

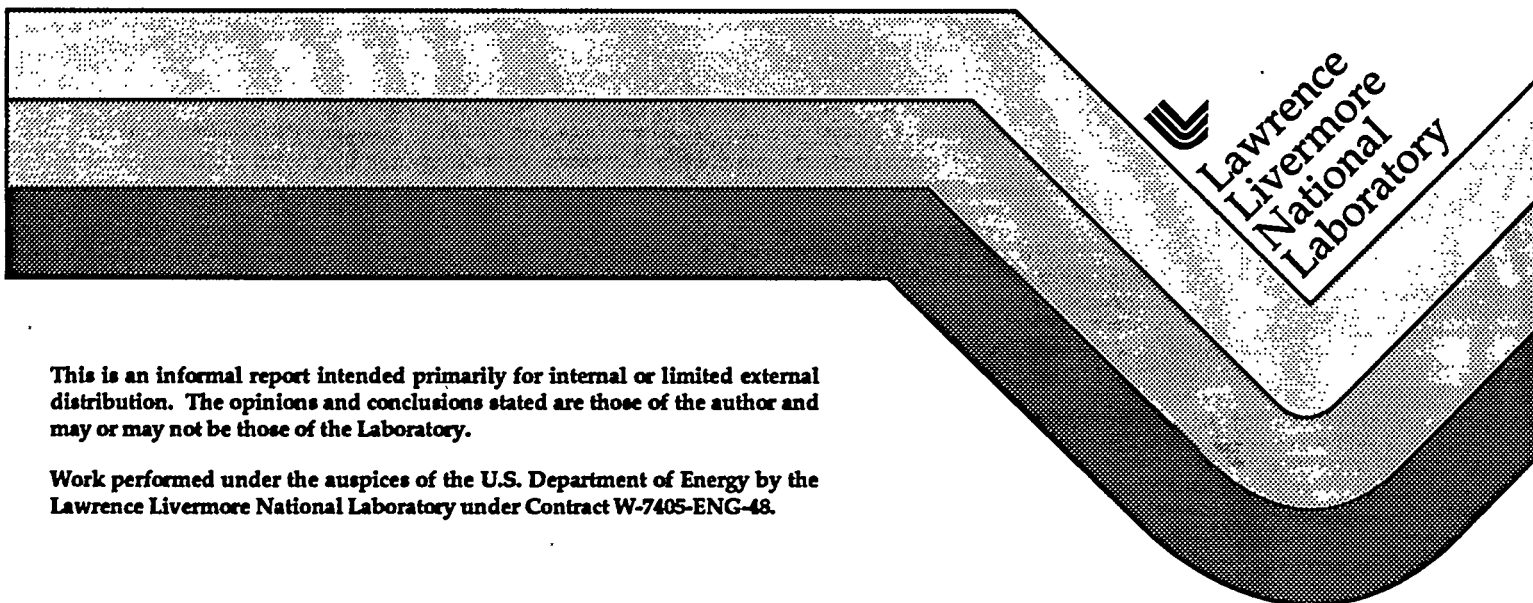
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**Small-Business Technology Transfer Program
Case Number 93119
Second Harmonic Generation for Lee Laser Inc.
Resonator Designs**

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**Small-Business Technology Transfer Program
Case Number 93119
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Resonator Designs

Gaylen V. Erbert

Introduction

We have investigated several resonator designs for Lee Laser Inc. as outlined in the Short-Term Technical Assistance Project, case number 93119. The scope of this work was to identify various resonator options which would be suitable for use in an intra-cavity doubled Nd:YAG laser and compatible with Lee Laser hardware. This work consisted of computer modeling of laser resonators to identify mirror curvatures, distances, beam sizes, and sensitivity to thermal loading of the laser rod.

Two basic resonator designs were investigated in this work. One was a TEM₀₀ mode design for low-power, high-brightness applications. The second design was a multi-mode laser for high-average-power applications. The critical design criterion for both cases is the resonator beam size on the KTP crystal which determines the size, cost and power density on this element. For some applications the sensitivity of this beam size with thermal lensing may be important so this was also included in the analysis. Generating short pulses is important for many applications so resonator cavity lengths were kept to a minimum. Output powers, pulse widths and thermal lens values used in this report are estimates based on information provided by Lee Laser and our own experience at LLNL.

TEM₀₀ Mode Design

The TEM₀₀ resonator is a challenging design because of the small beam size and corresponding high power density on the KTP crystal. The general design criterion used at LLNL is to keep the peak power density of the second-harmonic light on the KTP crystal below 1.0 MW/cm². This is not a hard number and operating at higher power densities is certainly possible. Damage to the KTP crystal is difficult to predict and depends on many factors. This includes details of the laser dynamics such as the spatial mode distribution and the temporal behavior of the pulse.

A symmetric flat/flat resonator with a 45 degree fold mirror is shown in Figure 1. The fold mirror is a dichroic which transmits the second-harmonic light and is the output mirror of the laser. The flat/flat

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"L" cavity is a simple and stable design which could easily be integrated with Lee Laser hardware. Figure 2 shows a plot of the calculated TEM₀₀ beam radius as a function of position in the resonator. The rod is located in the center of the cavity which ensures a symmetric spatial mode distribution throughout the rod. Figure 3 shows a plot of the beam size on the KTP crystal as a function of the thermal lens in the rod. The laser rod is modeled as a lens duct whose focal length is a function of the lamp power. As shown in Figure 3, the laser is stable over a large range of thermal loading in the rod. The spot size on the KTP crystal slowly decreases with increased lamp power.

With a thermal lens focal length of 500 mm the TEM₀₀ beam radius on the KTP crystal is .376 mm. If we assume a second-harmonic power of 5 watts at 5KHz and an 80 ns pulse width, the peak power density on the KTP crystal is 2.8 MW/cm². This is about a factor of three higher than the highest power densities routinely operated with at LLNL. It is unclear whether KTP will survive at this power density. The smooth gaussian beam profile of the TEM₀₀ mode may help in this respect. However, testing will be needed to determine whether the laser will operate reliably at this power density.

The resonator beam on the KTP crystal can be increased slightly by using a -1000 mm radius on the rod ends to compensate for the thermal lens. In this case the beam radius on the KTP crystal would be .55 mm reducing the peak power density to 1.3 MW/cm².

Figure 4 shows an alternative resonator design where the beam radius on the KTP crystal has been increased to 1.0 mm. This is achieved by using a negative curved mirror on one end of the resonator and operating near the edge of the stability curve. Figure 5 shows a plot of the calculated TEM₀₀ beam radius as a function of position in the resonator. The power density on the KTP crystal under the same conditions listed above is only 0.4 MW/cm² which should be well within the safe operating range of KTP. The disadvantage of this resonator design is the sensitivity of the spot size with thermal lens as shown in Figure 6. This resonator would only be stable at high lamp powers so adjusting the lamp power may not be a reliable method of varying the output power of the laser. In addition the spatial mode distribution in the rod is slightly asymmetric which may reduce the efficiency of the laser.

Multi-mode Design

For the multi-mode resonator design, the power density of the KTP crystal should not be as difficult a problem as for the TEM₀₀ design because of the larger rod and beam diameter. In this case the rod is the

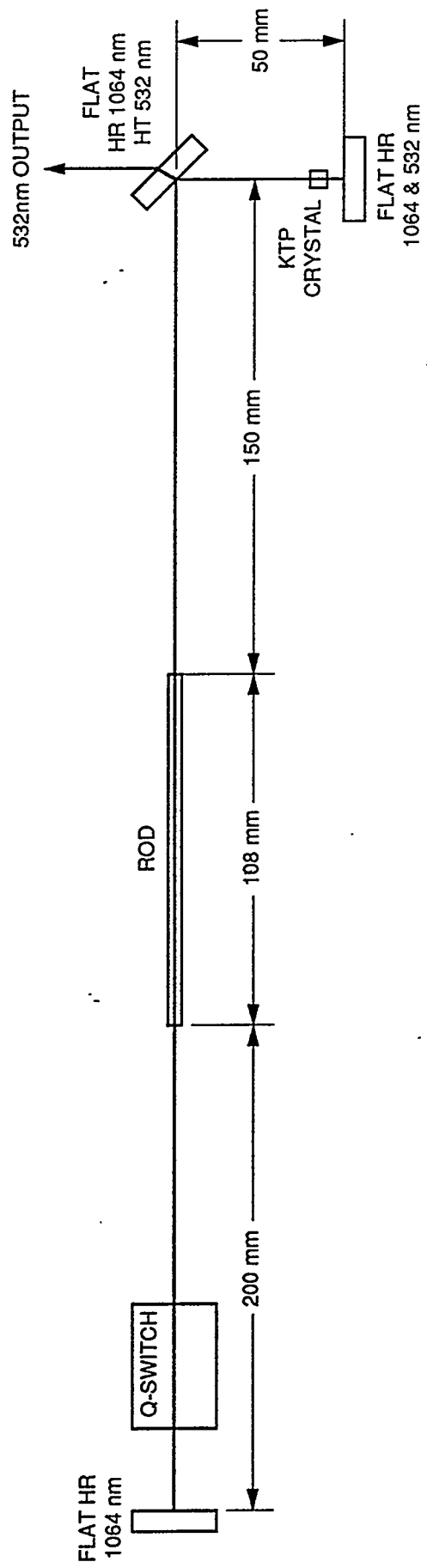


FIGURE 1. Symmetric flat/flat resonator design for TEM₀₀ operation.

Symmetric flat/flat TEMoo resonator design

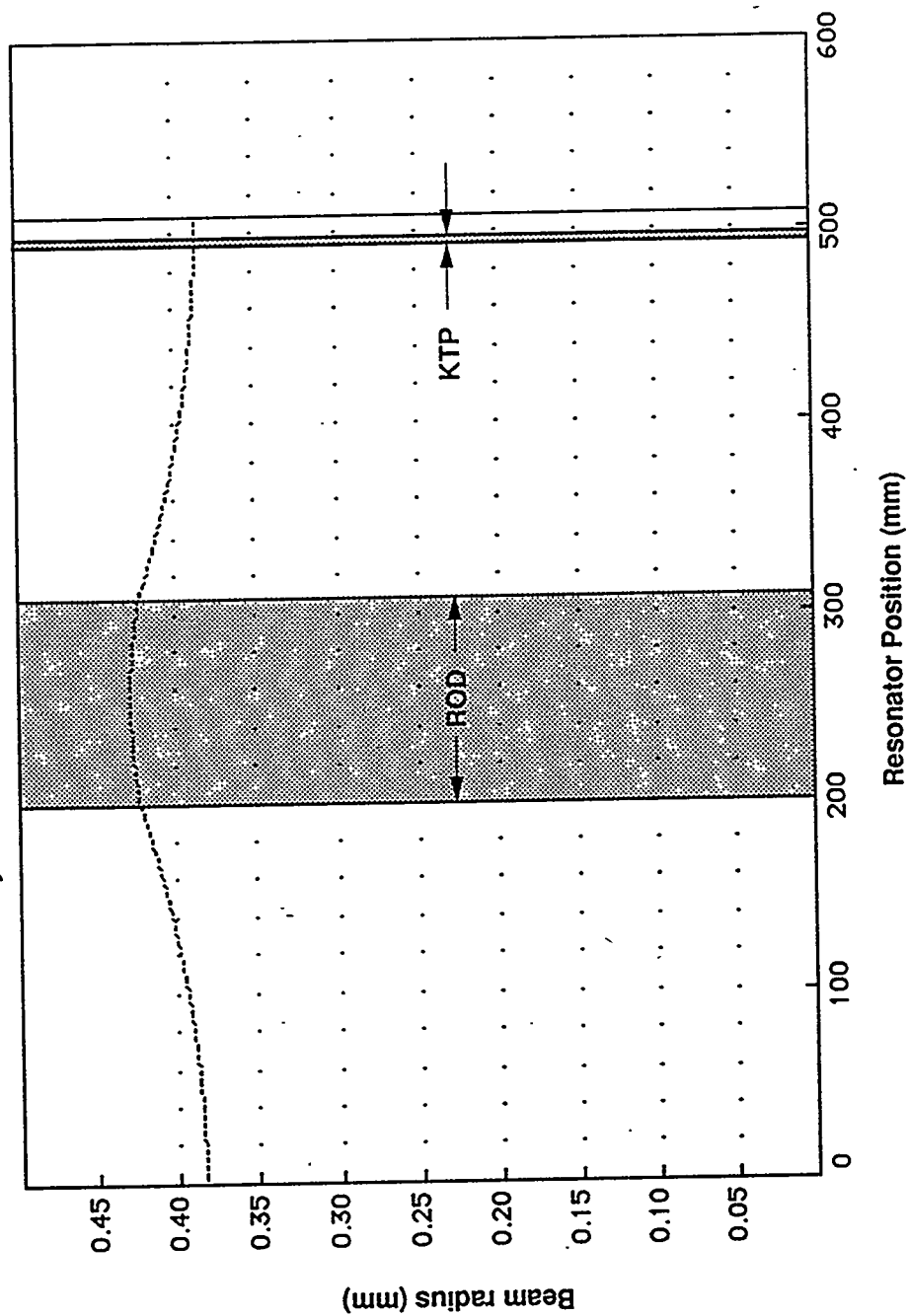


Figure 2. Calculated TEM₀₀ beam radius as a function of resonator position.

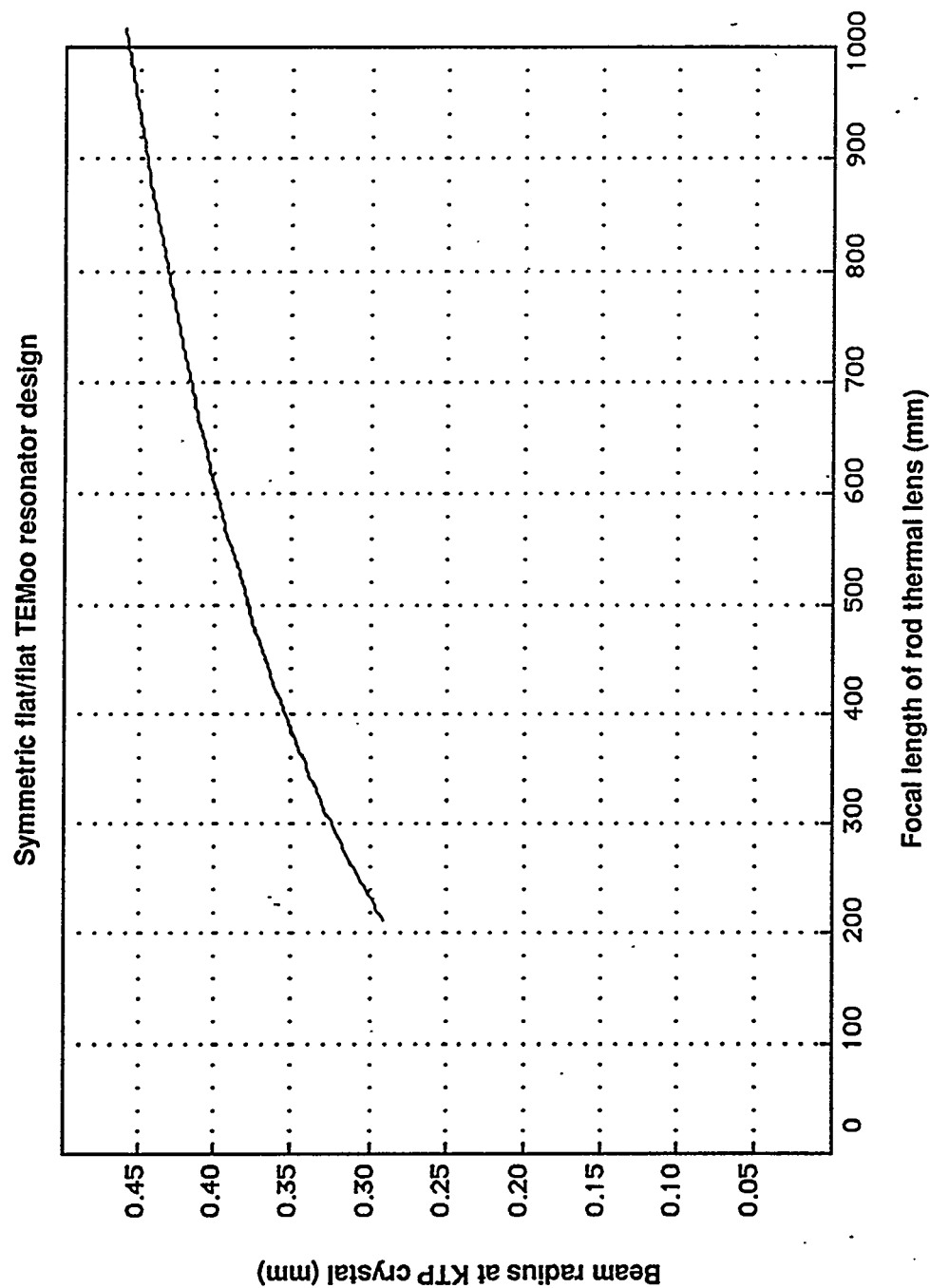


Figure 3. Calculated TEM₀₀ beam radius on KTP crystal as a function of thermal lens.

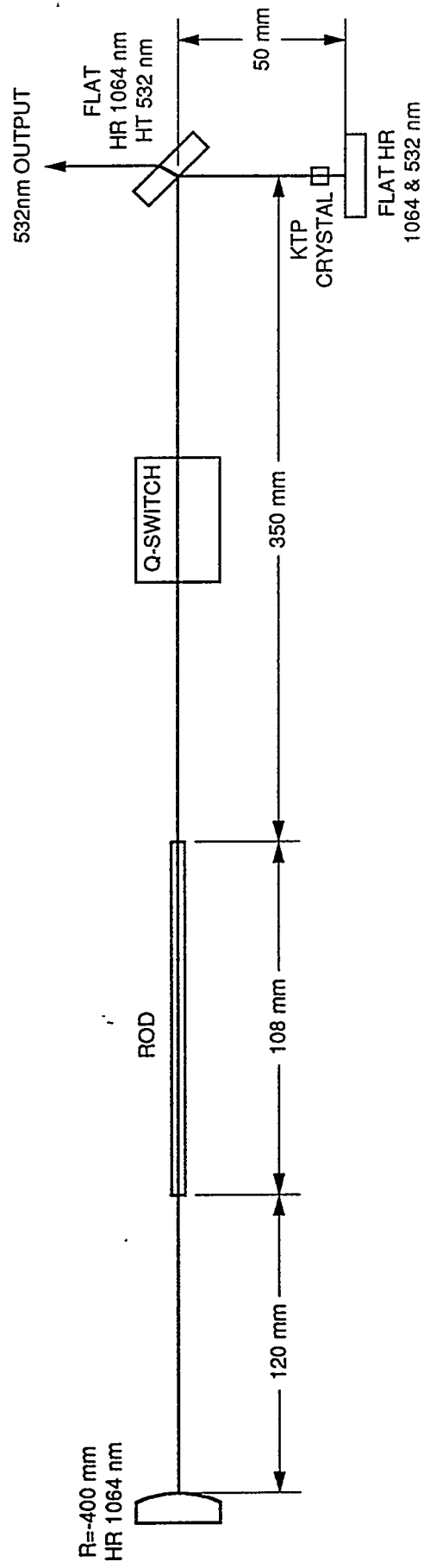


FIGURE 4. Alternate TEM₀₀ resonator design for large beam on KTP crystal.

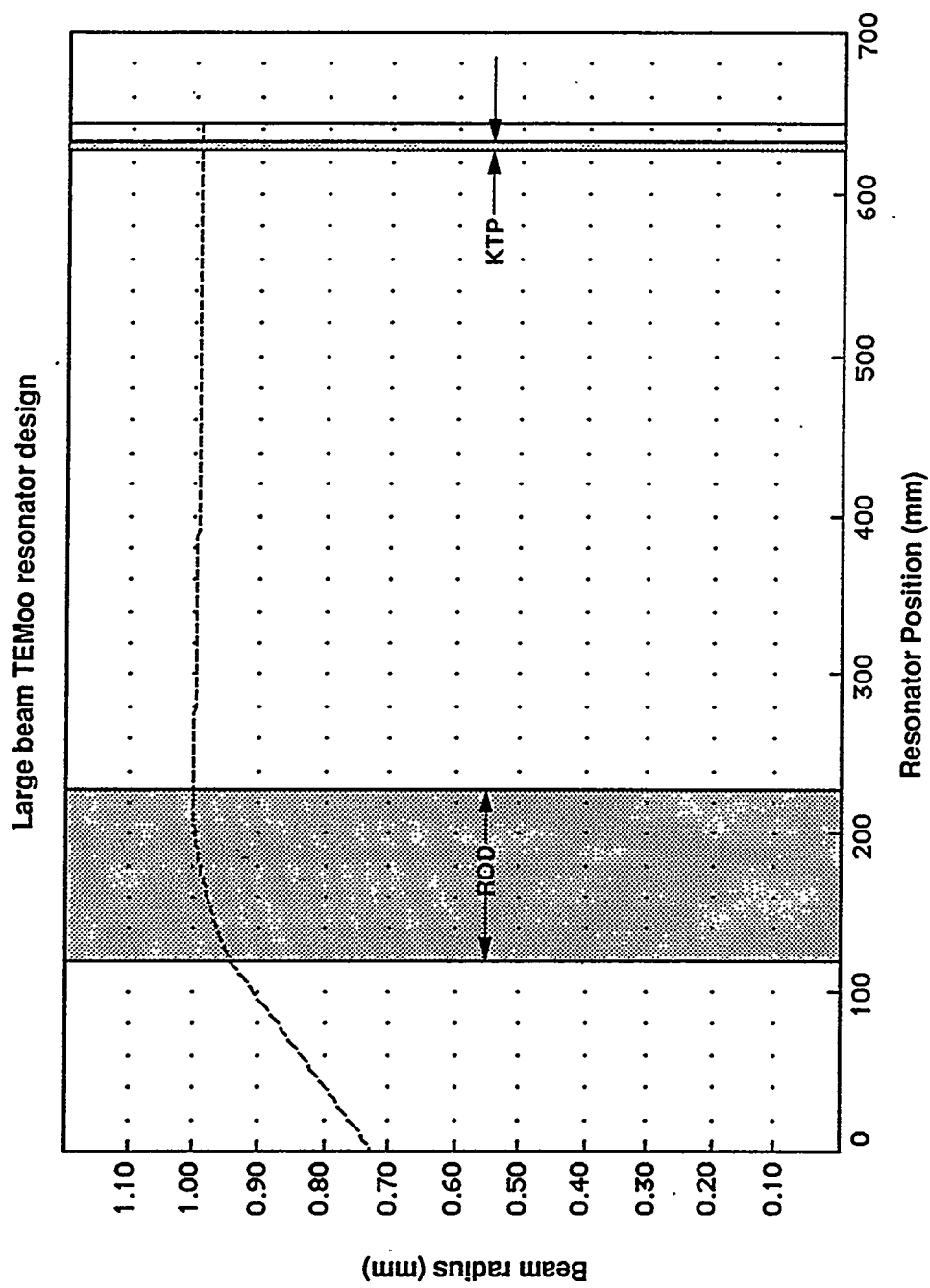


Figure 5. Calculated TEMoo beam radius as a function of resonator position.

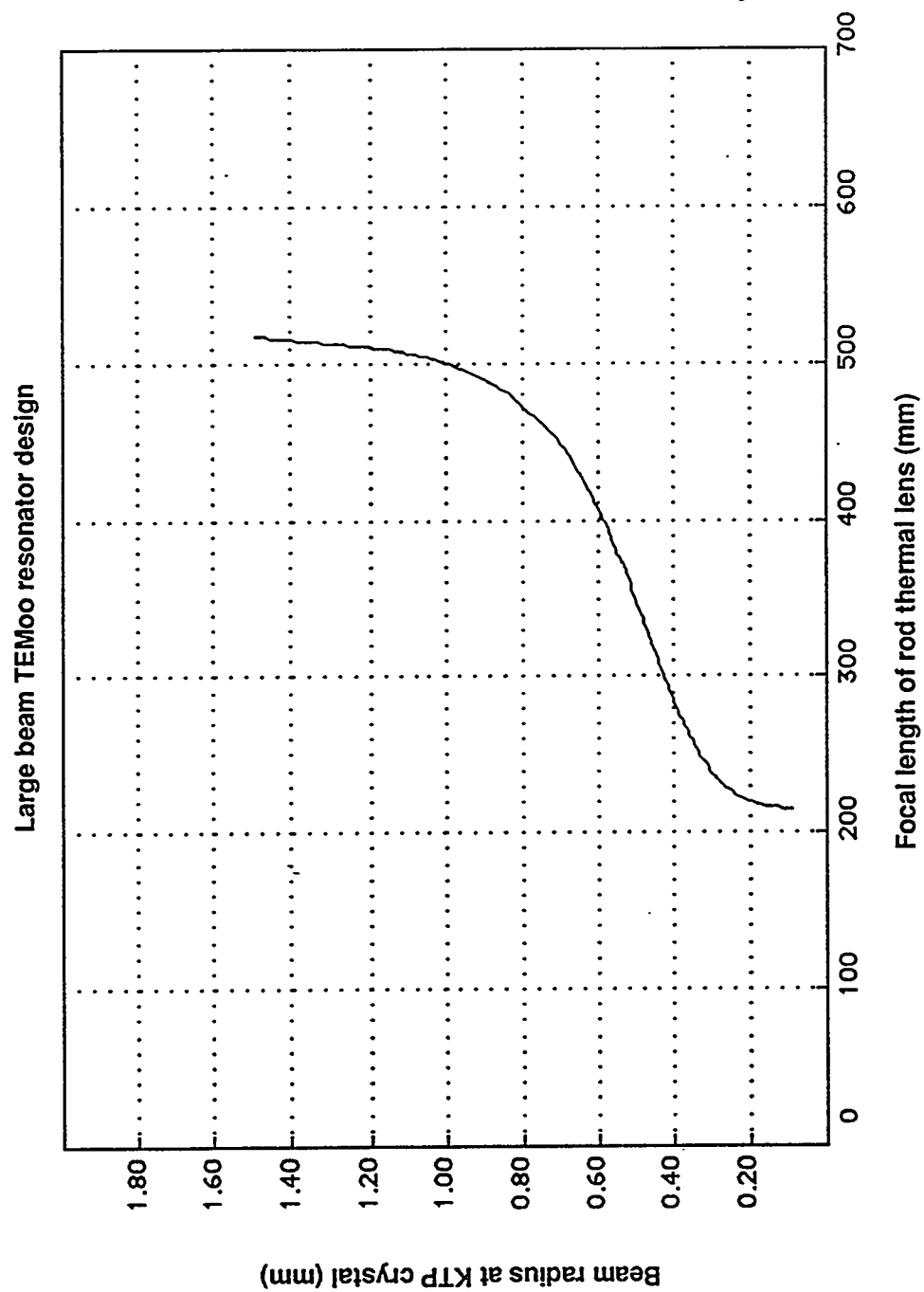


Figure 6. TEM₀₀ beam radius on KTP crystal as a function of thermal lens.

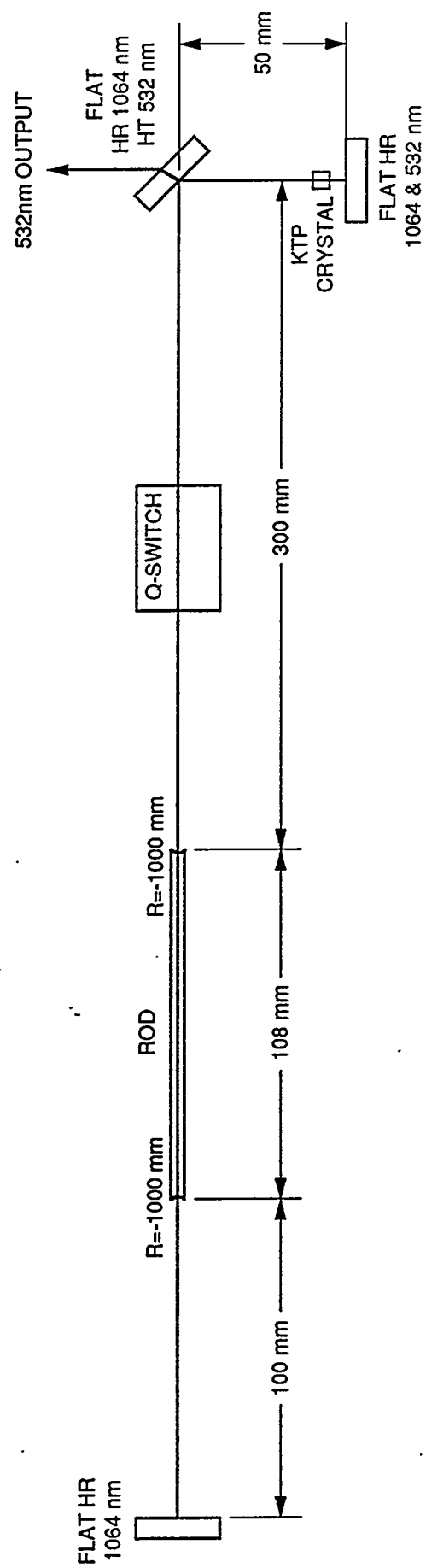


Figure 7. Asymmetric flat/flat resonator for multi-mode laser.

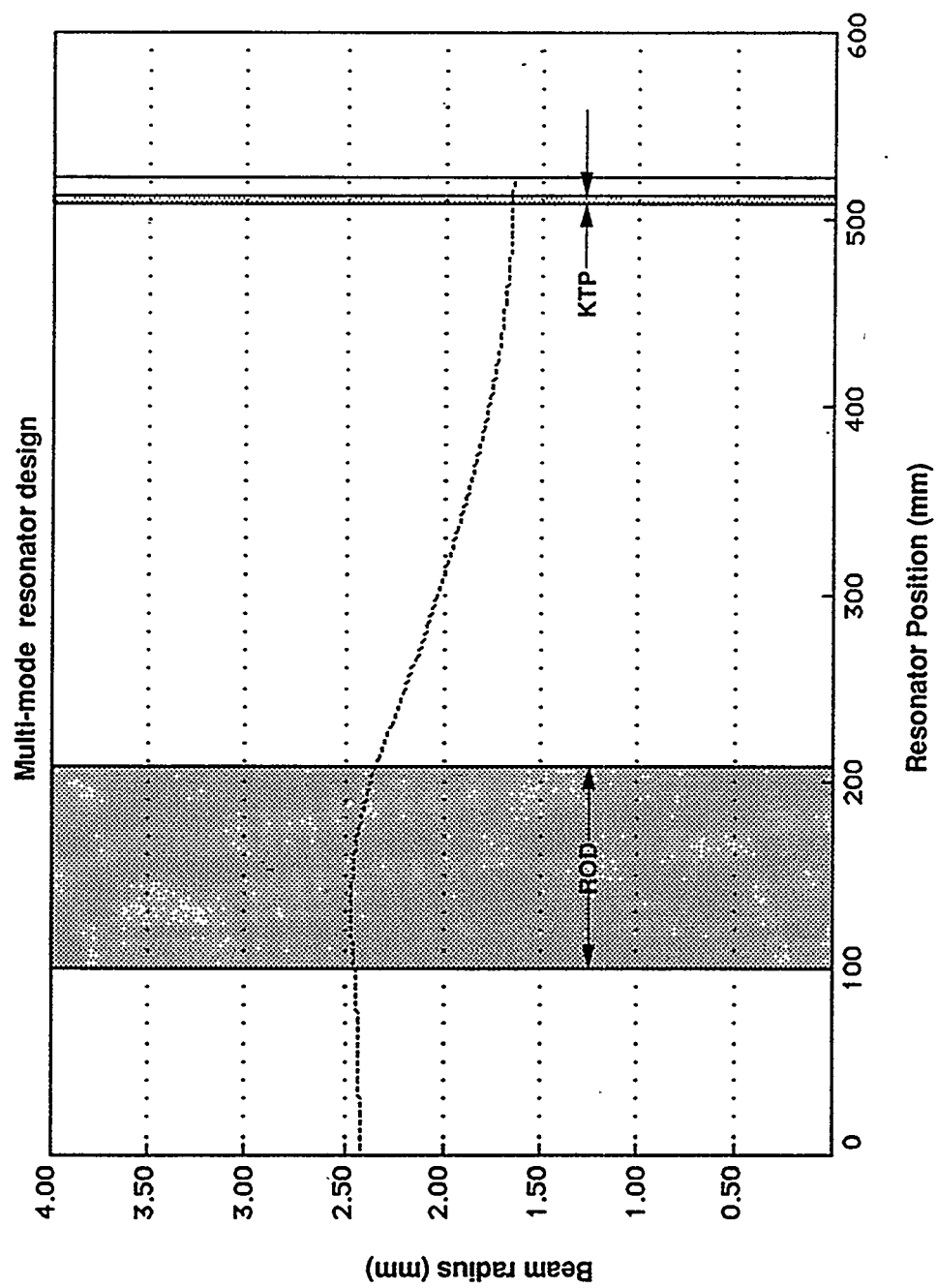


Figure 8. Calculated beam radius as a function of resonator position.

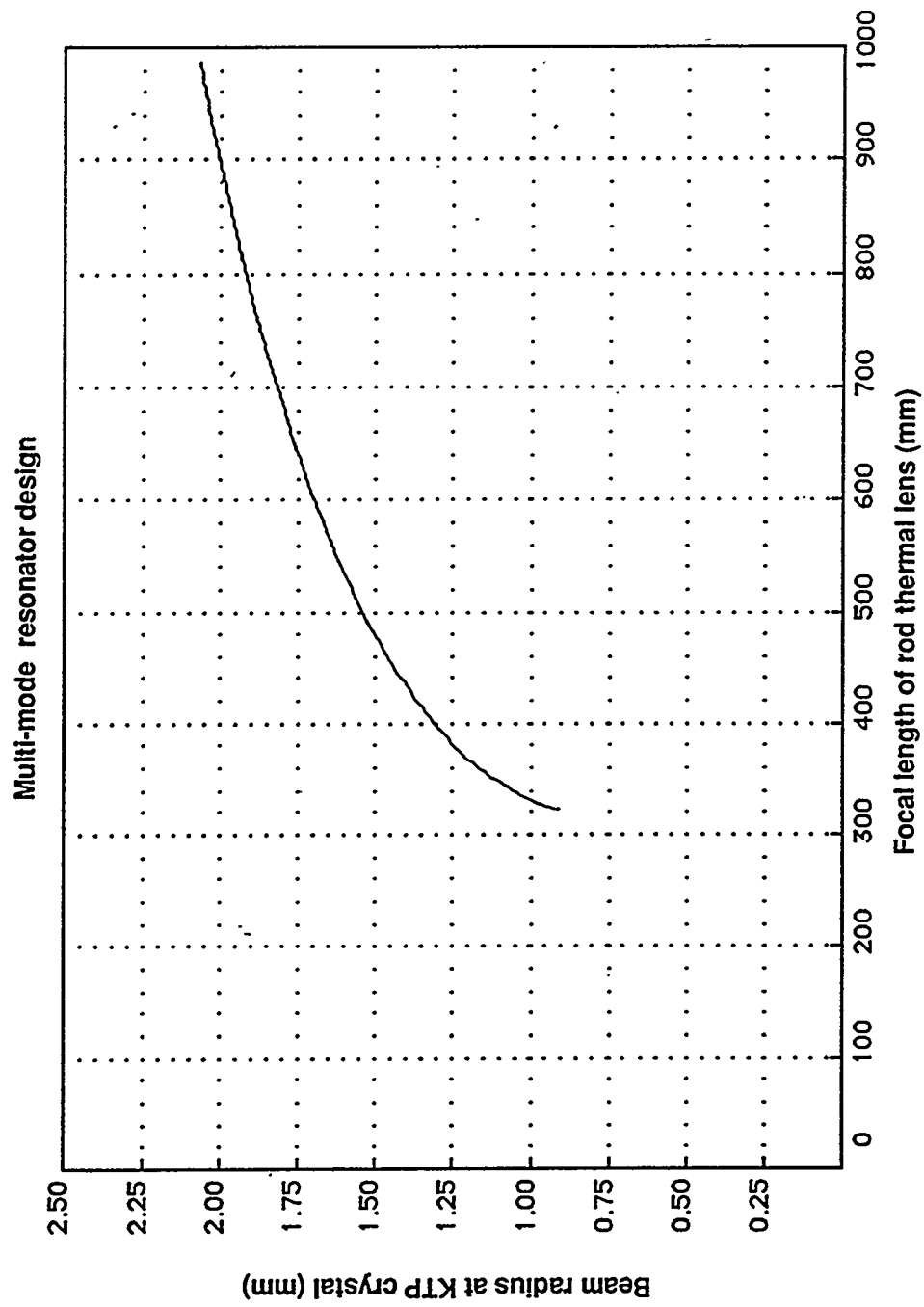


Figure 9. Beam radius on KTP crystal as a function of thermal lens.

limiting aperture of the resonator and the beam is assumed to fill the rod. Figure 7 shows an asymmetric flat/flat resonator where the rod is offset from the center of the cavity. The rod ends are polished with a ~ 1000 mm radius to compensate for the thermal lens and is a standard Lee Laser part. The residual thermal lens in the rod is used to reduce the resonator beam to a size appropriate for a 5X5 mm KTP crystal. Figure 8 shows the calculated beam diameter as a function of position in the resonator. In this calculation an M^2 value of 26 was used to generate a mode which has a beam diameter equal to that of the rod (5mm). For this resonator design, the beam radius on the KTP crystal is 1.65 mm. For a 40 watt laser operating at 5KHz with a 150ns pulse width the power density of the KTP crystal is $.6 \text{ MW/cm}^2$, which is well within the LLNL design criterion.

Figure 9 shows a plot of the beam size on the KTP crystal as a function of thermal lens. As with the flat/flat TEM₀₀ design the beam radius on the KTP crystal decreases with thermal loading of the laser rod. The resonator design would be adjusted so that at full lamp current the beam diameter on the KTP crystal would be about 70% of the clear aperture diameter of the crystal. A water cooled aperture placed directly in front of the crystal would ensure that the beam would not overfill the crystal at lower lamp powers and would allow the output power of the laser to be varied with lamp power.

Summary

We have modeled several resonator designs for use in intra-cavity doubled Nd:YAG lasers and, in this report, have presented the most promising designs consistent with Lee Laser's objectives. For the TEM₀₀ design there is a trade-off between operating at high power densities on the KTP crystal and operating near the instability point of the resonator. The multi-mode design appears to be straight forward and is similar to operating conditions used routinely at LLNL. In both cases the thermal lens is a critical part of the design and will need to be measured to finalize the mirror spacings. These resonator designs should be tested at the fundamental wavelength of Nd:YAG to verify efficiency, stability and beam sizes on the various elements before introducing the KTP crystal into the resonator. This will identify any issues not predicted by the passive resonator model used in this analysis.