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Janus Upgrade Using Brewster
Angle Disk Amplifier Technology

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JANUS UPGRADE
USING
BREWSTER ANGLE DISK
AMPLIFIER TECHNOLOGY*

October 1990

J. Hunt, R. Boben, R. Blocker, J. Clark, M. Henesian,
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Introduction

The Nuclear Test and Experimental Science Program (NTES) has requested that the Laser Program design and cost an upgrade to the Janus laser system (JANUS UPGRADE) capable of reliably delivering in excess of 200 joules per beamline in a range of pulse forms to three experiment areas. The facility is to have the following characteristics:

- Three experiment areas
- Two high energy beams, each with 200-400 joule/1 ns at a wavelength of 1.053 or 1.064 microns, and 125-250 J/1 ns when frequency doubled
- One probe beam (0.1 J rated at 30 ps) to be used for interferometry
- Reliable operation

The proposed facility would occupy approximately 5600 ft² and be located in the Bldg. 174 complex. A block diagram of the entire facility is shown in Fig. 1. The facility is further defined by the Work Breakdown Structure (also shown in Fig. 1). The main elements of the WBS are the conventional facility and modifications thereof (WBS 1), special equipment (WBS 2), the laser (WBS 3), the experiment areas (WBS 4), the controls and data acquisition system (WBS 5), and the project integration (WBS 6).

The experiment area has three target chambers and uses diagnostic hardware now in Janus.

Fig. 1. Block Diagram showing the Janus Upgrade system and the project WBS.

The twin beam, high energy portion of the laser system uses a double pass laser amplifier architecture and includes beam transport, remote manual laser alignment capability, and system diagnostics.

The initial laser pulse has a Gaussian temporal shape and is produced by one of three oscillators/preamplifiers (MOP) chains. These drive either of two high energy laser chains or an interferometry probe beam.

Two options were investigated — one using silicate laser glass, the other using more damage resistant optics and phosphate laser glass. A summary of our estimate of the cost of the phosphate option to construct this facility is given in Table 1. The costs for the WBS 1 category, Facilities, were obtained from the plant engineering report, "Augmented Scope for the Phoenix Laser Expansion," dated October 30, 1987. Although a contingency is included in this category, no contingency was estimated for the other WBS elements. A more detailed cost breakdown is given in Appendix 1.

Table 1. NTES laser cost summary (phosphate laser glass option), in \$/thousands (assumes 10/1/90 start date)

<u>WBS</u>	<u>Labor</u>	<u>Procure- ments</u>	<u>S&E</u>	<u>Total</u>	<u>Contingency</u>
1. Facilities		616	202	818	53
2. Special Equipment	74	74	24	172	
3. Laser	1680	2698	492	4870	
3.1 Alignmen/Sys. Diag.	0	0	0	0	
3.2 Front End	564	719	220	1503	
3.3 Power Section	376	862	124	1362	
3.4 Beam Transport	296	670	95	1061	
3.5 Pulsed Power	444	447	53	944	
4. Experiment Area	61	36	16	113	
5. Controls/data acquisition	170	74	13	257	
6. Project integration	<u>80</u>	<u>20</u>	<u>16</u>	<u>116</u>	<u> </u>
Total	2065	3518	763	6346	53

The silicate option cost was estimated by subtracting the appropriate laser glass, optics and hardware costs from the phosphate estimate. Manpower and S&E costs for the silicate option were approximated by taking 70% of the phosphate costs. The cost for this option is approximately four million dollars.

1.0 Facility Requirements and Modifications

The proposed Janus Upgrade facility would be located in the 174 Building Complex which presently houses an amplifier test facility and the Janus, Cyclops and ILS laser facilities. The proposed laser experiment facility would occupy approximately 5600 ft.² of the 174 Building complex, an area which is approximately 60 ft. long by 93.6 ft. wide. The pulse power equipment for the facility requires an additional 680 ft.² of floor area. Building 174 has 8 ft. ceilings.

Construction of the Janus Upgrade will require extensive modifications to Building 174 and the moving of the Cyclops laser. The quality of this area will have to be upgraded to provide the necessary cleanliness and temperature control. The use of specialized laboratory facilities will also be required in order for the proposed facility to operate reliably and effectively. The requirements for the specific facility areas are described below. The layout for the proposed Janus Upgrade facility is shown in Fig 1.1.

1.1 Laser Bay (~820 ft²)

The laser components require a vibration-free, stable platform on which to be mounted. This facility must be thermally stable and have an air filtration system capable of maintaining a class 10,000 clean room environment in the vicinity of the optical components.

Fig 1.1 Layout for proposed Janus Upgrade Laser Facility

1.2 Master Oscillator Preamplifier Room (~1260 ft²)

Like the laser bay, the MOP will house laser and optical components requiring thermal and vibrational stability and a suitable clean environment in order to maintain the critical alignments necessary to propagate a laser pulse to the experiment area.

1.3 Experiment Areas (2250 ft²)

The area will be comprised of up to three experiment areas (two initially), each of which will be approximately 31 ft. x 24 ft. (750 ft.²). The experiment chamber will require a vibrationally stable base and thermal equilibrium. These experiment areas should be arranged to minimize the number of turning mirrors required and the obstruction from laser and probe beam tube enclosures. Access to any experiment areas should be provided with minimal disruption to an ongoing experiment.

1.4 Pulse power (680 ft.²)

The power conditioning equipment and a ~one megajoule capacitor bank for the amplifiers and the Faraday rotators are presently housed in transportainers on the east and west side of Bldg. 174. Increased reliability and safety requirements will probably necessitate replacing most of this equipment. A pulse power system would be constructed in Bldg. 174 in the south end of Room 1506. Electrical isolation and safety interlocks will be required due to high voltage hazards.

1.5 Control and "War" Room (1000 ft²)

An area of approximately 1,000 ft² will be used by the Janus Upgrade laser system for control, diagnostics, and computers and data acquisition. It will also serve as a conference room. This area will require thermal conditioning for the sensitive equipment. In addition, it will need to be electrically isolated from any stray electromagnetic fields.

1.6 Component Assembly and Inspection Area

The Janus Upgrade Laser components will require several assembly and inspection facilities. These include a class 100 clean room for assembly of amplifiers, spatial filters, optical switches, etc.; an area for the alignment and characterization of KDP conversion crystals; an optical damage tester for validating optical damage thresholds on fabricated components; and a coating facility for sol-gel antireflection and neutral-solution coating on optics. All of these facilities currently exist within the Laser Program and will be used for the Janus Upgrade Laser.

2.0 Other Special Equipment

The bulk of the special equipment needed in this design is determined mostly by cleanliness requirements. The special equipment includes the beam tubes, nitrogen system, and HEPA filters.

3.0 The Laser

Some of the requirements that the proposed Janus Upgrade Laser must meet are:

- Two high energy beams that produce 200-400 J per beam at a wavelength of $1.053\ \mu\text{m}$ (or $1.064\ \mu\text{m}$) at 1 ns, 125-250 J/beam at $\sim 0.53\ \mu\text{m}$
- A master oscillator/preamplifier subsystem capable of delivering a variety of pulse forms to the high energy beamlines

The "low end" of the energy requirement can be achieved with silicate laser glass. The "upper" end would require the use of phosphate laser glass. The Janus Upgrade Laser employs a double-pass laser cavity with a booster amplifier exterior to the cavity (see Fig. 3.1).

Fig. 3-1 Diagram showing the components that would be used in the power section of a Janus Upgrade beamline.

Incorporated into the cavity are a retroreflecting mirror, a Faraday rotator-polarizer combination, and one 9.3 cm Brewster angle disk amplifier. Exterior to the cavity is a spatial filter and a 9.3 cm disk booster amplifier. A second spatial filter is located downstream from the booster amplifier and is used to relay the beam to the experiment areas. If so desired, the beam can be frequency doubled with a pair of KDP crystals located near the final spatial filter of the laser. The intracavity disk amplifier is double passed using the Faraday rotator as a switch. The Faraday rotator-polarizer combination also isolates the optical components in the two pass cavity and the preamplifier from any one micron light that might be inadvertently reflected into them during target experiments.

Most of the components that are presently in Janus use designs developed for the Shiva laser. A summary of the Shiva design and how it performed is given in JOE, Vol. Q.E.-17, No. 9 Sept. 1981 pp. 1599-1619. The laser glass is ED-2, a silicate. Most of the other passive transmissive optical components, such as polarizers and spatial filter lenses, employ silicate (BK-7) substrates. Because these optical components are made in platinum crucibles, they are known to contain damage producing platinum inclusions. Based on tests conducted on Nova, these platinum inclusions should cause optical damage in the transmissive optical substrates for subnanosecond mean fluences between two and four joules per cm^2 . Since very few shots on Shiva exceeded 500 joules, corresponding to a mean fluence of less than three joules per cm^2 , no platinum inclusion damage was observed.

In contrast, Nova, which uses phosphate laser glass, is operated with mean fluences of 5 to 9 joules per cm². As a consequence, it initially sustained optical damage in the high fluence portions of the chains. This problem has since been corrected by developing a manufacturing technique for phosphate glass that dissolves the platinum inclusions. Unfortunately, because the solubility of platinum in phosphate glass and silicate glass is different, this technique has not yet been fully developed for silicate glasses. Additionally, to avoid damaging them, BK-7 substrates are now used in Nova only in the low fluence portions of chains. Defect free "synthetic" quartz is used for the input lenses of the spatial filter where the fluences are high.

For damage free operation, a Janus Upgrade that employs silicate glass should be restricted to a mean fluence between two to four joules per cm² for pulse lengths less than a nanosecond. The effective area of the 9.3 cm disk amplifier is approximately 56 cm². Therefore, the energy would be between 100 and 200 joules (in this damage limited case). On the other hand, if fused silica is used for the spatial filter lenses and Nova-like defect-free phosphate laser glass is employed, one expects output energies between 200 and 400 joules.

For pulse lengths shorter than 500 psecs the intensity of the beam is high. The output energy in this operating regime is limited by nonlinear optical effects. Of particular concern is the phenomenon of self-focussing or beam breakup. The source of beam breakup is the intensity dependent portion of the index of refraction. As the beam passes through the optical elements in a beamline, its phase front accumulates a distortion that is dependent upon the intensity. If this phenomenon is not controlled, the phase distortion produced is converted into an intensity modulation. This increases the peak to mean ratio of the intensity (fluence) which increases the risk of beam induced damage to optical elements of the beamline. Self-focussing can also reduce the peak power that can be delivered to a small target. A discussion of the phenomenon of self-focussing and its effect on laser performance is given in the 1975 Laser Annual Report, pp. 223-243.

The parameter we used to characterize beam breakup is the B integral. It is the measure of the phase distortion (in radians) accumulated by the beam as it traverses the optical components of the chain. In particular,

$$B = \int_0^L \frac{2\pi\gamma}{\lambda_0} I(z) dz$$

is the change in the index of refraction caused by the beam's high intensity, which is proportionate to the nonlinear coefficient γ , I is the beam's mean intensity, λ_0 the vacuum wavelength and L is the beam's path length. The rate of growth in power of certain spatial frequency noise is given by $G \sim e^{2B}$. This growth is controlled by careful spatial filtering at critical points in a beamline.

We have found that the peak to mean value of the beam intensity can be kept to 1.5 to one if we limit the value of B between spatial filters; i.e., ΔB , to 2 or 2.5.

Development work done for the Nova upgrade project has resulted in components with optical coatings whose damage thresholds exceed 35 J/cm² for ten nanosecond pulses. Using $\sqrt{t}$ scaling for the pulse length dependence of optical damage, one finds that the damage threshold of these optics at one nanosecond is approximately 11 J/cm². If we use a flat top beam with an intensity profile that fills the aperture of the optical components with an efficiency of 80%, and assume that the peak to mean ratio of the intensity profile does not exceed 1.5 to 1, then a Janus beamline should be able to produce a one nanosecond pulse with an energy of 400 joules.

Figure 3-2 summarizes the one micron performance of a Janus beamline with "standard" silicate components. Figure 3-3 summarizes the beamline performance when damage resistant optics are used. Note that for silicate glasses that contain platinum inclusions, the energy is limited to 100-200 joules for pulses longer than 400 psec. Energies approaching twice this value can be achieved when damage resistant optics are used. A more detailed description of a 200 joule/one nanosecond silicate beamline and a 400 joule/one nanosecond phosphate beamline are given in Appendix 2.

Fig. 3.2 A silicate beamline's output energy versus pulsewidth. Note that the output energy is between 100 and 200 joules for pulsewidths greater than 400 psec. For shorter pulses the output energy is B limited.

Fig. 3.3 A phosphate beamline's output energy versus pulsewidth. The darkly shaped area represents the operating system.

These designs are "ΔB limited" for pulses shorter than 400 psec in the silicate case and 200 psec for the phosphate case. However, calculations indicate that the short pulse power could be increased by rearranging the gain distribution in the 10 cm amplification stage. Because this would require redesigning the 10 cm amplifier, this option is not reported here.

The frequency doubling efficiency for the proposed Janus Laser Upgrade has been estimated using a 2ω quadrature scheme (see the 1983 Laser Annual Report pp 6-64 through 6-69). When optimized, this can provide high efficiency (>70%) over a large range of intensities. Thus the 2ω performance of a Janus Upgrade beamline is obtained by multiplying the output energy in Figs. 3-2 and 3-3 by 70%.

3.1 Alignment and System Diagnostics

This subsystem has neither been designed nor costed in this study. The present Janus system will be used.

3.2 Master Oscillator and Preamplifier

The master-oscillator/preamplifier (MOP) laser room would have three beamlines that employ rod amplifiers, the largest of which has an aperture of 25 mm. The details of the optical configuration of these beamlines would depend upon whether phosphate or silicate glass is used as the lasing medium. All of them use Faraday-rotator-isolators to protect them from any damage that might be caused by amplification of spurious reflections. Pockel cell-polarizers combinations are used to control the prepulse reaching the experiment areas.

Two of these small aperture beamlines would produce pulses with energies of 100 mJ to 1 joule for pulse durations between 100 to 1000 psec. They would be used to drive the two main laser chains. The third beamline would employ YLF and phosphate glass amplifiers and be capable of producing chirped/compressed pulses with durations of 1 psec to 50 psec. This beamline will be used as an optical probe to do interferometry and x-ray back lighting. It can be delivered to any of the experiment areas.

Space has been provided in the MOP design for the addition of capabilities such as temporal pulse shaping, broadband pulse generation via optical phase modulation in optical fibers, and longpulse (>1 nsec) generation. These capabilities have not been detailed nor costed in this study, although they are routinely used in the Nova MOP. A laser oscillator will be located on one of the tables in the MOP room to provide (quasi) CW harmonic beams for target alignment. After exiting the final 25 mm rod, all three beamlines will enter relay vacuum spatial filters. The two beamlines used to drive the main laser chains will be directed to them with a set of mirrors. The beamline used as an optical probe would be converted to the appropriate harmonic and then directed by mirrors into the experiment areas. A layout of the three amplifier beamlines is shown in Figs. 3.2.1 and 3.2.2.

Figure 3.2.1 Layout for Master Oscillator/preamplifiers for the two main beamlines.

Fig. 3.2.2 Layout of probe beam

3.3 Power Section of the Beamline

The power section of a beamline is shown in Fig. 3.1. It is fully relayed and is 15 meters long. It contains spatial filters, amplifiers, and Faraday-rotator isolators. This section of the laser contains two different sizes of amplifiers, the largest of which has an aperture of 93 mm.

The two spatial filters in the power section provide the necessary interstage beam magnification and control the beam modulation that results from diffraction and beam breakup. The 40 mm to 93 mm spatial filter is 3,720 mm long and relays the image of the beam entering it to the exit plane of the 93 mm Faraday rotator isolator. The second filter has a clear aperture of 100 mm and is 2 m long. It relays the beam from its entrance lens to the entrance lens of the beam transport spatial filter. The parameters for the spatial filters are listed in Table 3.3.1.

Table 3.3.1 Spatial filter parameters

Unit	Length	Input Lens		Exit Lens	
		Focal Length (mm)	Thick-ness (mm)	Focal Length (mm)	Thick-ness (mm)
40 mm to 93 mm	3660	1120	20	2600	20
93 mm to 93 mm	2000	1000	20	1000	20
Beam Transport	5800	2900	20	2900	20

There are two types of amplifiers in the power section — 45 mm or 50 mm diameter rods and 93 mm disk amplifiers. If the silicate option is exercised, a 50 mm Nova style rod would be used in double pass configuration. If the phosphate option is employed, then a 45 mm rod would be doubled passed. The phosphate rod assembly would be purchased from a commercial vendor such as Continuum. The final stage of amplification would be provided by Nova/Shiva style 93 mm disk amplifiers. Each beamline would use two of these amplifiers, one of which would be doubled passed the other single passed. The parameters for these amplifiers are given in Table 3.3.2.

Table 3.3.2 Laser amplifier parameters

Unit	Silicate			Phosphate		
	α -rod	β -rod	β -disk	α -rod	45-rod	β -disk
Aperture (mm)	25	50	93	25	45	93
Small Signal Module Gain	40X	12X	3.8X	—	~8X	7X
Thickness/Disk or Length (mm)	400	400	24	—	245	24
# of Disks per module	—	—	6	—	—	6
Bank Energy per Module (kJ)	20	30	175	—	18	175

A Faraday rotator is an electro-optic device that is used to protect optics from back reflected light and suppress self-oscillation of the laser. It also serves as an optical switch in two pass operation. The Janus Upgrade requires two isolators per beamline in the power section of the laser. One has a clear aperture of 45 or 50 mm, the other one is 93 mm. The 93 mm aperture rotator is pulsed, the smaller aperture one may be pulsed or use a permanent magnet. Table 3.3.3 lists the parameters of Faraday rotator isolators used in the power section.

Table 3.3.3 Parameters of the Faraday rotator isolators

<u>Unit</u>	<u>45 mm</u>	<u>90 mm</u>
Aperture (mm)	45	90
Thickness (mm)	66	15
Stored Energy (kj)	*	21

*The 45 mm Faraday rotator probably uses a permanent magnet.

3.4 Beam Transport and Frequency Conversion

This portion of a beamline serves two functions. It is used to transport the beam from the 93 mm amplifiers to the target and, if desired, frequency double the beam. The frequency convertors are located on the output side of the beam transport spatial filters.

The beam is transported from the final 93 mm amplifier to the target chamber by a 10 cm aperture spatial filter relay element(s) and a series of 10 cm aperture mirrors. The spatial filter(s) is located downstream from the amplifier. There are a total of 22 mirrors and 8 spatial filter elements in the entire beam transport subsystem.

The frequency doubling efficiency for the proposed Janus Laser Upgrade has been estimated using a 2ω quadrature scheme that uses two crystals per beamline. When optimized, this scheme provides a conversion efficiency of greater than 70% over the desired range of drive intensities.

The KDP crystal lengths determined in the study are close to optimum for the 1ω drive shown in Fig. 3-3 (shown on Page 10). From Fig. 3-3, one finds that the maximum 1ω intensity could be:

100 ps:	15.2 to 22.8 GW/cm ²
1 ns:	4.8 to 7.2 GW/cm ²
3 ns:	2.8 to 4.2 GW/cm ²

Over this range, a crystal conversion efficiency of greater than 80% is desired. With target chamber focus lens and debris shield transmission of $(.98)^4 = .92$ and a 3.5% loss for a diagnostic beam splitter this would give us an overall energy conversion efficiency of better than 70% to target chamber center. At less than maximum 1ω performance, say about 1 GW/cm², we would also like to have ~ 70% efficiency.

Fortunately, with the 2ω quadrature used in this design, one can choose the first and second doubler lengths somewhat independently, so as to efficiently convert over a wide intensity range. Typically, the higher 1ω intensities are converted in the first "thin" doubler, followed by a "thick" second doubler, optimized to convert the low intensities. The 2ω light from the "thin" doubler, would normally cause a "back-conversion" problem in the "thick" doubler, except that in quadrature, the 2ω from the "thin" doubler is along the wrong polarization in the "thick" one, and so does not phasematch for any wave-mixing process. Additionally, for 2ω quadrature the 2ω light output from the crystal pair is elliptically polarized since the total 2ω electric field contains orthogonal polarizations. In fact, the state of polarization will vary with 1ω drive intensity, and for Gaussian or shaped temporal pulses, will vary in time.

A number of designs were considered with the first doubler ranging from 0.6 to 1.4 cm thick and the second doubler from 1.4 to 2.8 cm thick. The best designs work with a 0.8 cm "thin" doubler followed by a "thick" doubler of from 2.0 to 2.8 cm. The "flat in space and time" conversion efficiency curves are shown in Fig. 3.4.1. Other crystal combinations might also work as shown in Fig. 3.4.2 for (1.0,1.8), 1.2,2.0, and (1.4,2.2) designs. Notice, however, the large dips in performance at 8, 12, and 20 GW/cm².

Fig. 3.4.1 Frequency conversion efficiency versus drive intensity for frequency doubling using a quadrature scheme in which the first crystal is 0.8 cm thick and the second crystal is 2, 2.4, or 2.8 cm thick. Note the high conversion efficiency over a large range of drive intensities.

Fig. 3.4.2 Frequency conversion efficiency versus drive intensity for a frequency doubling quadrature scheme using crystal thicknesses of 1.0, 1.8; 1.2, 2.0; and 1.4, 2.2 cm thick respectively.

One note of caution needs to be added. We are not aware of any experiments having been done in KDP at intensities beyond 6 ~ 8 GW/cm². One should certainly be concerned about two-photon absorption and nonlinear refractive index effects in the 10 ~ 25 GW/cm² range. For the 100ps duration pulses, we might wish to have some beam expansion, say by 1.4 x, so as to lower the 1ω drive intensity at the crystals.

Thus, with a well polarized 1ω beam with good quality, and precision crystal tuning (which is routinely done on Nova), we should be able to get over 80% crystal conversion efficiency over a large operating range. Figure 3.4.3 assumes a crystal angle tuning error of not more than 150 micro radians, which in practice can readily be achieved. For comparison, Fig. 3.4.3 shows the efficiency for the (0.8, 2.8) cm combination with 150, 225, and 300 μ radians tuning error. Note that a 70% crystal conversion efficiency above 1 GW/cm^2 can be achieved even with as large an error as 300 μ radians, although we know from experience that we need to make efforts to minimize tuning errors.

Three sets of target focussing lenses are used in this design. The focal lengths are 20, 40 and 100 cm.

Fig. 3.4.3 Frequency conversion efficiency versus drive intensity for a frequency doubling quadrature scheme that uses crystal thicknesses of 0.8 and 2.8. The three angle detunings assumed were 150, 225, and 300 microradians.

3.5 Pulse Power

The pulsed power system drives the amplifier's flashlamps and energizes the Faraday rotator's magnetic coils. The total stored electrical energy required for all of these components is roughly 1 megajoule. Each 10 cm disk amplifier requires a capacitive storage bank of 175 kJ. The 10 cm Faraday rotators require about 25 kJ each while 4 cm rod amplifiers require 18 kJ each.

3.5.1 Capacitor Bank

The capacitor bank circuits will all be rebuilt using high energy density capacitors with two capacitors per circuit. They will be the same design as present Nova circuits. The capacitor dump circuits will also be upgraded and have a single point ground. They will be installed in a capacitor-bank room near the laser, and the power cables and signal cables will be installed in separate cable trays. Some of the charging supplies have recently been replaced with newer, smaller power supplies. The rest of these will be replaced with the newer power supplies that will be amenable to computer control with an upgraded control system.

3.5.2 Safety Interlocks

The present safety interlock system will be replaced with a system based on a programmable logic controller (PLC). It will be programmed to allow access to target rooms that do not have active experiments.

4.0 Experiment Area

4.1 Hardware Description

The 174 Bldg. Complex will be modified to include three experiment areas (Fig 4.1) for use with the laser system. All experiment areas will be enclosed (light barriers) so that they can be occupied while the laser is being fired into another area. Two of the areas will use experiment chambers and vacuum systems from the present Janus facility. The laser beams will enter the rooms through shuttered wall ports and will be directed into the chambers by mirrors. The main components of the experiment areas are discussed in subsequent sections.

Fig. 4.1 Sketch of one experiment area.

4.1.1 Test Chambers and Stands

The two existing Janus experiment chambers and stands (Fig. 4.1.1) will be moved to a new location in the Bldg. 174 Complex.

Fig. 4.1.1. One of the two target chambers to be taken from the Janus facility for use in the NTES facility.

4.1.2 Vacuum System

The existing Janus vacuum systems (including controls) for the two experiment chambers will be moved to a new location in the Bldg. 174 complex. The only new component common to both chamber rooms will be an exhaust duct for venting pumped gases outside.

4.1.3 Target Positioning

The targets will be positioned by the devices used on the two existing Janus target chambers.

4.1.4 Target Alignment

The target alignment system for each chamber will consist of the TV cameras and monitors presently installed on Janus. There will be two cameras for each chamber, one looking down each beamline.

4.2 Operational Description

The experiment area will operate almost exactly like the Janus facility. The two target positioning systems, target alignment systems, vacuum systems, and chambers will be moved and reconnected as they were. Operation of the new system will be similar to the old, except for any differences dictated by the new laser system.

It will be safe to work in an enclosed experiment area while laser beams are being propagated to other chambers. This will eliminate the time wasted in clearing each bay before the frequent laser shots. The experiment area being fired into will be cleared of personnel at the time of the shot. There will be a safe exit from each experiment area.

5.0 Control and Data Acquisition System

Operation of the Janus laser system will be upgraded by using a computer control system based on Macintosh II workstations that provide graphics-based control screens at the operator console in the control room. The LabView computer language will be used. This is an icon-based language that can provide an intuitive transform to the systems controlled. The control system will integrate the controls of the capacitor banks that will fire the flash lamps, Faraday rotators and Pockels cells while ensuring permissive signals from the personnel safety interlock system, and laser safety interlocks such as vacuum in the pinhole filters and cooling fluids for the laser rods, disks, and flashlamps. The control computer will also be able to monitor the laser system output signals such as flashlamp current, calorimeter output and spatial distributions, and provide some data storage, trending and quick-look analysis capabilities. The computer system would be capable of expanding via networking to allow interaction with target data acquisition systems though no target data acquisition systems are a part of this proposal.

6.0 Integration

This element of the WBS includes environmental, safety and health considerations. It also includes quality assurance and system documentation.

7.0 Summary

Two options for upgrading the Janus laser/experiment facility were investigated. One option assumed the use of both damage resistant phosphate laser glass and optical coatings; the other assumed the use of the more damage prone silicate laser glass. Whenever possible, existing hardware was used in the design and to reduce cost. The projected energy per beamline in these two cases was 400 and 200 joules respectively. Three experiment areas were used in both designs. Execution of either option will require extensive and costly modifications to the 174 Building Complex. Unfortunately, both designs are quite expensive. The cost estimate for the high performance phosphate option was \$6.35M whereas the lower performance silicate option was estimated to cost about \$4M.

We are now investigating alternate laser architectures in the hope that they will result in a substantially reduced facility cost.

APPENDIX 1: Janus Upgrade Costs (FY 90 K\$)

APPENDIX 1: Janus Upgrade Costs (FY 90 K\$)																						
WBS	Labor				S&E		Procurements						Total FY Costs				Total Labor	Total Proc	Total S&E	IR&D Tax	Total Cost	Cont
	FY 91		FY 92		FY 91		FY 92		FY 91		FY 92											
	FY 91	FY 92	FY 91	FY 92	Oper	Cap	Oper	Cap	Oper	Cap	Oper	Cap										
1.0 Facilities																						
1.1 Bldg. 174 Mods																						
1.2 Cyclops Relocation																						
2.0 Other Special Equipment	74																					
3.0 Laser																						
3.1 Alignment & System Diag.																						
3.2 Front End	564																					
3.3 Power Section																						
3.3.1 Amplifiers	62																					
3.3.2 Cavity Mirrors	67																					
3.3.3 Cavity Spatial Filters	77																					
3.3.4 Faraday Rotator	39																					
3.3.5 Beam Diag/Beam Dump	38																					
3.3.6 Space Frame	93																					
3.4 Beam Transport																						
3.4.1 BT Spatial Filters	60																					
3.4.2 BT Mirrors	79																					
3.4.3 Crystal Assemblies	88																					
3.4.4 Focus Systems	69																					
3.5 Pulsed Power	444																					
4.0 Experiment Area	61																					
5.0 Controls	170																					
6.0 Integration	80																					
TOTAL	2065																					

Appendix 2

The performance of the Janus Upgrade beamline was simulated using the "B-T Gain" computer code.

Table 3.1 summarizes the results of a beamline simulation that assumed the use of silicate laser glass (ED-2). The beam's fluence at the exit to plane of the beamline is 3.7 J/cm^2 and the output energy is 200 Joules.

Table 3.2 summarizes the results for a beamline that uses phosphate laser glass (LHG-8) and optical components that have high damage threshold coatings. In this case, the beam's fluence at the exit plane of a beamline is 7.4 J/cm^2 and the output energy is 400 Joules.

APPENDIX 2 (Page 1 of 4)

TABLE 3.1 Performance summary of a Janus Upgrade beamline that uses silicate laser glass. The output energy, rated at one nanosecond, is about 200 Joules.

Program BTGAIN Input

Thing Number	Thing I.D.	Diam (cm)	Thick (cm)	S.S. Gain	% Trans	Angle (deg)	Refr. Index	Nonlin Index	Dist (cm)
(** Subchain 0 **)									
0	Cyclops Upgrade, Single Pass Front End- FF=0.8 ED2 (Graphics->)								
	[INITIAL FORWARD INJECTION, Match Output Fluence = 3.68 (J/cm2), 1 (ns)]								
1		2.300	0	0	0	0	0	0	0
2	SF1 lens1	2.300	2.000	1.000	0.990	0	1.508	1.200	280.0
3	PINHOLE transmission 1, cutoff 10000 milliradians								
4	SF1 lens2	2.300	2.000	1.000	0.990	0	1.508	1.200	45.00
	[SATURATION FLUX = 7.78 (J/cm2)]								
5	25mm Rod Amp-1	2.300	40.00	40.00	0.976	0	1.570	1.410	43.00
6	Polarizer	2.300	1.400	1.000	0.960	56.43	1.507	1.240	5.000
7	Rotatator	2.300	9.000	1.000	0.913	0	1.673	2.396	14.00
8	Polarizer	2.300	1.400	1.000	0.960	-56.43	1.507	1.240	48.00
9	25mm Rod Amp-2	2.300	40.00	40.00	0.976	0	1.570	1.410	45.00
10	Expanding lens	2.300	1.000	1.000	0.990	0	1.508	1.200	20.00
11	Recolimating le	3.750	2.000	1.000	0.990	0	1.508	1.200	106.0
12	Polarizer	3.750	2.400	1.000	0.960	56.43	1.507	1.240	10.00
13	Rotatator	3.750	4.300	1.000	0.960	0	1.673	2.396	14.00
14	Polarizer	3.750	2.400	1.000	0.960	-56.43	1.507	1.240	10.00
15	40mm Rod Amp-3	3.750	23.50	4.300	0.965	0	1.570	1.410	35.00
16	SF2 lens1	3.750	2.000	1.000	0.990	0	1.508	1.200	366.0
17	PINHOLE transmission 1, cutoff 10000 milliradians								
18	SF2 lens2	9.300	2.000	1.000	0.990	0	1.508	1.200	133.0
19	Interface	9.300	0	1.000	1.000	0	1.000	1.000	0
20	PLOT, Distance from last component = 0 (cm) (Activated while FORWARD)								

Small signal gain for above components is '4433'

(** Subchain 1 **)									
0	Janus Upgrade Double Pass - FF=0.8 ED-2 (Graphics->)								
1	Mirror1	9.300	0	1.000	1.000	0	1.000	1.000	25.00
	[Subchain FORWARD INJECTION]								
2	[SWITCH transmits 1 times; switch distance = 10]								
3	SWITCH	9.300	0	1.000	1.000	0	1.000	1.000	45.00
4	Polarizer	9.300	2.400	1.000	0.960	56.43	1.507	1.240	62.50
5	Rotatator	9.300	4.300	1.000	0.960	0	1.673	2.100	62.50
6	Polarizer	9.300	2.400	1.000	0.960	-56.43	1.507	1.240	30.00
	[SATURATION FLUX = 7.78 (J/cm2)]								
7	B-head-1	9.300	2.400	1.249	0.989	57.51	1.570	1.410	25.00
8	B-head-1	9.300	2.400	1.249	0.989	-57.51	1.570	1.410	25.00
9	B-head-1	9.300	2.400	1.249	0.989	57.51	1.570	1.410	25.00
10	B-head-1	9.300	2.400	1.249	0.989	-57.51	1.570	1.410	25.00
11	B-head-1	9.300	2.400	1.249	0.989	57.51	1.570	1.410	25.00
12	B-head-1	9.300	2.400	1.249	0.989	-57.51	1.570	1.410	60.00
13	Mirror2	9.300	0	1.000	0.995	0	1.000	1.000	0

Small signal gain for above components is '3.128'

(** Subchain 2 **)									
0	Power Amps (Graphics->)								
1	SF5 lens1	9.300	2.000	1.000	0.990	0	1.508	1.200	200.0
2	PINHOLE transmission 1, cutoff 10000 milliradians								
3	SF5 lens2	9.300	2.000	1.000	0.990	0	1.508	1.200	30.00
	[SATURATION FLUX = 7.78 (J/cm2)]								
4	B-head-2	9.300	2.400	1.249	0.989	57.51	1.570	1.410	25.00
5	B-head-2	9.300	2.400	1.249	0.989	-57.51	1.570	1.410	25.00
6	B-head-2	9.300	2.400	1.249	0.989	57.51	1.570	1.410	25.00
7	B-head-2	9.300	2.400	1.249	0.989	-57.51	1.570	1.410	25.00
8	B-head-2	9.300	2.400	1.249	0.989	57.51	1.570	1.410	25.00
9	B-head-2	9.300	2.400	1.249	0.989	-57.51	1.570	1.410	20.00
10	SF5 lens1	9.300	2.000	1.000	0.990	0	1.508	1.200	200.0
11	PINHOLE transmission 1, cutoff 10000 milliradians								
12	SF5 lens2	9.300	2.000	1.000	0.990	0	1.508	1.200	10.00
13	PLOT, Distance from last component = 0 (cm) (Activated while FORWARD)								

Small signal gain for above components is '3.413'

Time (ns) for output: 1
Power density (GW/cm2): 0.0006858
Photon duration (ns): 0.0001
Wavelength (microns): 1.053
Patch radius (cm): 0
Beginning distance (cm): 0
Beginning diameter (cm): 2.3
Minimum angle (milliradians): 0
Maximum angle (milliradians): 50
No. of angles: 100
No. of pictures: 3;
Overall extraction efficiency: 0.9898

APPENDIX 2 (Page 2 of 4)

TABLE 3.1 (Continued.)

Thing Number	Thing I.D.	Patch Inten	Vacum Dist	Equiv Dist	Patch X-Val	Patch Y-Val	Patch Z-Val	Delta B-Int	Sigma B-Int	Solid Path	SAT GAIN	Slice Count
Subchain '0'												
0	Cyclops Upgrade, Single Pass Front End- FF=0.8 ED2											
1	7e-04											
2	SF1 lens1	7e-04	0	0	0	0	0.0	3e-05	3e-05	2.000	1.000	1.000
3	PINHOLE transmission 1, cutoff 10000 milliradians											
4	SF1 lens2	7e-04	278.0	-278.0	0	0	280.0	3e-05	5e-05	2.000	1.000	1.000
SATURATION FLUX = 7.78 (J/cm2)												
5	25mm Rod Amp-1	0.026	43.00	43.00	0	0	325.0	0.006	0.006	40.00	39.89	39.00
6	Polarizer	0.025	3.000	3.000	0	0	368.0	6e-04	0.007	1.680	1.000	1.000
7	Rotatator	0.023	3.452	3.452	-0.653	0	373.0	0.008	0.015	9.000	1.000	1.000
8	Polarizer	0.022	5.984	5.984	-0.653	0	388.0	5e-04	0.016	1.680	1.000	1.000
9	25mm Rod Amp-2	0.791	45.47	45.47	0	0	435.0	0.193	0.209	40.00	36.82	38.00
10	Expanding lens	0.784	5.000	5.000	0	0	480.0	0.016	0.224	1.000	1.000	1.000
11	Recolimating le	0.292	19.00	11.65	0	0	500.0	0.011	0.236	1.950	1.000	1.000
12	Polarizer	0.280	104.0	104.0	0	0	606.0	0.011	0.247	2.880	1.000	1.000
13	Rotatator	0.269	7.346	7.346	-1.119	0	616.0	0.043	0.290	4.300	1.000	1.000
14	Polarizer	0.258	11.39	11.39	-1.119	0	631.7	0.011	0.301	2.880	1.000	1.000
15	40mm Rod Amp-3	0.984	5.659	5.659	0	0	640.0	0.287	0.588	23.50	3.952	15.00
16	SF2 lens1	0.975	11.50	11.50	0	0	675.0	0.039	0.627	2.000	1.000	1.000
17	PINHOLE transmission 1, cutoff 10000 milliradians											
18	SF2 lens2	0.157	364.0	-146.8	0	0	1041.0	0.006	0.633	1.996	1.000	1.000
19	Interface	0.157	131.0	131.0	0	0	1174.0	0	0.633	0	1.000	1.000
20	PLOT, Distance from last component = 0 (cm)											
Subchain '1'												
0	Cyclops Upgrade, Single Pass Front End- FF=0.8 ED2											
2	0.157											
3	SWITCH	0.157	0	0	0	0	1174.0	0	0.633	0	1.000	1.000
4	Polarizer	0.151	45.00	45.00	0	0	1219.0	0.006	0.640	2.880	1.000	1.000
5	Rotatator	0.145	59.85	59.85	-1.119	0	1281.5	0.020	0.660	4.300	1.000	1.000
6	Polarizer	0.139	59.89	59.89	-1.119	0	1345.7	0.006	0.666	2.880	1.000	1.000
7	B-head-1	0.171	25.66	25.66	0	0	1374.0	0.006	0.672	2.845	1.246	3.000
8	B-head-1	0.211	24.31	24.31	-1.203	0	1400.9	0.008	0.680	2.845	1.245	3.000
9	B-head-1	0.259	20.53	20.53	0	0	1424.0	0.010	0.689	2.845	1.244	3.000
10	B-head-1	0.319	24.31	24.31	-1.203	0	1450.9	0.012	0.701	2.845	1.243	3.000
11	B-head-1	0.392	20.53	20.53	0	0	1474.0	0.014	0.715	2.845	1.242	3.000
12	B-head-1	0.481	24.31	24.31	-1.203	0	1500.9	0.018	0.733	2.845	1.241	3.000
13	Mirror2	0.478	55.53	55.53	0	0	1559.0	0	0.733	0	1.000	1.000
12	B-head-1	0.582	57.60	57.60	0	0	1616.6	0.022	0.755	2.845	1.231	3.000
11	B-head-1	0.708	24.31	24.31	-1.203	0	1643.5	0.026	0.781	2.845	1.230	3.000
10	B-head-1	0.861	20.53	20.53	0	0	1666.6	0.032	0.813	2.845	1.229	3.000
9	B-head-1	1.044	24.31	24.31	-1.203	0	1693.5	0.039	0.851	2.845	1.227	3.000
8	B-head-1	1.264	20.53	20.53	0	0	1716.6	0.047	0.898	2.845	1.224	3.000
7	B-head-1	1.524	24.31	24.31	-1.203	0	1743.5	0.057	0.955	2.845	1.220	3.000
6	Polarizer	1.463	25.53	25.53	0	0	1771.6	0.060	1.015	2.880	1.000	1.000
5	Rotatator	1.405	57.95	57.95	-1.119	0	1832.2	0.197	1.212	4.300	1.000	1.000
4	Polarizer	1.349	61.79	61.79	-1.119	0	1898.3	0.055	1.268	2.880	1.000	1.000
3	SWITCH	1.349	43.06	43.06	0	0	1944.0	0	1.268	0	1.000	1.000
Subchain '2'												
0	Power Amps											
1	SF5 lens1	1.335	10.00	10.00	0	0	1954.0	0.054	1.321	2.000	1.000	1.000
2	PINHOLE transmission 1, cutoff 10000 milliradians											
3	SF5 lens2	1.322	198.0	-198.0	0	0	2154.0	0.053	1.374	2.000	1.000	1.000
4	B-head-2	1.596	28.00	28.00	0	0	2184.0	0.059	1.434	2.845	1.221	3.000
5	B-head-2	1.918	24.31	24.31	-1.203	0	2210.9	0.071	1.505	2.845	1.215	3.000
6	B-head-2	2.292	20.53	20.53	0	0	2234.0	0.086	1.591	2.845	1.209	2.000
7	B-head-2	2.723	24.31	24.31	-1.203	0	2260.9	0.102	1.693	2.845	1.201	2.000
8	B-head-2	3.210	20.53	20.53	0	0	2284.0	0.121	1.814	2.845	1.192	2.000
9	B-head-2	3.755	24.31	24.31	-1.203	0	2310.9	0.142	1.956	2.845	1.182	2.000
10	SF5 lens1	3.717	15.53	15.53	0	0	2329.0	0.149	2.105	2.000	1.000	1.000
11	PINHOLE transmission 1, cutoff 10000 milliradians											
12	SF5 lens2	3.680	198.0	-198.0	0	0	2529.0	0.148	2.253	2.000	1.000	1.000
13	PLOT, Distance from last component = 0 (cm)											

TABLE 3.2 Performance summary of a Janus Upgrade beamline that uses phosphate laser glass. The output energy, rated at one nanosecond, is about 400 Joules.

Program BIGAIN Input

Thing Number	Thing I.D.	Diam (cm)	Thick (cm)	S.S. Gain	% Trans	Angle (deg)	Refr. Index	Nonlin Index	Dist (cm)
(** Subchain 0 **)									
0 Cyclops LHG-8, Single Pass Front End - FF=0.8 (Graphics->)									
[INITIAL FORWARD INJECTION, Match Output Fluence = 7.36 [J/cm2], 1 (ns)]									
1		2.300	0	0	0	0	0	0	0
2	SF1 lens1	2.300	2.000	1.000	0.990	0	1.508	1.200	280.0
3	PINHOLE transmission 1, cutoff 10000 milliradians								
4	SF1 lens2	2.300	2.000	1.000	0.990	0	1.508	1.200	45.00
[SATURATION FLUX = 5.387 (J/cm2)]									
5	25mm Rod Amp-1	2.300	40.00	50.00	0.976	0	1.519	1.120	43.00
6	Polarizer	2.300	1.400	1.000	0.960	56.43	1.507	1.240	5.000
7	Rotator	2.300	9.000	1.000	0.913	0	1.673	2.396	14.00
8	Polarizer	2.300	1.400	1.000	0.960	-56.43	1.507	1.240	48.00
9	25mm Rod Amp-2	2.300	40.00	50.00	0.976	0	1.519	1.120	45.00
10	Expanding lens	2.300	1.000	1.000	0.990	0	1.508	1.200	20.00
11	Recollimating le	3.750	2.000	1.000	0.990	0	1.508	1.200	106.0
12	Polarizer	3.750	2.400	1.000	0.960	56.43	1.507	1.240	10.00
13	Rotator	3.750	4.300	1.000	0.960	0	1.673	2.396	14.00
14	Polarizer	3.750	2.400	1.000	0.960	-56.43	1.507	1.240	10.00
15	40mm Rod Amp-3	3.750	23.50	6.000	0.965	0	1.519	1.120	35.00
16	SF2 lens1	2.750	2.000	1.000	0.990	0	1.508	1.200	366.0
17	PINHOLE transmission 1, cutoff 10000 milliradians								
18	SF2 lens2	9.300	2.000	1.000	0.990	0	1.508	1.200	133.0
19	Interface	9.300	0	1.000	1.000	0	1.000	1.000	0
20	PLOT, Distance from last component = 0 (cm) (Activated while FORWARD)								

Small signal gain for above components is '9664'

(** Subchain 1 **)

0 Janus LHG-8 Double Pass - FF=0.8 (Graphics->)

1	Mirror1	9.300	0	1.000	1.000	0	1.000	1.000	25.00
[Subchain FORWARD INJECTION]									
2	[SWITCH transmits 1 times; switch distance = 10]								
3	SWITCH	9.300	0	1.000	1.000	0	1.000	1.000	45.00
4	Polarizer	9.300	2.400	1.000	0.960	56.43	1.507	1.240	62.50
5	Rotator	9.300	4.300	1.000	0.960	0	1.673	2.100	62.50
6	Polarizer	9.300	2.400	1.000	0.960	-56.43	1.507	1.240	30.00
[SATURATION FLUX = 5.387 (J/cm2)]									
7	B-head-1	9.300	2.400	1.396	0.989	56.71	1.523	1.050	25.00
8	B-head-1	9.300	2.400	1.396	0.989	-56.71	1.523	1.050	25.00
9	B-head-1	9.300	2.400	1.396	0.989	56.71	1.523	1.050	25.00
10	B-head-1	9.300	2.400	1.396	0.989	-56.71	1.523	1.050	25.00
11	B-head-1	9.300	2.400	1.396	0.989	56.71	1.523	1.050	25.00
12	B-head-1	9.300	2.400	1.396	0.989	-56.71	1.523	1.050	60.00
13	Mirror2	9.300	0	1.000	0.995	0	1.000	1.000	0

Small signal gain for above components is '6.097'

(** Subchain 2 **)

0 Power Amps LHG-8 (Graphics->)

1	SF5 lens1	9.300	2.000	1.000	0.990	0	1.508	1.200	200.0
2	PINHOLE transmission 1, cutoff 10000 milliradians								
3	SF5 lens2	9.300	2.000	1.000	0.990	0	1.508	1.200	30.00
[SATURATION FLUX = 5.387 (J/cm2)]									
4	B-head-2	9.300	2.400	1.396	0.989	56.71	1.523	1.050	25.00
5	B-head-2	9.300	2.400	1.396	0.989	-56.71	1.523	1.050	25.00
6	B-head-2	9.300	2.400	1.396	0.989	56.71	1.523	1.050	25.00
7	B-head-2	9.300	2.400	1.396	0.989	-56.71	1.523	1.050	25.00
8	B-head-2	9.300	2.400	1.396	0.989	56.71	1.523	1.050	25.00
9	B-head-2	9.300	2.400	1.396	0.989	-56.71	1.523	1.050	20.00
10	SF5 lens1	9.300	2.000	1.000	0.990	0	1.508	1.200	200.0
11	PINHOLE transmission 1, cutoff 10000 milliradians								
12	SF5 lens2	9.300	2.000	1.000	0.990	0	1.508	1.200	10.00
13	PLOT, Distance from last component = 0 (cm) (Activated while FORWARD)								

Small signal gain for above components is '6.653'

Time (ns) for output: 1

Power density (GW/cm2): 0.0001515

Photon duration (ns): 0.0001

Wavelength (microns): 1.053

Patch radius (cm): 0

Beginning distance (cm): 0

Beginning diameter (cm): 2.3

Minimum angle (milliradians): 0

Maximum angle (milliradians): 50

No. of angles: 100

No. of pictures: 1

Overall extraction efficiency: 0.188

APPENDIX 2 (Page 4 of 4)
TABLE 3.2 (Continued.)

Thing Number	Thing I.D.	Patch Inten	Vacum Dist	Equiv Dist	Patch X-Val	Patch Y-Val	Patch Z-Val	Delta B-Int	Sigma B-Int	Solid Path	SAT GAIN	Slice Count
Subchain '0'												
0	Cyclops LHG-8, Single Pass Front End - FF=0.8											
1		2e-04										
2	SF1 lens1	1e-04	0	0	0	0	0.0	6e-06	6e-06	2.000	1.000	1.000
3	PINHOLE transmission 1, cutoff 10000 milliradians											
4	SF1 lens2	1e-04	278.0	-278.0	0	0	280.0	6e-06	1e-05	2.000	1.000	1.000
	SATURATION FLUX = 5.387 (J/cm2)											
5	25mm Rod Amp-1	0.007	43.00	43.00	0	0	325.0	0.001	0.001	40.00	49.96	42.00
6	Polarizer	0.007	3.000	3.000	0	0	368.0	2e-04	0.002	1.680	1.000	1.000
7	Rotatator	0.006	3.452	3.452	-0.653	0	373.0	0.002	0.004	9.000	1.000	1.000
8	Polarizer	0.006	5.984	5.984	-0.653	0	388.0	1e-04	0.004	1.680	1.000	1.000
9	25mm Rod Amp-2	0.288	45.47	45.47	0	0	435.0	0.054	0.058	40.00	48.37	41.00
10	Expanding lens	0.285	5.000	5.000	0	0	480.0	0.006	0.064	1.000	1.000	1.000
11	Recolimating le	0.106	19.00	11.65	0	0	500.0	0.004	0.068	1.950	1.000	1.000
12	Polarizer	0.102	104.0	104.0	0	0	606.0	0.004	0.072	2.880	1.000	1.000
13	Rotatator	0.098	7.346	7.346	-1.119	0	616.0	0.016	0.088	4.300	1.000	1.000
14	Polarizer	0.094	11.39	11.39	-1.119	0	631.7	0.004	0.091	2.880	1.000	1.000
15	40mm Rod Amp-3	0.516	5.659	5.659	0	0	640.0	0.107	0.199	23.50	5.695	19.00
16	SF2 lens1	0.510	11.50	11.50	0	0	675.0	0.021	0.219	2.000	1.000	1.000
17	PINHOLE transmission 1, cutoff 10000 milliradians											
18	SF2 lens2	0.082	364.0	-146.8	0	0	1041.0	0.003	0.223	1.996	1.000	1.000
19	Interface	0.082	131.0	131.0	0	0	1174.0	0	0.223	0	1.000	1.000
20	PLOT, Distance from last component = 0 (cm)											
Subchain '1'												
0	Cyclops LHG-8, Single Pass Front End - FF=0.8											
2		0.082										
3	SWITCH	0.082	0	0	0	0	1174.0	0	0.223	0	1.000	1.000
4	Polarizer	0.079	45.00	45.00	0	0	1219.0	0.003	0.226	2.880	1.000	1.000
5	Rotatator	0.076	59.85	59.85	-1.119	0	1281.5	0.011	0.237	4.300	1.000	1.000
6	Polarizer	0.073	59.89	59.89	-1.119	0	1345.7	0.003	0.240	2.880	1.000	1.000
7	B-head-1	0.100	25.66	25.66	0	0	1374.0	0.003	0.242	2.871	1.393	4.000
8	B-head-1	0.138	24.10	24.10	-1.141	0	1400.7	0.004	0.246	2.871	1.392	4.000
9	B-head-1	0.189	20.63	20.63	0	0	1424.0	0.005	0.251	2.871	1.390	4.000
10	B-head-1	0.260	24.10	24.10	-1.141	0	1450.7	0.007	0.259	2.871	1.388	4.000
11	B-head-1	0.356	20.63	20.63	0	0	1474.0	0.010	0.269	2.871	1.385	4.000
12	B-head-1	0.407	24.10	24.10	-1.141	0	1500.7	0.014	0.282	2.871	1.381	4.000
13	Mirror2	0.484	55.63	55.63	0	0	1559.0	0	0.282	0	1.000	1.000
12	B-head-1	0.652	57.60	57.60	0	0	1616.6	0.018	0.301	2.871	1.362	4.000
11	B-head-1	0.876	24.10	24.10	-1.141	0	1643.3	0.025	0.325	2.871	1.359	4.000
10	B-head-1	1.172	20.63	20.63	0	0	1666.6	0.033	0.358	2.871	1.352	4.000
9	B-head-1	1.556	24.10	24.10	-1.141	0	1693.3	0.044	0.403	2.871	1.343	4.000
8	B-head-1	2.046	20.63	20.63	0	0	1716.6	0.058	0.461	2.871	1.329	3.000
7	B-head-1	2.654	24.10	24.10	-1.141	0	1743.3	0.076	0.537	2.871	1.311	3.000
6	Polarizer	2.548	25.63	25.63	0	0	1771.6	0.104	0.641	2.880	1.000	1.000
5	Rotatator	2.446	57.95	57.95	-1.119	0	1832.2	0.344	0.985	4.300	1.000	1.000
4	Polarizer	2.348	61.79	61.79	-1.119	0	1898.3	0.096	1.082	2.880	1.000	1.000
3	SWITCH	2.348	43.06	43.06	0	0	1944.0	0	1.082	0	1.000	1.000
Subchain '2'												
0	Power Amps											
1	SF5 lens1	2.324	10.00	10.00	0	0	1954.0	0.093	1.175	2.000	1.000	1.000
2	PINHOLE transmission 1, cutoff 10000 milliradians											
3	SF5 lens2	2.301	198.0	-198.0	0	0	2154.0	0.093	1.268	2.000	1.000	1.000
4	B-head-2	2.965	28.00	28.00	0	0	2184.0	0.085	1.353	2.871	1.303	3.000
5	B-head-2	3.747	24.10	24.10	-1.141	0	2210.7	0.109	1.462	2.871	1.278	3.000
6	B-head-2	4.632	20.63	20.63	0	0	2234.0	0.136	1.598	2.871	1.250	3.000
7	B-head-2	5.586	24.10	24.10	-1.141	0	2260.7	0.166	1.764	2.871	1.219	3.000
8	B-head-2	6.562	20.63	20.63	0	0	2284.0	0.198	1.961	2.871	1.188	2.000
9	B-head-2	7.509	24.10	24.10	-1.141	0	2310.7	0.229	2.191	2.871	1.157	2.000
10	SF5 lens1	7.434	15.63	15.63	0	0	2329.0	0.299	2.489	2.000	1.000	1.000
11	PINHOLE transmission 1, cutoff 10000 milliradians											
12	SF5 lens2	7.360	198.0	-198.0	0	0	2529.0	0.296	2.785	2.000	1.000	1.000
13	PLOT, Distance from last component = 0 (cm)											

END

DATE FILMED

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