ORTION
F THIS
CUMEN
ARE
EGIBL

LA-UR-80-1492

CONF-800707--9

TITLE: PROGRESS IN INERTIAL FUSION RESEARCH AT THE LOS ALAMOS SCIENTIFIC LABORATORY

AUTHOR(S): Roger B. Perkins

SUBMITTED TO: 8th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Brussels, Belgium, 1-10 July 1980

MASTER

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

Form No. 836 R3
St. No. 2629

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

INTERNATIONAL ATOMIC ENERGY AGENCY

8th INTERNATIONAL CONFERENCE ON PLASMA PHYSICS AND CONTROLLED NUCLEAR FUSION RESEARCH

Brussels, 1–10 July 1980

IAEA-CN-38/ B-2

PROGRESS IN INERTIAL FUSION RESEARCH AT THE LOS ALAMOS SCIENTIFIC LABORATORY

Roger B. Perkins
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

Paper Number IAEA-CN-38/B-2

PROGRESS IN INERTIAL FUSION RESEARCH AT THE LOS ALAMOS SCIENTIFIC LABORATORY*

ABSTRACT

The Los Alamos Scientific Laboratory Inertial Confinement Fusion Program is reviewed. Experiments using the Helios CO_2 laser system delivering up to 6 kJ on target are described. Because breakeven energy estimates for laser drivers of 1 μm and above have risen and there is a need for CO_2 experiments in the tens-of-kilojoule regime as soon as practical, a first phase of Antares construction is now directed toward completion of two of the six original modules in 1983. These modules are designed to deliver 40 kJ of CO_2 laser light on target.

1. Objectives

The Los Alamos Scientific Laboratory is pursuing inertial confinement fusion for the dual goals of commercial power and military applications. For both of these goals, efficient burning of fusion fuel is required. This requires development of suitable high-power drivers to provide sufficient energy to a fuel pellet to achieve ignition (and eventually high gain), and a target physics program to guide design and fabrication of the requisite targets.

2. CO_2 Laser Systems

At LASL, we are developing a series of short-pulse, high-energy carbon-dioxide laser systems. A dual beam system, Gemini, was developed and used in early 1977 for our initial experiments with DT-filled exploding pusher targets. Currently, Gemini is being used for laser plasma interaction experiments at energy levels of up to 450 joules per beam, with a pulse length of 1 ns. Gemini was also used as a laser prototype for the eight-beam Helios laser, which began operation in 1978.

The Helios system (Fig. 1) consists of four dual-beam modules which provide a total of eight laser beams for simultaneous target illumination in a central target chamber. Helios employs an oscillator amplifier configuration. The master oscillator produces a smooth, gain-switched 100-ns pulse of about 100 mJ. This output pulse is directed to a three-stage Pockels cell shutter system capable of modifying the

*Work performed under the auspices of the U. S. Department of Energy.

input to a 1-ns or shorter pulse with a contrast ratio in excess of one million. Double-discharge amplifiers amplify this master pulse to a level of about 1 J. The pulse is then split into four beams, further amplified and again split to provide the eight synchronous beams required for the final amplifiers.

The final amplifier stages are pumped by the electron-beam-controlled-discharge technique. A three-pass configuration is used to reduce the drive requirements from about 100 J (required for a single pass configuration) to about 0.1 J. However, the small signal gain per pass in this system is about 1000, increasing the possibility of optical parasitic oscillations. Such parasitics have been observed and it was determined that the main parasitic coupling was through the rear collimating mirror. A gaseous, saturable absorber cell was developed to optically decouple this mirror from the gain medium at low intensity levels. A gas mixture consisting of SF_6 and a combination of five freons was chosen to ensure that the small signal gain in both the 9- and 10-μm bands was blocked, while high-intensity pulses were transmitted. When the saturable cell was placed between the second and third passes of the module, the parasitic threshold was increased and the modules were able to reach full design energy of 1250 J. In full system tests, approximately 10 kJ were generated in a pulse shorter than 1 ns for a power output in excess of 21 TW.

Current operational characteristics of Helios are shown in Table I. The target is illuminated along the diagonals connecting the eight corners of an imaginary cube whose top half is rotated 45^o to prevent the beams from directly facing each other. Encircled energy measurements indicate that, typically, 80% of beam energy will pass a 120-μm-diameter aperture. Prepulse energy on target is measured to be less than 20 μJ, a level which is safely below the target damage threshold. Recently, the optical configuration between the first and second passes of the power amplifier has been modified and simplified to eliminate a spatial filter, two windows, and related hardware. Performance of the amplifiers has become much more reproducible, with typical energy output of 900 J per beam in the presence of a target.

Antares, the next step in the sequence of CO_2 lasers at LASL, is under construction (Fig. 2). The laser system consists of six large power amplifier modules (PAM), each producing 12 annular beams. Antares is designed to deliver 100 kJ to targets with a pulse length of 1 ns. Building construction is complete and installation of the first two PAM's has begun. Figure 3 is an artist's conception of the PAM. The twelve CO_2 gain regions are pumped with an electron-beam controlled discharge using a central electron gun assembly. The optical beam makes two passes through the gain region and is then periscoped down to form an annular beam which is transported to the target through a vacuum system. Construction of the target vacuum system is well underway.

We plan to complete Antares in two phases. The first phase will consist of two PAM's delivering 40 kJ symmetrically to the target. This system will be completed in late 1983. After performing target experiments in 1984 and 1985, we plan to complete the full system at an energy level of 100 kJ or more, if possible.

3. Experiments

Since June 1978, Helios has been used for target experiments aimed at extending our understanding of the laser-plasma interaction. Initial experiments used exploding pusher targets; recently, attention has turned to targets called Sirius B (Fig. 4), which consist of thin glass microballoons (GMB) containing gaseous DT fuel covered with a low-density plastic coating. The external plastic coating serves two purposes: it shields the interior fuel, thus preventing significant preheating prior to compression, and it provides an efficient means of converting absorbed laser energy into compressional motion. These characteristics allow one to achieve fuel densities higher than those attained with exploding pusher targets.

It is most energy efficient to drive targets to high density and temperature adiabatically. The goal for ignition targets is a compression of the fuel to densities of over 1000 times normal liquid hydrogen density. By varying the thickness of the plastic coating, one can study the transition in performance from that of an exploding pusher target (no coating) to that of a more nearly adiabatically driven target. As the plastic thickness is increased, the fuel density increases, but the neutron yield decreases. This decrease in neutron yield is due to the lower fuel temperatures which occur as the thickness is increased and the electron preheat is reduced under the condition of constant incident laser energy.

The compression is inferred from self-luminous x-ray imaging and, for coating thicknesses up to about 50 μm, from line spectroscopy and from one-dimensional spatial imaging of x-ray emissions from Ar added to the DT fuel gas. Figure 5 shows fuel density measurements by these techniques, as well as values inferred from neutron yield and fuel ion temperatures deduced from neutron energy spread measurements described below. These data are from early shots when the input energy was approximately 3 kJ. Table II displays higher energy specific shot data which compares measured fuel density with computer simulation for the actual target and incident laser energy condition. Work is underway on improved compression diagnostics making use of time-resolved x-ray shadowgraphs of the target at peak compression. To date, we have reached fuel compressions of twenty times liquid-hydrogen density.

In addition to compression, neutron-yield, fuel temperatures and implosion times have been measured. Time to implosion is determined from time of occurence of the neutron signal; the fuel temperature is determined from the neutron spectrum measured by time-of-flight techniques. These measurements are made with a fast neutron detector consisting of an ultrafast, quenched scintillator and a high-gain micro-channel plate photomultiplier. This system provides a neutron response time of 400 ps (FWHM) and it is possible to obtain a resolution of less than 100 ps in time shift and neutron pulse broadening. Figure 6 shows the variation of the measurables: the neutron yield, the implosion time (time to peak neutron generation rate) and the peak fuel temperature. The agreement between the measurements and calculation is good for total yield and implosion time, but the calculation suggests a higher temperature should have been achieved than was measured. This may suggest that the density in the experiment may be higher than calculated; we see from Figure 5 that this is confirmed, at least for the thicker ablator coatings. Table II compares neutron yield data with computer simulation, again for the specific experimental conditions. We plan to extend these measurements to higher laser energy, where we expect both higher neutron yields and fuel compressions.

We are perfecting a radiochemical diagnostic technique which will permit measurement of the thickness-density product of the fuel and pusher, which can be compared to theoretical calculations of target perf mance. A suitable detector material will be incorporated i to the fuel or pusher, and the nuclear activation of this detector by 14-MeV fusion neutrons can be measured. Control experiments using targets activated in a reactor have determined that 16% of the target is collected by our catcher assembly.

Future experiments with Helios and Antares will permit confirmation of compression and neutron yield predictions, and will allow determination of the driver energy required for demonstration of ignition, breakeven, and high gains.

4. Heavy Ion Drivers

LASL has recently been assigned the lead role for managing the U. S. Heavy Ion Fusion Program. The use of high-energy heavy ions for inertial fusion is believed to be very attractive for two reasons: the interaction of heavy ions with targets is expected to be classical and highly efficient, leading to high gain with a minimum of input energy; in addition, the heavy-ion accelerator is an extension of the well-developed high-energy proton accelerator and is expected to have efficiency considerably higher than lasers.

Acknowledgment

The paper reports work carried out by many members of the LASL Inertial Fusion Program, and I acknowledge their contributions. I wish to thank A. Hauer, C. M. Gillespie, G. McCall, and G. A. Sawyer for help in preparing the paper.

TABLE I

CURRENT OPERATIONAL CHARACTERISTICS
OF HELIOS

Laser Energy	10 kJ*
Prepulse Energy	20 μJ
Pulsewidth	0.7 ns
Cycle Time Laser	5 min
Target Shot Rate	10/day
Efficiency (Laser Energy/ Electrical Energy)	1%
Wavelength	10.6 μm
Max. Target Irradiance	10^{17} W/cm^2
80% Encircled Energy Diameter	65 μm
Focusing Optics	f/2.4 off-axis parabola

*Maximum on-target energy currently limited to 6 kJ by target parasitics.

TABLE II

REPRESENTATION MEASUREMENTS OF FUEL DENSITY AND NEUTRON YIELD COMPARED WITH COMPUTER SIMULATION

Ablator Thickness (μm)	Incident Laser Energy (J)	Measured Density (gm/cm^3) Spectro-metric	X Ray Image	Calculated Density (gm/cm^3)	Neutron Yield Measured	Calculated
0	3030	0.35	0.25	0.25	5×10^7	--
35	4900	1.9	0.8	2.1	6×10^7	8×10^7
37	4520	2.5	2.1	--	1×10^8	2×10^8
50	6280	3.1	1.7	2.9	1×10^8	2×10^8

Figure Captions:

Fig. 1 Helios, the 10 kJ CO_2 laser system.

Fig. 2 Model of Antares, the 100 kJ CO_2 laser system.

Fig. 3 Antares power amplifier module.

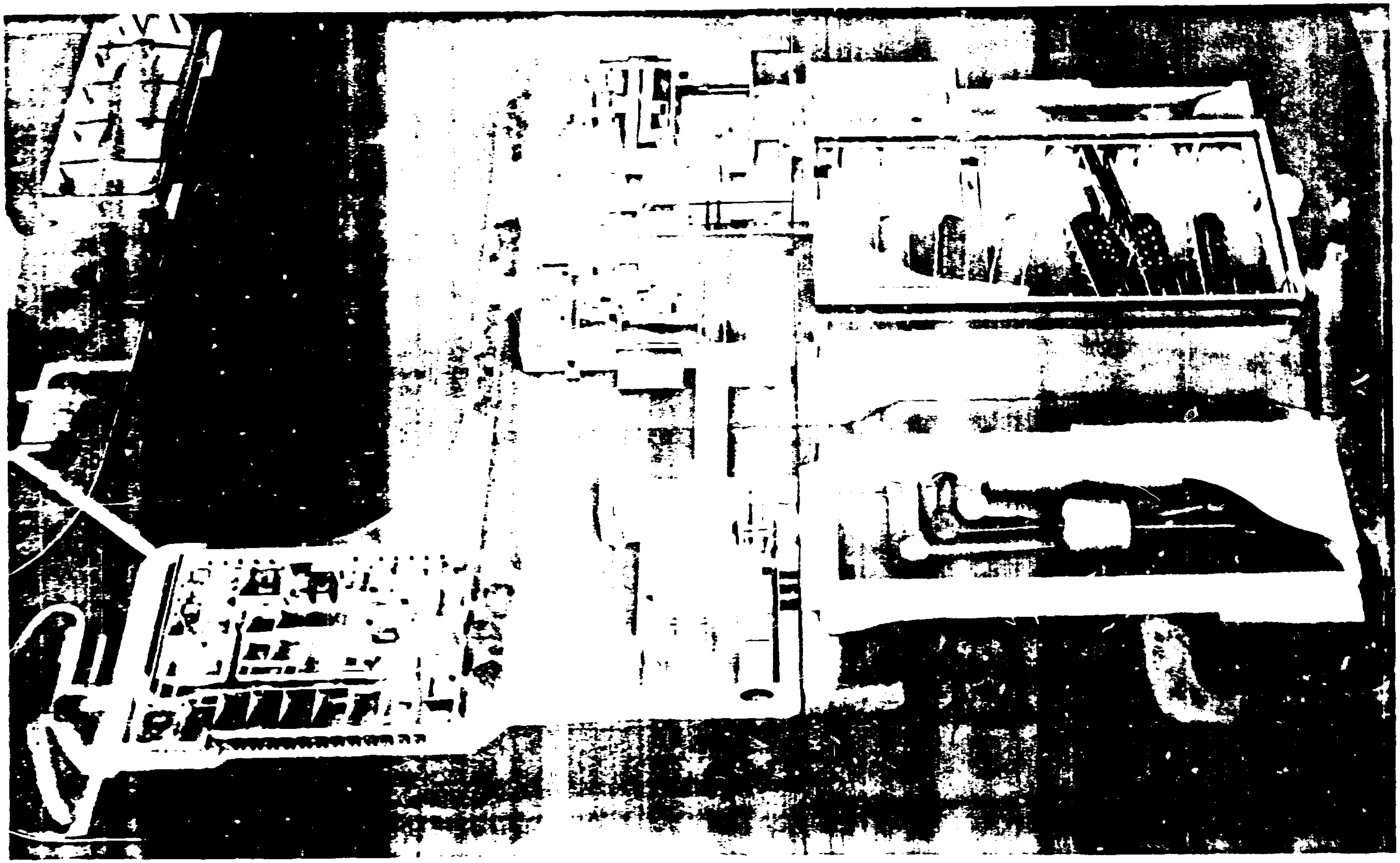
Fig. 4 Sirius B target schematic.

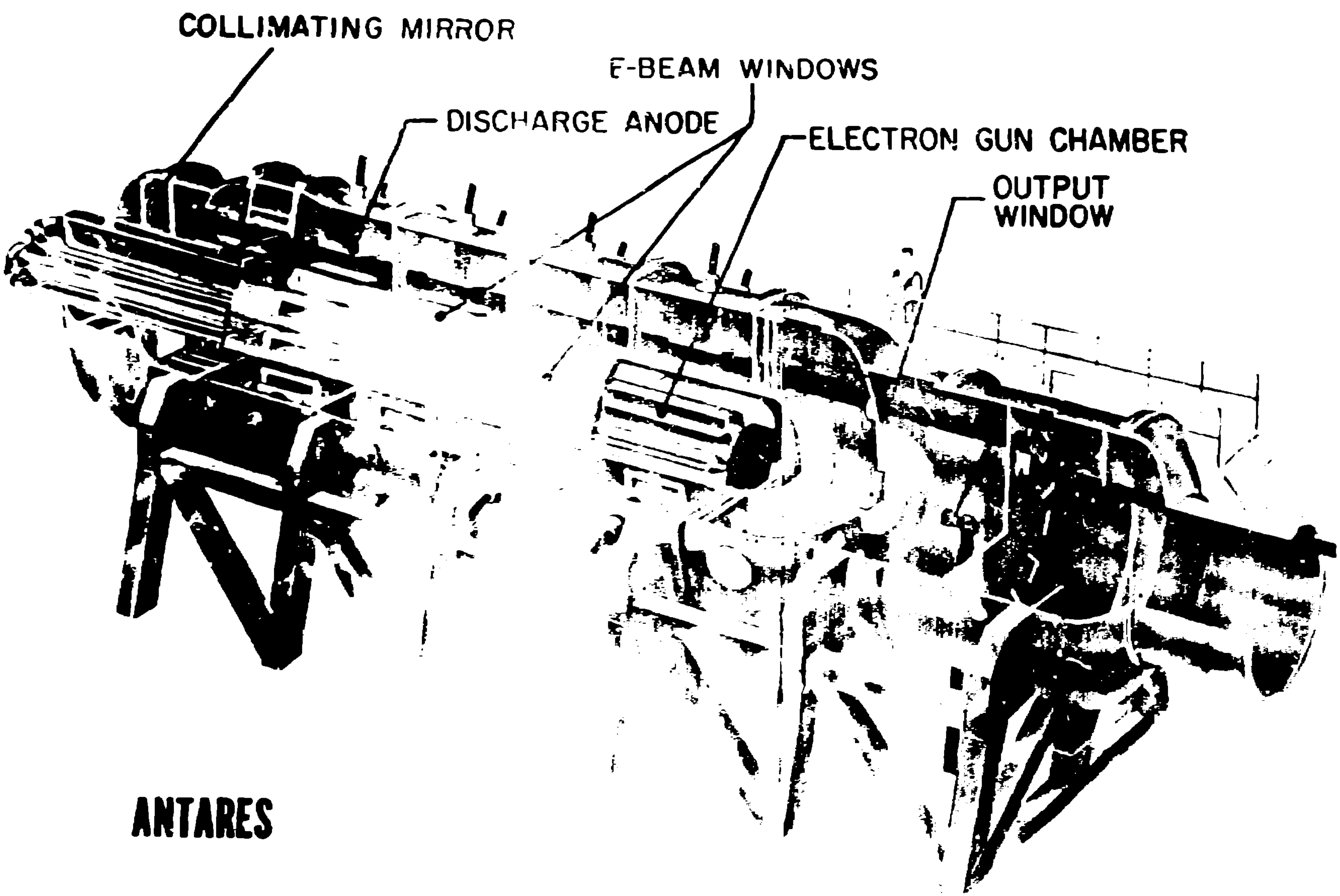
Fig. 5 Compressed fuel density versus initial target ablator thickness

Fig. 6 Quantities derived from neutron measurables versus initial target ablator thickness

los alamos
scientific laboratory
of the University of California

LASER FUSION LABORATORY

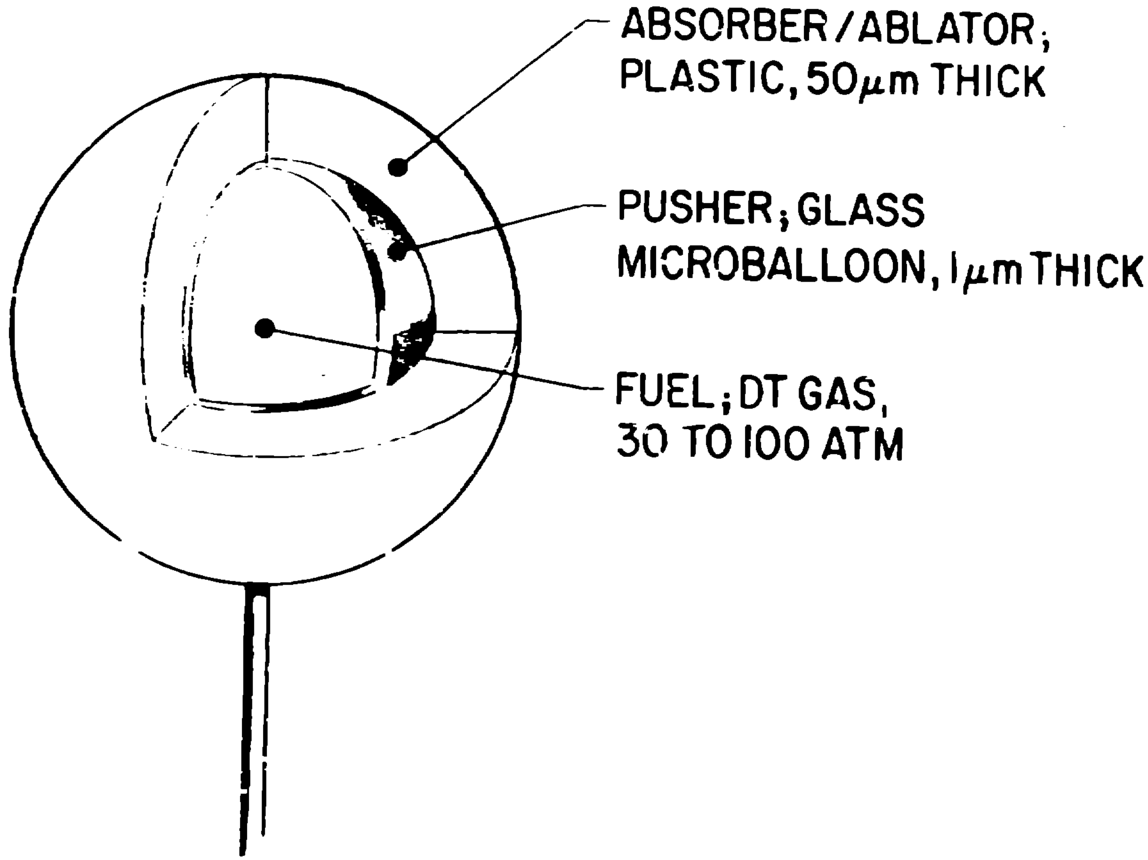




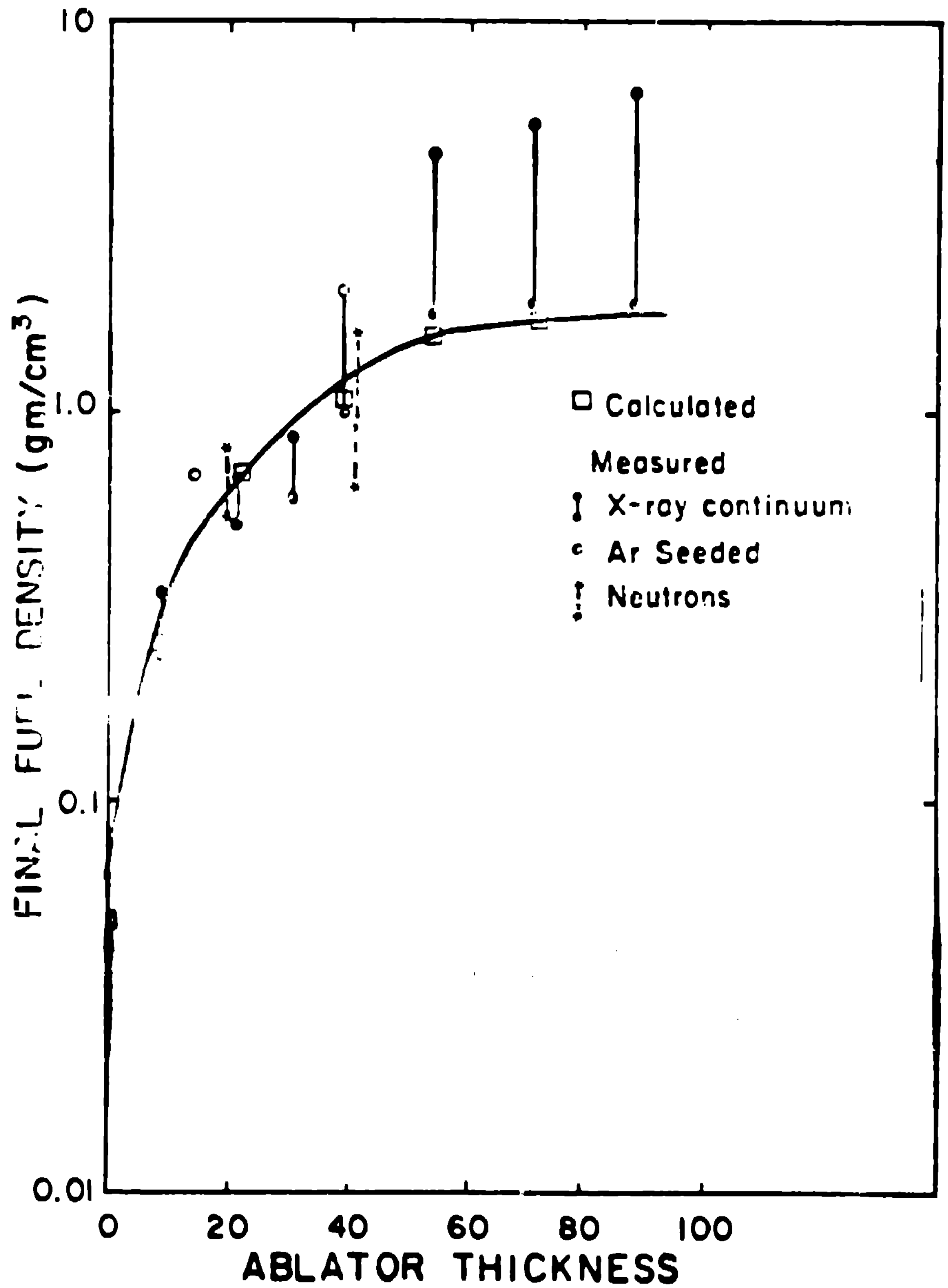
COLLIMATING MIRROR
E-BEAM WINDOWS
DISCHARGE ANODE
ELECTRON GUN CHAMBER
OUTPUT WINDOW

ANTARES

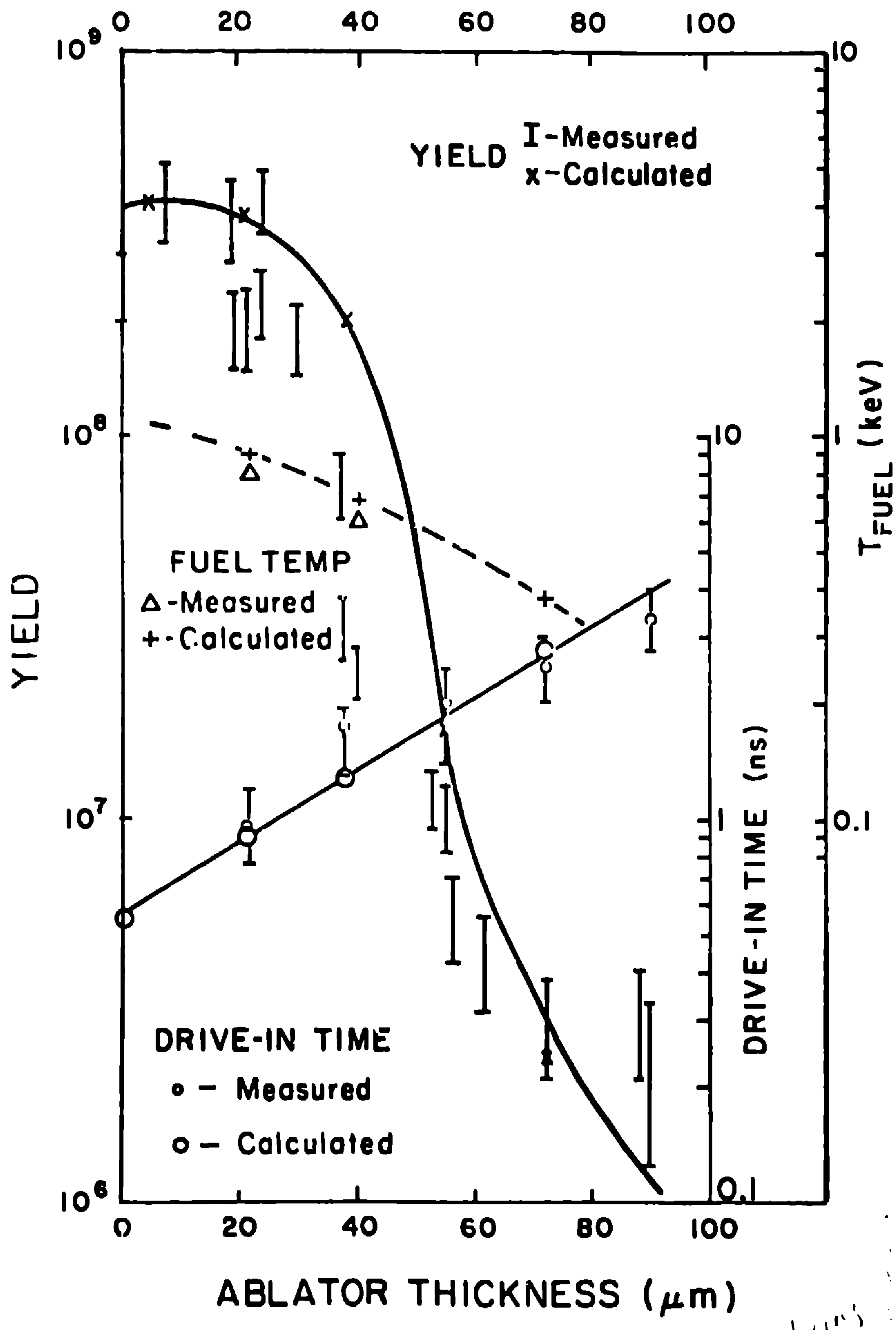
SIRIUS B



OVERALL DIAMETER ≃ 400μm



10
1.0
0.1
0.01
0
20
40
60
80
100
ABLATOR THICKNESS
FINAL FUEL DENSITY (gm/cm³)
Calculated
Measured
X-ray continuum
Ar Seeded
Neutrons



YIELD I-Measured
x-Calculated
FUEL TEMP
Δ-Measured
+-Calculated
DRIVE-IN TIME
∘ – Measured
○ – Calculated
YIELD
T_{FUEL} (keV)
DRIVE-IN TIME (ns)
ABLATOR THICKNESS (μm)
0 20 40 60 80 100
10^9 10^8 10^7 10^6
10 1 0.1
10 1 0.1