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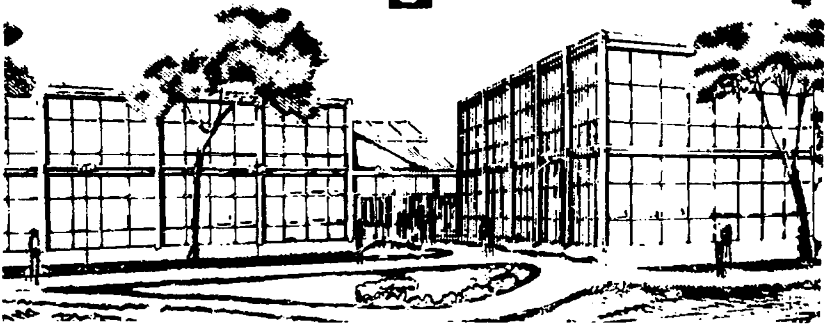

Super Liquid Density Target Designs*

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ABSTRACT

The success of laser fusion depends on obtaining near isentropic compression of fuel to very high densities and igniting this fuel. To date, the results of laser fusion experiments have been based mainly on the exploding pusher implosion of fusion capsules consisting of thin glass microballoons (wall thickness of less than 1 micron) filled with low density DT gas (initial density of a few mg/cc). Maximum DT densities of a few tenths of g/cc and temperatures of a few keV have been achieved in these experiments. We will discuss the results of LASNEX target design calculations for targets which: (a) can compress fuel to much higher densities using the capabilities of existing Nd-glass systems at LLL; (b) allow experimental measurement of the peak fuel density achieved.

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The success of laser fusion depends on obtaining near isentropic compression of fuel to very high densities and igniting this fuel.[1] To date, the results of laser fusion experiments have been based mainly on the exploding pusher implosion of fusion capsules consisting of thin glass microballoons (wall thickness of less than 1 micron) filled with low density DT gas (initial density of a few mg/cm^3). Maximum DT densities of a few tenths of g/cm^3 and temperatures of a $\sim$8 keV have been achieved in these experiments.[2] Experiments which can compress fuel to higher densities are desirable and necessary. We present the results of design calculations for targets which:

A. Can compress fuel to a peak average-density of 1-10 g/cm^3 using the capabilities of a 0.5 TW, Nd-glass system similar to the JANUS laser facility at LLL with the two-beam clamshell focusing system[3].

B. Can be fabricated.

C. Allow experimental determination of the peak fuel density achieved by measuring the α-particle energy loss and/or the observation of neon x-ray line emission in the 1 keV region. Approximately 10^5 DT reactions in the target are required to produce a detectable signal in the α-particle time-of-flight detector which has an energy resolution of about 150 keV.[4] The threshold for the neutron detector is in the range of 10^2-10^3. An energy resolution of about 1 eV is necessary to measure the neon x-ray line width.[5]

Given a laser system without pulse shaping capabilities, the limit in compressing fuel to high densities is the electron preheat effect. The preheat of the fuel can be reduced by lowering the peak laser power used. But this would decrease, at the same time, the strength of the neon emission signal as well as the DT reaction yields. Thus, the proper target design must give both density and DT reaction yield if experimental determination of the peak average-density achieved is to be measured by the α-particle energy loss.

We show in Figure 1, three target designs which can compress fuel to peak average-densities of about 1-10 g/cm^3. In each case, the fuel is at an initial density of 2 x 10^{-3} g/cm^3 and is composed of DT and 1% neon by mole fraction. The capsule which encloses the fuel can be made of glass, plastic, carbon, beryllium, etc. In Figure 1c, the capsule is surrounded by a high Z tamper which also acts as a preheat shield and a low Z ablator. The fuel capsule is encased by a low Z ablator in Figure 1b. Figure 1a, represents a thick-wall fuel capsule. The advantages of the target shown in Figure 1c is overshadowed by the fabrication complexities. Therefore, we will omit further discussions concerning this target. It is clear that the simplest target to construct is a glass microballoon (Figure 1a). Therefore, we concentrate our discussion on this type of targets. But, it is important to note that oxygen and high Z material in the glass (SiO_2) wall increase the x-ray background in the 1 keV region and thereby increase the difficulty in the neon line emission measurements.

The target design calculations have been performed using the LASNEX

MHD code with laser absorption due to classical as well as plasma instability processes.[6] To simulate the laser absorption due to plasma instabilities, we assume that if the laser radiation penetrates to or beyond a density of 0.8 ρ_c, where ρ_c is the critical density for the laser electrons, then 25% of the laser energy is placed in the suprathermal electrons.[7] The suprathermal electron spectrum is characterized by a temperature which is six times the thermal electron temperature. Laser absorption due to inverse bremsstrahlung is reduced by a factor of 5 to simulate density profile steepening effects.[8] Using these parameters, we have been able to obtain good agreement between experimental and LASNEX simulation results for several different targets.[9]

The clamshell focusing system can illuminate a spherical target in a near uniform manner. Thus, one-dimensional (1D) LASNEX simulation calculations can yield reasonably satisfactory results. Figures 1 and 3 show the 1D simulation results for a 60 μm diameter, 3.2 μm thickness glass microballon irradiated with a 100 J, laser pulse of varying pulse length. A Gaussian temporal pulse shape is assumed in all cases. As expected, we find that the peak average-fuel-density is inversely proportional to its temperature, thermonuclear yield, and the laser power used. Shock heating of the DT ions from the exploding glass microballoon which causes the electron and ion temperatures to diverge with reduced pulse width (increased laser power) is apparent. The results for the same target using the three-temperature (3T) model where suprathermal electrons do not exist are shown in Figure 2 to demonstrate the effect of fuel preheat.

As noted above, approximately 10^5 DT reactions are required by the α-particle time-of-flight detector. From Figure , we see that this requirement can be satisfied by a 100 J laser pulse with a width of less than 200 ps. Figure 4 shows the effects of laser irradiation energy on the peak average-density and neutron yield for a 200 ps Gaussian temporal pulse. Not surprisingly, the neutron yield drops rapidly with reduced laser energy. The peak average-fuel-density of about 1 g/cm^3 is, however, insensitive to the large incident energy variations.

We have attempted to design a 60 μm diameter glass microballoon target which can compress fuel to peak-average-densities of about 1 g/cm^3 using 50 J of laser energy and a pulse length of about 200 ps. The thickness of the glass microballoon has been reduced. But the results indicate that it is not possible to obtain a peak average-fuel-density of 1 g/cm^3 and 10^5 DT reactions using a 50 J laser pulse. It is, however, instructive to show the relationship between the electron temperature in the fuel and the neon line emission strength versus x-ray background in the 1 keV region, Figure 5. The target is a 60 μm diameter, 1 μm thickness glass microballoon irradiated with a 50 J laser pulse of varying duration. Since the neon line emission strength can vary with time, a steady state calculation can lead to serious errors. We have, therefore, used a time dependent calculation.[20] The attenuation of the neon x-ray line emission by the glass has not been included in these calculations. Preliminary estimates indicate an error of less than a factor of 2 from this source. Conservatively, a minimum electron temperature of about 300 eV in the fuel or a line/background ratio of about 4 is desirable for the observation of the neon line emission with a 1 μm thickness glass microballoon. Because of this, experimental verification of the achievement of a peak average-fuel density of greater than about 1 g/cm^3 using a 50 J, 200 ps laser pulse and a 60 µm diameter glass microballoon is improbable.

Experimental verifications can be made for a density of about 1 g/cm^3 using a 50 J laser pulse and a 40 µm diameter glass microballoon. We discuss the results of two-dimensional (2D) LASNEX calculations. Geometrical ray tracing is used, in this case, to calculate the focal, refractive, and reflective properties of the laser radiation. Magnetic field effects are also included. An example of the laser spatial profile used in these calculations is shown in Figure 6. Table 1 shows the results of these 2D simulations for a 40 µm diameter, 1 µm thickness glass microballoon irradiated by a 100 ps, 50 J gaussian pulse. The offset has been varied. These results are in good agreement with those obtained from 1D simulations and show that a peak density of about 1 g/cm^3 can be achieved and experimentally verified. The results are insensitive to small variations in the clamshell focusing positioning.

Using other target designs and with a maximum laser energy of 50-100 J and longer pulse lengths, peak average-fuel-densities of greater than 1 g/cm^3 can be achieved. The DT reaction yields are, however, extremely low. Therefore, neon x-ray line emission measurements must be relied upon to verify the peak density achieved. For this method to be effective, the x-ray background in the 1 keV range must be reduced from those calculated for the glass microballoons discussed above. We find that it is possible to verify and achieve densities of 2-3 g/cm^3 with a thin-glass microballoon target surrounded by low Z ablator, e.g., CH, C, Be, Figure 1b, using

50 J of incident laser energy. For densities of about 10 g/cm^3, 100 J of incident laser energy and a target constructed entirely of low Z material, Figure 1a, are required. The results of these calculations are also shown in Table 1.

It is important to note that the choice of the low Z microballoon material is controlled by three factors:

(1) X-ray background (proportional to Z^4) is greatly reduced with low Z capsule material.

(2) To obtain the maximum hydrodynamic implosion efficiency, the initial density of the capsule material should be as high as possible. For this reason, carbon is preferred over CH although they have the same Z.

(3) Since all the targets must be fabricated, fabrication must be considered to be the dominating factor. Glass microballoons are unsuitable for our purposes because of its oxygen content. (Oxygen has a bound-free edge at about 870 eV.) Thus, the elimination of all oxygen from microballoon material is crucial.

We have presented LASNEX simulation results which indicate that fuel at an initial density of 2 mg/cm^3 can be compressed to peak average-densities in the range 1-10 g/cm^3 using 50-100 J of incident 1.06 μm laser energy. No temporal pulse shaping is required. Proper choice of the capsule material should allow experimental verification of the peak average-fuel-densities achieved.

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Figure Captions

Fig. 1 Three target designs which can compress fuel to peak average-densities of about 1-10 g/cm^3.

Fig. 2 1D LASNEX results (peak average-fuel-density and neutron yield versus pulse length) for a 60 μm diameter, 3.2 μm thickness glass microballoon target irradiated by a 100 J, 1.06 μm laser pulse.

Fig. 3 1D LASNEX results (peak average-fuel-density, peak electron and ion temperatures versus pulse length) for a 60 μm diameter, 3.2 μm thickness glass microballoon target irradiated by a 100 J gaussian temporal laser pulse.

Fig. 4 1D LASNEX results (peak average-fuel-density and neutron yield versus incident laser energy) for a 60 μm diameter, 3.2 μm thickness glass microballoon target irradiated by a 200 ps (FWHM) gaussian temporal laser pulse.

Fig. 5 1D LASNEX results (peak electron temperature in the fuel and the ratio of the neon line emission to x-ray background in the 1 keV range versus incident laser pulse length) for a 60 m diameter, 1.0 μm thickness glass microballoon irradiated by a 50 J laser pulse.

Fig. 6 An example of the assumed spatial profile of the laser beam used in our 2D LASNEX calculations. The angle θ is measured from the positive Z axis. The laser beam is assumed to be symmetrical about the X and Z axes.

INCREASED SHELL THICKNESS DECREASES ELECTRON PREHEAT OF THE FUEL

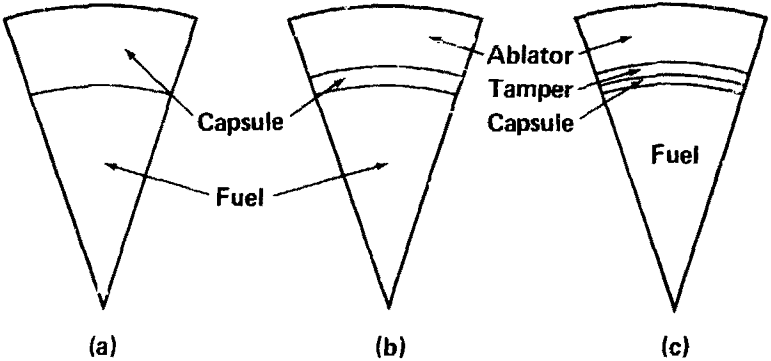

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Fig. 1

DENSITY INCREASES WITH DECREASING LASER POWER. NEUTRON YIELD INCREASES WITH INCREASING LASER POWER

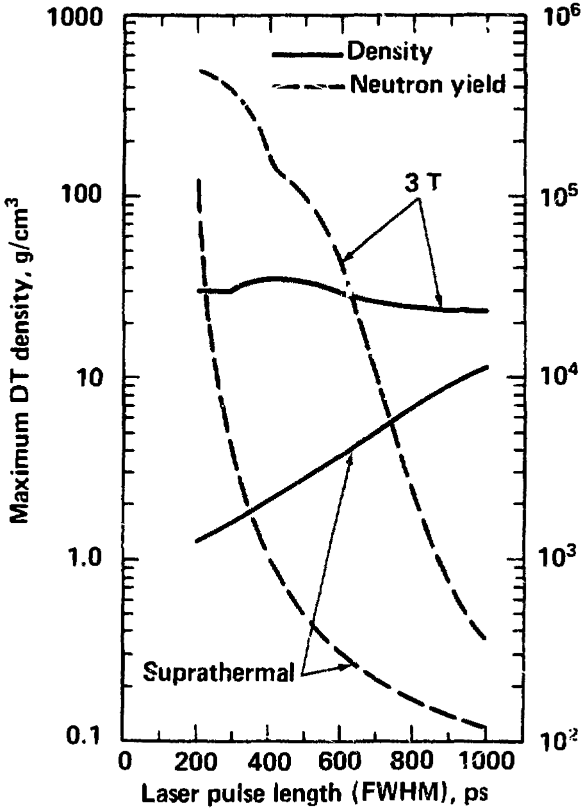

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Fig. 2

HIGHER ION AND ELECTRON TEMPERATURES IN THE FUEL IMPLY LOWER FUEL DENSITY

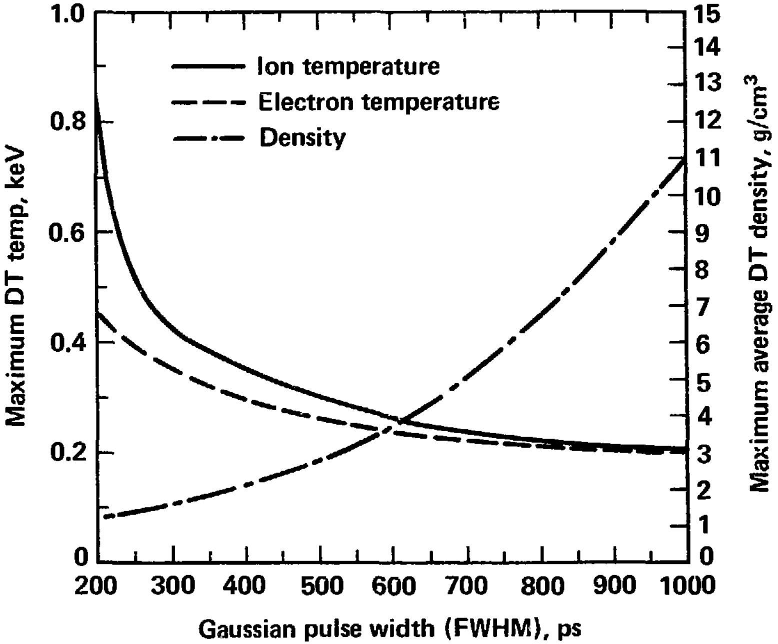

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Fig. 3

PEAK FUEL DENSITY IS NOT SENSITIVE TO LASER ENERGY VARIATIONS

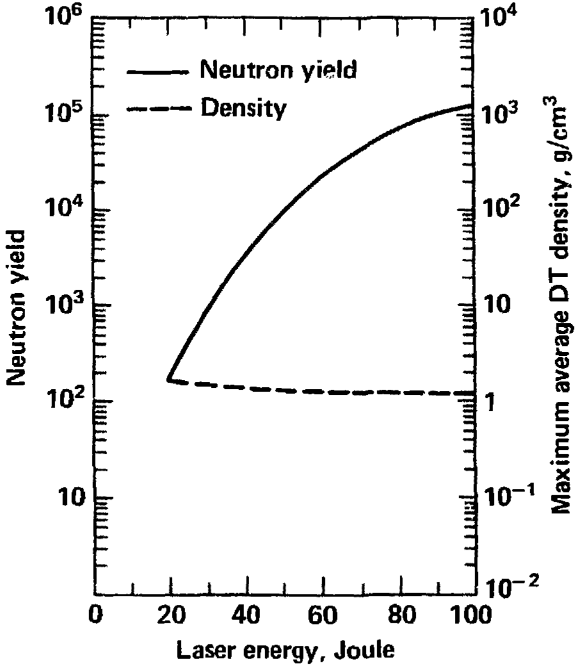

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Fig. 4

A MAXIMUM ELECTRON TEMPERATURE OF 300 eV OR HIGHER IN THE FUEL IS DESIRABLE FOR NEON X-RAY LINE EMISSION MEASUREMENTS

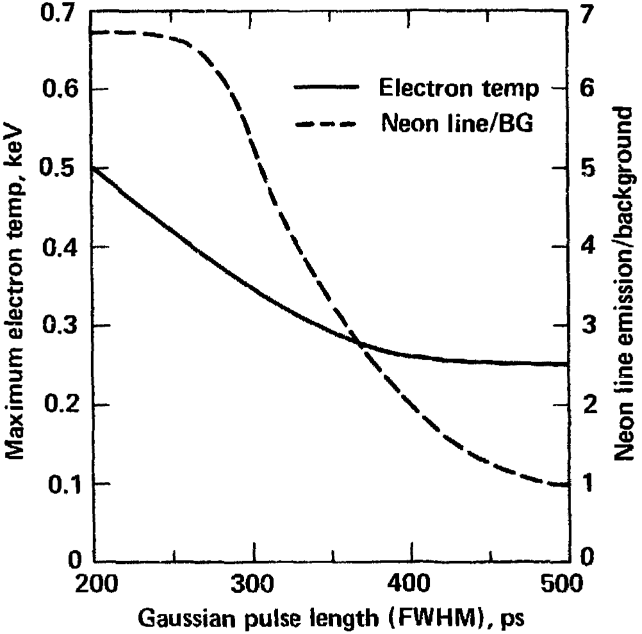

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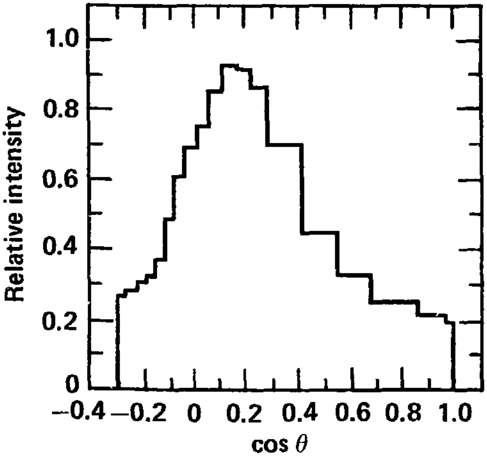
Fig. 5

UNIFORM LASER ILLUMINATION OF THE MICROSPHERE IS DESIRABLE, BUT NOT ESSENTIAL, FOR SUPER LIQUID DENSITY TARGET IMPLOSION EXPERIMENTS



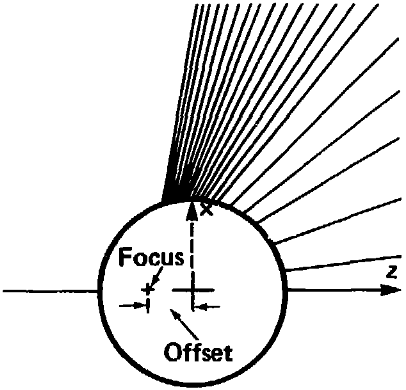


Fig. 6

DT FUEL CAN BE COMPRESSED TO DENSITIES OF 1–10 g/cm^3 WITH EXISTING Nd-GLASS LASER SYSTEMS. EXPERIMENTAL VERIFICATIONS ARE POSSIBLE

Laser Energy – J FWHM – ps	Target Diam. – µm Thick. – µm material	Offset µm	Peak average-DT density g/cm^3	DT reaction yield	X-ray emission (keV/keV)			Alpha-particle energy loss (keV)	
					Neon line	Back-ground	Line/BG	DT	SiO_2
50 100	40 1.0 SiO_2	3.5	1.3	4.5×10^6	8.2×10^{15}	9.4×10^{14}	8.7	250	285
50 100	40 1.0 SiO_2	6.5	1.1	2.3×10^6	8.4×10^{15}	9.4×10^{14}	8.9	210	240
50 100	40 1.0 SiO_2	-0.5	1.1	2.8×10^6	5.4×10^{15}	8.2×10^{14}	6.6	125	290
50 250	60 0.6 – SiO_2 0.8 – C	16	3.1	4.5×10^3	4.0×10^{15}	1.2×10^{15}	3.3	–	–
100 1000	70 4.5 Be	6.5	13.7	35	1.6×10^{15}	2.5×10^{14}	6.4	–	–

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Table 1