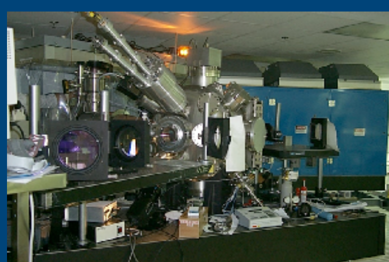
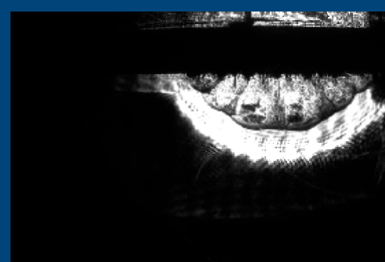
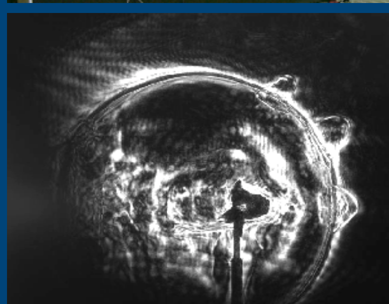
Proposal to create the Sandia Z-Beamlet/Petawatt Two-Beam Target Area


February, 2004

Proposal to create the Sandia Z-Beamlet/Petawatt Two-Beam Target Area

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I. Introduction

The activation of the Z-Beamlet laser at the Sandia Z machine has enabled a dramatic new capability at Z in permitting x-ray radiography of the Z targets in a way previously impossible at Z. This laser, which is presently the third largest laser in the US, has also opened an enormous potential in science research beyond the core program mission of backlighting Z. Used as a stand alone target shooter, Z-Beamlet has the potential for driving a wide range of experiments. It has a shot rate capability which is much greater than the backlighter demand on Z. As a result, we see that a significant scientific opportunity may be developing.

To capitalize on this opportunity we propose the construction of a dedicated target area to exploit the shot capabilities of the Z-Beamlet laser and the future Z-Petawatt laser. This new target area, the Sandia Two-Beam Target Area (the STBTA) leverages the large investment made in developing the laser capability at Z and will enable a large range of experiments relevant both to Stockpile Stewardship and more fundamental science applications. This target area will be constructed in a way that will allow many different kinds of experiments in areas ranging from HED science like radiative hydrodyanamics, hot matter equation of state measurement and particle transport in hot matter, to a broad set of other applications like the study of shocked metals, the radiation effects testing or directed energy weapons. It will also represent a conduit for interaction between Sandia and the outside academic research community.

The principle motivation for the construction of the STBTA is the untapped potential for target shots on one of the largest laser facilities in the world. In 2003, Z-Beamlet fired roughly 100 system shots in support of Z experiments. It also fired nearly 200 additional full system shots in support of other activities including stand alone experiments in a small calibration chamber located in the Z-Beamlet target bay. As Z-Beamlet operations continue to mature, we envision that as many as 1000 shots per year could be possible. Many of the additional laser activities to date have utilized the small calibration chamber. While adequate for diagnostic testing and some preliminary experiments, this chamber is inadequate to realize fully the shot capability of the laser or to allow many of the sophisticated experiments that would be possible by combining the Z-Beamlet long pulse beam line with a short pulse laser (such as that possible with the Z-Peatwatt laser currently under development). A dedicated target area, properly designed to take full advantage of the Z-Beamlet capabilities would open a vast range of possibilities in research and outside collaborations.

Furthermore, with the looming need to train new scientists in HED science and prepare them for work on the large scale stewardship facilities (NIF, ZR, and Omega EP), there is a compelling need for the NNSA complex to have available facilities that are large enough to train people in the culture of larger scale, single shot HED experiments but is at the same time small enough that experiments are manageable by experienced graduate students and post –docs. The Z-PW and Z-Beamlet lasers represent just such a facility and the construction of the STBTA will allow permit heavy participation of new scientists in a science program on these lasers.

One of the significant aspects of this proposed target area is that it will have quite significant participation of outside users. The proposed target area in fact can act as a vehicle for drawing outside academic scientists in HED science to Sandia. For example, we see that the STBTA could become a major point of use for the new Z-PW consortium being proposed by a number of academic institutions. In particular, the University of Texas has a strong interest in developing the science program on Z-Beamlet and the future Z-Petawatt. UT has been a major user of Z-Beamlet during 2003, and successfully collaborated with Sandia on a number of radiative hydrodynamic experiments using a small scale target chamber in the Z-Beamlet bay. We envision that UT will be a major partner in the development of the proposed target area, helping develop the detailed design of the area and aiding in forming the science program. This

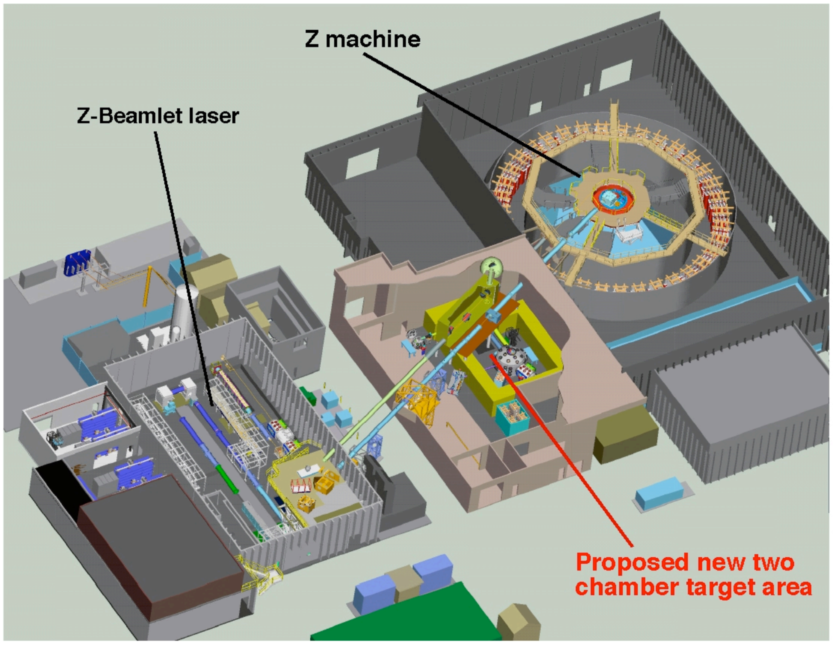


Figure 1: Proposed site of the the Sandia Two Beam Target area and its relationship to the Z-Machine and the Z-Beamlet laser bay

involvement would likely result in a long term, constant presence of graduate students and post docs from UT and other academic institutions at Z-Beamlet. As a result, the STBTA represents a significant link between Sandia and the outside scientific community.

The target area will be situated in a renovated area adjacent to the Z machine. This area is shown in figure 1. It will have two target chambers with one of these designed to accommodate experiments with two laser beams, the Z-Beamlet long pulse beam and the Z-Petawatt short pulse beamline. A number of unique diagnostics and probing capabilities will be installed in and around the target area to permit maximum flexibility in allowing different kinds of science to be performed.

II. Science Motivations for the proposed STBTA

The construction of this new target area is driven by a number of new opportunities in laser driven high energy density science. These science applications each utilize a slightly different set of laser parameters and would require slightly different diagnostics packages. As a result, the target area we are proposing is designed to permit experiments in all of the top priority science areas. Flexibility will be a high priority in the STBTA design and our present conceptual design is laid out to enable expansion to even more diverse, long range application areas than the main areas presented here.

The main areas of science that we envision as possible research areas at the STBTA include the following:

Top priority Science areas:

1) Hydrodynamic physics with laser driven explosions
The multi-kJ laser pulses delivered by Z-Beamlet can create an energetic explosion from a solid target which drives very high Mach number blast waves in gases. These blast waves can reach the radiative regime. This allows study of radiative hydrodynamics, instabilities and other physics, some of which is relevant to astrophysics and much of which is synergistic with the radiative hydro studies funded in the core Sandia program. We have initial early success in this area on Z-Beamlet and believe that there are a number of opportunities if a larger scale, dedicated target chamber could be used for these studies. The introduction of an external magnetic field would allow radiative MHD studies as well.
Target area requirements: Multi kJ nanosecond beam line; a synchronized short pulse laser probe; pulsed power supply for magnetic field generation

2) High strain rate dynamics in laser shocked materials
The Z-Beamlet laser can also drive shock waves in slabs of materials. This permits study of the high strain rate dynamics of these shocks by probing the material evolution dynamically. This dynamic evolution can be studied with optical or x-ray probes. High pressure strength, spall formation and ejecta production studies are all possible. This class of experiments complements materials experiments currently being performed on Z
Target area requirements: Multi kJ many nanosecond pulse; picosecond optical probe; high energy laser pulse for producing x-rays

3) Short pulse laser heating of shock compressed matter
With the combination of a long pulse driver laser and a short pulse heater petawatt laser, novel equation of state measurements are possible, in which the long pulse shock compresses a material and the short

pulse then heats it. In this way, multi-Gbar pressures can be accessed in a controlled manner which will enable study of the materials properties well off the principal shock Hugoniot.
Target area requirements: Combined long pulse, short pulse beams for shocking/heating the sample; sub-picosecond optical probe and sub-picosecond x-ray pulse for probing the material properties; suite of interferometric and x-ray diagnostics

4) Proton diagnosis of hot compressed matter
With the petawatt laser, beams of multi-MeV protons can be generated. These represent a novel probe for high energy density matter which could be used ultimately as a diagnostic on Z. With the two beam capability proposed here, this diagnostic could be developed on both laser produced and small scale pulsed power generated plasmas.
Target area requirements: Petawatt beam line with either short/long pulse plasma generation laser or a small pulsed power machine

5) Fast Ignition and hot electron transport in hot matter
The Z-Petawatt laser will ultimately be used for fast ignition studies on Z. Prior to those fully integrated studies, many issues of hot electron generation and transport in hot plasmas must be studied. These can be addressed in many ways using a pre heated target with the nanosecond Z-Beamlet laser and hot electrons generated The STBTA will enable these fundamental fast ignition physics studies and will permit development of techniques that can be implemented on a full scale integrated ignition experiment on Z in the future.
Target area requirements: Petawatt beam with at least 100 J of long pulse heater laser energy; various time resolved x-ray imaging diagnostics and high energy electron spectrometers

6) HED science with magnetic fields
A new and unexplored area of HED science is the study of plasma evolution in strong magnetic fields. This kind of experiments could be performed at the STBTA using a laser to generate a plasma flow or explosion in an externally imposed magnetic field. These studies include many astrophysically relevant studies such as magnetized jet formation or collisionless shock dynamics. Such studies naturally tie into the MHD science of Z-pinches and the core Sandia Z-pinch program.
Target area requirements: multi-kJ long pulse laser for plasma formation; ~100 kJ pulsed power device for B field generation; optical probe pulse

Long Term Science areas

In addition to these top priority science areas, which drive the majority of the target area design parameters, we will also design the target area to enable some other, longer term science applications:

1) Ion Beam fast ignition
In addition to the standard hot electron fast ignition technique, there is evidence that fast ions, like protons, could be used as the heated source in novel fast ignition experiments. These kinds of experiments could be pursued at the STBTA.

2) Radiation effects testing
The Z-Petawatt laser can produce high fluxes of energetic radiation, including hard x-rays with energy up to 100 MeV and multi-MeV neutrons. These very short, bright bursts of radiation could be used to study radiation damage effects.

3) Plasma channels and directed energy
There is a great interest in the Air Force in novel directed energy laser weapons schemes. The propagation and lethality physics of high energy sub-picosecond pulse lasers is largely unexplored and could be studied at the STBTA with some upgrades.

III. Description of the STBTA

With this varied science motivations, the target area should be designed with a number of capabilities. With the six science thrusts and their general target area requirements, we believe that the STBTA should include:

- Two target chambers, one for stand alone long pulse multi-kJ laser experiments and a second, larger chamber that permits experiments with the Z-Petawatt laser or combined, two beam experiments with the Z-Beamlet/Z-Petawatt lasers.

- A synchronized probe laser which will have at least 10 J of energy in a pulse width of ~0.5 ps and can be transported to either target chamber in the area

- A 100 kJ pulsed power supply which can drive a load in either the long pulse or two beam chambers

- A complete set of core diagnostics which include: an optical and an x-ray streak camera, a set of x-ray spectrometers, optical interferometers, science grade optical CCD cameras, and an electron spectrometer.

A conceptual design for how such a target area would look is illustrated in figure 2. A larger scale, walk in chamber that accommodates both the kJ long pulse beam and the petawatt beam would be located in the space beneath the planned petawatt compressor chamber. This chamber will be shielded with 3 ft concrete for radiological safety. A second, long pulse only chamber will be sited to the north of the main two beam chamber. This chamber is outside the shielding and will be placed with access control so that one set of experimentalists can install experiments here while shots are taking place in the central chamber.

To the south of this long pulse chamber, a table top Nd:glass laser will be installed. This laser will be seeded with pulses from the Z-Beamlet front end to ensure high temporal synchronization and will deliver 10 J pulses with 0.5 ps pulse duration. Transport tubes will allow this beam to be sent to either target chamber. It will be used either as a direct optical probe or as a proton generating beam for proton diagnostics. Next to this chamber, the high voltage and energy storage hardware will be installed to drive a pulse power load in either chamber. This will be a ~100 kJ pulsed power machine with <100 ns synchronization to the laser.

IV. Estimated Costs and construction schedule of the STBTA

The estimated cost for the STBTA including target chambers, shielding, probe laser, pulsed power and core diagnostics is $8.3 M. We have performed a detailed cost estimate for the area and the cost breakdown can be summarized in table 1.

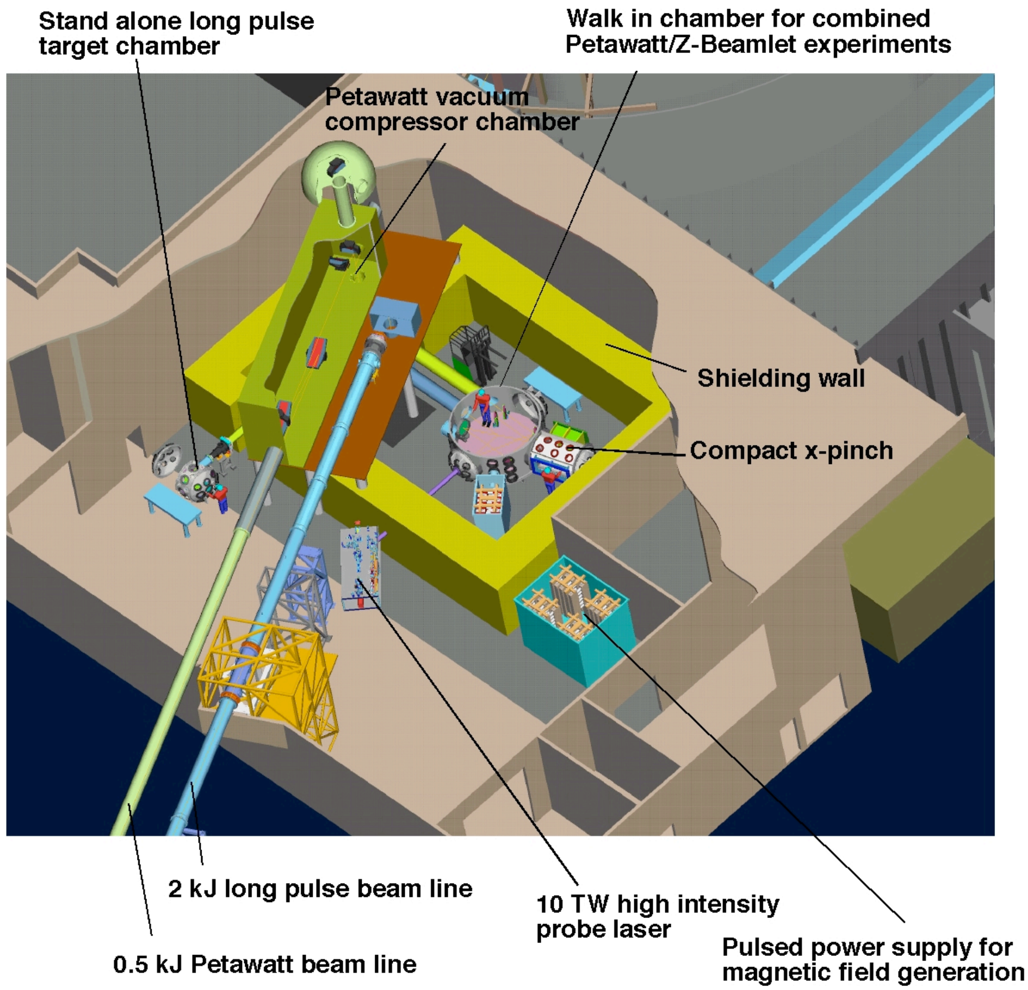


Figure 2: Conceptual layout of the STBTA showing the placement of both target chambers, the two high energy laser beam lines and the supporting diagnostics.

The schedule for constructing the STBTA would follow a plan in which detailed engineering design would be performed in FY05; construction would follow in FY06 and finish in FY07.

V. Operating costs and users operating mode for the STBTA

The operating mode of this area will be based on dual use by Sandia scientists and outside academic collaborators. Shot time will be allocated based on the overriding Z priorities. Of the shot time available for experiments, shots will be allocated to experimentalists by a shot committee. The specific make up of this committee will be determined by a Z-Petawatt Consortium (ZPC) group, presently chaired by Prof. Rick Freeman from Ohio State University. This Consortium has formulated a propsoed use policy

document for the near term use of the 100 TW precursor to the Z-PW laser. We envision that the STBTA will operate on a model similar to that prposed by the ZPC, perhaps with an expanded list of participants. A likely operating plan will be to allocate shot series with durations ranging from a few days to as much as one month.

High energy transport optics and mounting hardware	$1550 k
Periscope and other misc. beam tube transport hardware	$ 300 k
Vacuum vessels and pump hardware	$1500 k
PW focusing parabola	$ 300 k
Concrete shield walls	$ 200 k
Access control system/ Faraday shielding	$ 175 k
10 TW synchronized probe laser	$ 900 k
Pulsed power machine	$ 475 k
Core diagnostics	$ 375 k
Labor (10 man years)	$2500 k
Total	**$8275 k**

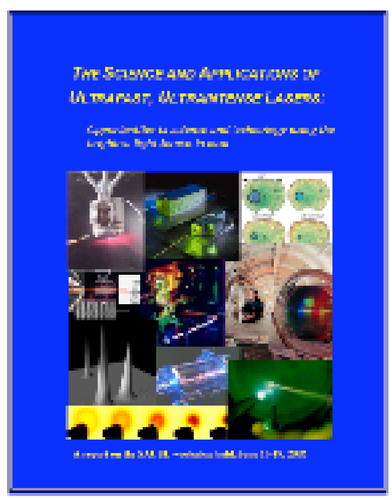
Table 1: Estimated cost break down for the Sandia STBTA

The STBTA will require a core of operating personnel and replacement hardware. These are important to permit active use by experimentalists and a regular rotation of experiments between the two target chambers. The operating costs of this facility will be:

- 4 FTE effort (target scientist, two laser techs., one electrical tech.) $1000 k/yr
- Replacement optics and debris shields for the PW $ 250 k/yr

VI. Link of the STBTA to the national SAUUL initiative

The construction of the STBTA will provide a good conduit to outside researchers, particularly experimentalists (grad students, post docs and faculty) from the University of Texas. This target area in fact fits well into a national initiative which is currently being proposed in the US. The initiative on the Science and Applications of Ultrafast, Ultraintense Lasers (SAUUL) has been proposed in a recent report to the NSF, the DOE Office of Science and NNSA. (This report can be downloaded at http://www.ph.utexas.edu/~utlasers/papers/SAUUL_report.pdf).



The STBTA would represent an important node in the proposed SAUUL network. As such, we envision that operations of this facility and the science done here would be funded in some way as a part of a SAUUL initiative if ultimately established. The STBTA would place Sandia in the SAUUL network and tie Sandia closely to the broader national community in high intensity lasers.