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Preconceptual Design Requirements for the X-1 Advanced Radiation Source*

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ABSTRACT

The X-1 Advanced Radiation Source represents the next step in providing the U.S. Department of Energy's Stockpile Stewardship Program with the high-energy, large volume, laboratory x-ray source for the Radiation Effects Science and Simulation, Inertial Confinement Fusion, and Weapon Physics Programs. Advances in fast pulsed power technology and in z-pinch hohlraums on Sandia National Laboratories' Z Accelerator provide sufficient basis for pursuing the development of X-1. The X-1 plan follows a strategy based on scaling the 2 MJ x-ray output on Z via a 3-fold increase in z-pinch load current. The large volume (>5 cm^3), high temperature (>150 eV), temporally long (>10 ns) hohlraums are unique outside of underground nuclear weapon testing. Analytical scaling arguments and hydrodynamic simulations indicate that these hohlraums at temperatures of 230-300 eV will ignite thermonuclear fuel and drive the reaction to a yield of 200 to 1,000 MJ in the laboratory. X-1 will provide the high-fidelity experimental capability to certify the survivability and performance of non-nuclear weapon components in hostile radiation environments. Non-ignition sources will provide cold x-ray environments (<15 keV), and high yield fusion burn sources will provide high fidelity warm x-ray environments (15 keV-80 keV).

I. INTRODUCTION

The X-1 Advanced Radiation Source represents the next step in providing the United States Department of Energy's (DOE) Stockpile Stewardship Program with the high-energy, large volume, laboratory x-ray source for the Radiation Effects Science (RES) and Simulation, Inertial Confinement Fusion (ICF), and Weapon Physics Programs. X-1's mission is to assist DOE in its Strategic and Stockpile Stewardship Program plans. The Stockpile Stewardship Program relies on the experimental and modeling capabilities necessary to certify the performance, survivability, and reliability of weapon components and subsystems in the absence of underground nuclear weapon testing. X-1 enhances the experimental capability necessary to certify weapon components in the cold x-ray regime (<15 keV), and provide sufficient capability in the warm range (15 keV to 80 keV range) to perform needed component studies. Material response in these regimes cannot presently be adequately simulated and X-1 will provide a necessary and unique capability for RES.

The X-1 Project is being configured in three major phases. The first phase is the construction and initial operation of an advanced facility. This facility is capable of achieving high yield ($\geq$200 MJ) fusion burn using fast z-pinch pulsed power technology. In the second (operational) phase, X-1 will demonstrate the capability of generating 16 MJ of x-ray drive energy, 1,000 TW of x-ray power, and achieve hohlraum temperatures of 300 eV in non-ignition experiments. The third (applications) phase will demonstrate the capability of driving a cryogenic capsule to fusion burn and a minimum high-energy yield of 200 MJ.

X-1 will utilize the integrated multilaboratory experience of the national ICF program in order to achieve its goals. Target physics experience derived from the laser, ion beam, and z-pinch programs will be utilized to design experiments

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and demonstrate scaled performance on critical physics issues. Technology advances driven by the Lawrence Livermore Laboratory Nova Technical Contract, the National Ignition Facility, and the Sandia National Laboratories (SNL) Z Accelerator are essential to the success of the X-1 project. Experiments in these and other facilities are needed to provide the basic understanding and expertise to support the X-1 design and its applications.

II. FUNCTIONAL REQUIREMENTS

Advances in fast pulsed power technology and in z-pinch hohlraums at SNL's Z Accelerator (formerly the Particle Beam Fusion Accelerator II) in 1997 and 1998 provide sufficient basis for pursuing the development of X-1. The Z Accelerator has achieved an x-ray power of 290 TW and x-ray energy of nearly 2 MJ.[1] The X-1 development strategy is based on scaling the 2 MJ x-ray output achieved on Z via a 3-fold increase in z-pinch load current to attain 16 MJ of drive energy (exponential scaling with current). The large volume (>5 cm^3), high temperature (>150 eV), temporally long (>10 ns) hohlraums on the Z Accelerator are unique outside of underground nuclear weapon testing. Analytical scaling arguments and hydrodynamic simulations indicate that these hohlraums at temperatures of 300 eV ignite thermonuclear fuel and drive the reaction to a yield of 200 to 1,000 MJ in the laboratory.

A systems approach has been adopted to form the preconceptual functional requirements for design of the facility.[2] The functional requirements developed to date are summarized in Table I.

III. PRECONCEPTUAL DESIGN

Two pulsed power designs are presently being examined. One approach, shown in Figure 1, utilizes a technology similar to the Z Accelerator.[3] A second design, shown in Figure 2, utilizes a technology developed for the Hermes III Accelerator.[4] The differentiating principle between the designs is the location of the dielectric fluid/vacuum interface in the pulse forming/power flow section. In the Z-style design, the interface is located close to the x-ray source while in the Hermes III design, the interface is located on the outer periphery of the accelerator. Both designs have advantages and will be closely analyzed during the Conceptual Design of the X-1 Project.

Function	Requirement
Fusion Yield	200 to 1,000 MJ output (70% neutrons, 22% x-rays, 6% debris)
X-Ray Drive Energy (non-ignition)	16 MJ
X-Ray Drive Power (non-ignition)	1,000 TW
X-Ray Source	Fast Z-pinch tungsten wire array plasma
Minimum Hohlraum Temperature	300 eV
Target Fuel	Cryogenic, Beta-layered Deuterium/Tritium
Source Driver	60 MA – peak current, 120 ns – risetime Pulsed Power
Desired Experiment Rate	1 non-ignition shot/day, 2 high yield shots/month, 200 shots/year
Unobstructed Source Accessibility	2π steradians (Radiation Effects Sciences) $<\pi/3$ steradians (all others)

Table I. X-1 Preconceptual Design Functional Requirements.

Critical to all X-1 concepts is the Experiment Chamber. This chamber must contain all the radioactive debris generated by the high yield fusion reaction while providing the highest degree of access to experiment packages.[5] One Experiment Chamber concept is shown in Figure 3. The design employs a "defense in depth" strategy. Multiple layers of protection are used to confine the radiation, shrapnel, debris, and vapor generated by the energy in the chamber. Integral to the aluminum chamber is a water shield tank to absorb fusion neutrons so as to minimize the radiation dose outside the Experiment Chamber area of the facility.

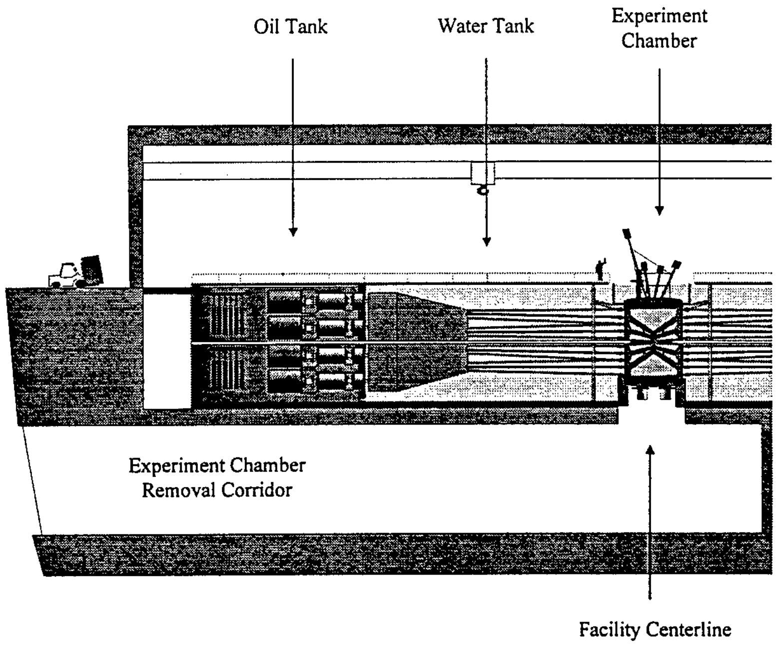

Figure 1. Preconceptual Design of X-1 Pulsed Power Driver and Experiment Chamber using Z technology.

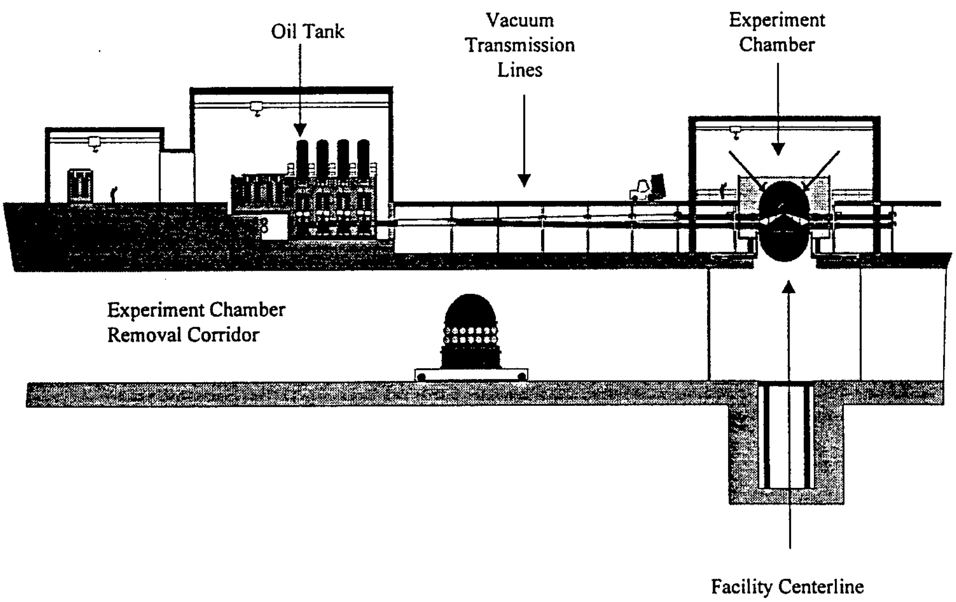

Figure 2. Preconceptual Design of X-1 Pulsed Power Driver and Experiment Chamber using Hermes III technology.

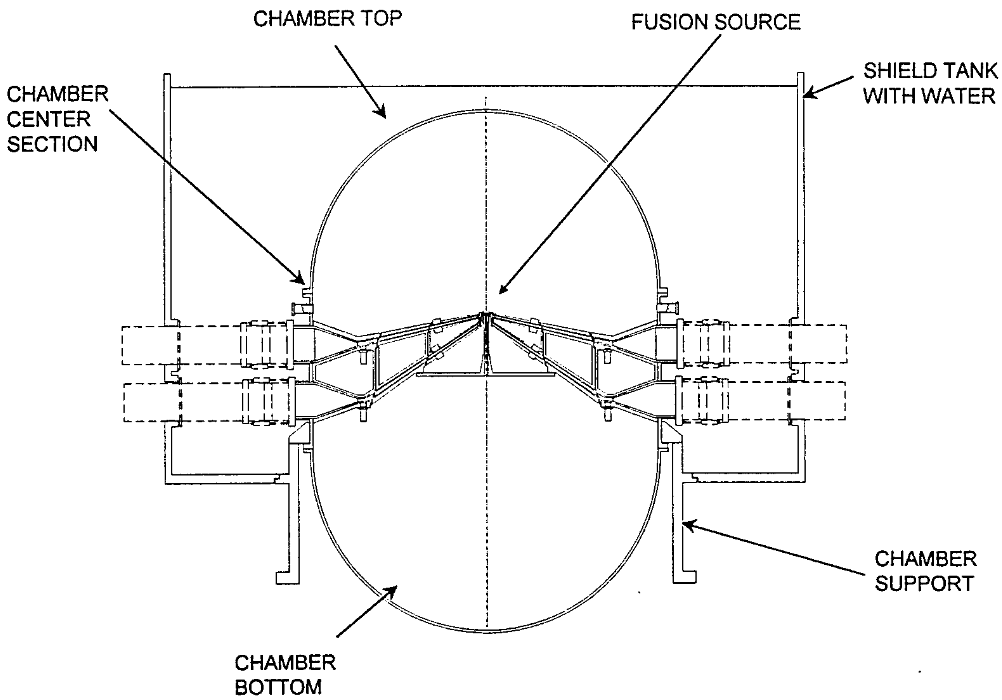

Figure 3. Schematic representation of X-1 Experiment Chamber for containment of radiation and debris.

IV. SUMMARY

The X-1 Advanced Radiation Source is an anticipated facility for performing experiments that can utilize 200 to 1,000 MJ of radiation from a fusion source as well as lower energy non-ignition experiments. The facility will utilize fast pulsed power technology readily scaled from existing SNL accelerators to drive z-pinch x-ray sources to heat a cryogenic capsule and drive it to ignition and high yield burn. Conceptual design studies and engineering prototyping are the next planned steps in the development program.

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