2.5"); middle, 92.6mm (~3.75"); bottom: 124.5mm (~5") focal length for $CO_2$ laser welds on 304SS.




### Schematic conduction and keyhole welds vs. focus position



## Summary

**Standard ISO11146 analysis emphasizes beam shape, quality and focus location in a plane, but is misleading as to the beam intensity distribution.**

**An alternative and simple form of beam characterization: iso-intensity contour plotting versus radial and beam propagation directions requires no additional information beyond that obtained from modern beam profilers, but adds insight about the spatial extent of a laser beam and how this may affect beam- material interactions.**

*References:*

1. **Document ISO/11146:1999(E),** *Test methods for laser beam parameters: Beam widths, divergence angle and beam propagation factor, ISO, June. 1999.*
2. **Ready, J.F,** *Industrial Applications of Lasers, Academic Press, New York, 1978, p41.*
3. **Brandon, E.D.,** "Characterization of Focusing Lenses For CO2-Laser Beam-Welding", Welding Journal; Jun 1992; v.71, no.6, p.55-63 ,
4. **Essien, M., Fuerschbach, P.W. ,** *"Beam characterization of a materials processing CO2 laser", Welding Journal, Feb. 1996; v.75, no.2, p.47s-54s*

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