X-1 Target Chamber Issues and Preliminary Design

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October 1997

UWFDM-1054

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Introduction

In this report, critical issues for the design of a target chamber for X-1 are discussed and preliminary estimates for parameters for the X-1 target chamber are made. The estimates are all based on simple scaling from previously performed work. They all must be re-calculated to have any credibility. These are meant to be the roughest of estimates to show where high level areas of research exist.

X-1 Chamber Issues

Target chamber issues for X-1 are listed listed in Table 1. Included in this table are the specific needs, previous studies [1 - 5] which can provide a database, and proposed analysis methods for each issue. I have identified six issues that need to be addressed:

- **Source Characterization** X-1 will have two general types of sources: a pinch x-ray source or an ICF target driven to ignition by pinch generated x rays. The nature of that source (time-dependent x-ray, debris and neutron spectra) is critical to the understanding of the target chamber behavior.
- **Vaporization/Melting** Emanations from both types of targets and input current heating of the power feeds will cause melting and vaporization of target chamber materials. Vaporization of the target chamber wall, power feeds, current return posts, and internal target chamber structures, will increase the mass of gas in the target chamber substantially. The target chamber materials that are melted can be accelerated to become shrapnel. The material rapidly vaporized by x rays and/or debris will leave the surface of the structure rapidly, leading to a recoil pressure that can be dominant in the pressure loading of the target chamber wall. In shots with yield, all vapor and molten materials may be radioactive and represent a safety issue. Molten materials and vapor may resolidify and recondense in inconvenient places.
- **Pressure Loading** The pressure on target chamber walls drives the structural response of the target chamber. The pressure on power feeds, return current pins, and debris mitigation systems and other internal structures is important in the generation of shrapnel through spall and fragmentation. Shocks in the target chamber vapor also contribute to the pressure loading on all target chamber structures. The vapor will remain in the target chamber until it is vented into the MITL or elsewhere or until it condenses back on the walls. This is slow compared to the vibrational period of the target chamber and leads to a transient gas pressure loading on the walls.

- **Shrapnel** Shrapnel can be very damaging to the inside of a target chamber. Optics and other diagnostics are particularly sensitive to shrapnel damage. Cratering and the associated cracking can penetrate deep into materials, leading to excessive wall erosion. The nature of the shrapnel is very dependent on the object being spalled or fragmented and the pressure loading.

- **Structural Response** The target chamber will vibrate due to the pressure loading. As the stress and strain in the wall oscillate, fatigue damage occurs, leading to limits on the number of shots of given yield that the target chamber can withstand. The target chamber must contain the possibly radioactive vapor and can not be allowed to leak in any way. This is complicated by the presence of ports for diagnostics and experimental access, which can concentrate stresses. The recoil pressure will generate the vibrations impulsively, but the later and longer term loading from shock and stagnant vapor will cause these vibrations to oscillate around a non-zero stress, leading to larger maximum stresses. Shrapnel can generate shocks that penetrate into the wall, causing fragmentation and cratering.

- **Activation** Neutrons from ICF targets with yield will cause nuclear transmutations in target chamber structures. The high voltages in the accelerator and power feeds can accelerate ions across an insulated gap, leading to additional transmutations on all shots. The resulting nuclei may have radioactive half-lives in the range that will lead to dose rates in the target chamber that impact operations. The activation must be assessed and shielding developed to mitigate the operations problems. Some activated material will be molten or vaporized for a time, which will have safety implications. Radioactivity in the target chamber structure will reach a saturation level that depends on the shot rate, yields, and materials. Multiple target chambers may be employed, leading to an inventory of radioactive material in a remote site which must be safely controlled. At the end of life, the remaining radioactive material must be disposed of in a manner prescribed by regulation.

Chamber Parameters

The target chamber for X-1 will have similarity in design to Jupiter [1] and the light ion Laboratory Microfusion Facility (LMF) [2 - 5] chambers. Jupiter was a concept that used similar amounts of pulsed power to X-1 to drive a cylindrical pinch. In the case of Jupiter, the pinch was for a Plasma Radiation Source (PRS), much like the case of X-1 without yield. Because the power delivery is similar, the X-1 target chamber will be similar in appearance to Jupiter. The light ion LMF [4] used many light ion beams to drive an ICF target to implosion and burn. The X-1 with yield will have a similar thermonuclear yield to LMF and similar strategies to control x-ray vaporization must be used. The general parameters for

Table 1. X-1 Target Chamber Issues

1. **Source Characterization**
   (a) Needs: neutron, x-ray, debris time-dependent spectra
   (b) Database: LMF target, Jupiter PRS, Z wire array pinches
   (c) Proposed Analysis Methods: Lasnex, Bucky

2. **Vaporization/Melting**
   (a) Needs: mass vaporized, mass melted, recoil loading, recondensation
   (b) Database: LMF, NIF, and Jupiter target chambers
   (c) Proposed Analysis Methods: Bucky

3. **Pressure Loading**
   (a) Needs: flow of vapor and debris, shocks on walls, transient gas pressure
   (b) Database: LMF and Jupiter target chambers
   (c) Proposed Analysis Methods: Bucky, Zeus-2D, Rage

4. **Shrapnel**
   (a) Needs: shrapnel spectrum (size and speed)
   (b) Database: NIF and Jupiter target chambers
   (c) Proposed Analysis Methods: CTH, Grady method

5. **Structural Response**
   (a) Needs: shrapnel damage, wall thickness, lifetime, supports
   (b) Database: LMF, NIF, Jupiter target chambers
   (c) Proposed Analysis Methods: ANSYS, CTH, LS-DYNA, ProEngineer, Patran

6. **Activation**
   (a) Needs: neutron transport, accelerator activation, vapor radioactivity, target chamber cool down time, radwaste
   (b) Database: LMF, Jupiter
   (c) Proposed Analysis Methods: ONEDANT, TWODANT, MCNP, DKR-ICF

Table 2. General Target Chamber Parameters

	TDF	LMF	Jupiter	X-1 (0)	X-1 (1000)
Neutron Yield (MJ)	144	680	0	0	680
Debris Yield (MJ)	12	100	30	30	100
X-Ray Yield (MJ)	44	200	8.3	16	200
Chamber Radius (m)	3.0	3.0	2.0	2.0	3.0
Debris Fluence (J/cm^2)	11	88	60	60	88
X-Ray Fluence (J/cm^2)	39	177	17	33	177

X-1, Jupiter, LMF, and the Target Development Facility (TDF) [2, 3], an early form of the LMF, are shown in Table 2.

The X-1 target chamber will be similar in design to Jupiter, shown in Figure 1. There will be a disk or conical power feed on which a PRS or ICF target will be mounted. This feed will be destroyed by the combined effects of the 60 MA drive current, x-rays, and debris. The feed must be designed to minimize the effects of shrapnel; perhaps with the use of a low mass feed that will fracture into a non-damaging shapnel spectrum by design. The Jupiter design used a conical feed to remove most of the feed from the line-of-sight of PRS x rays; this could be employed in X-1 as well. The cylinder with hemispherical end cap design allows easy access for large experimental packages. The design allows fairly easy shielding and removal to a remote site. The Jupiter target chamber was made of bare steel; the LMF and yield option for X-1 are lined with woven graphite and are made of either aluminum alloy or steel.

Blast and Vaporization

The X-1 option without yield will behave like Jupiter; with yield it will be like LMF. The results of vaporization analysis for Jupiter and LMF are shown in Table 3, along with scaled values for X-1 with 0 yield and 1000 MJ. The Jupiter and X-1 without yield target chambers are identical and so are the assumed x-ray and debris spectra. The only difference is X-1 has twice the x-ray energy. It is assumed that vaporization scales with x-ray yield. The LMF and 1000 MJ yield option are assumed identical in all respects.

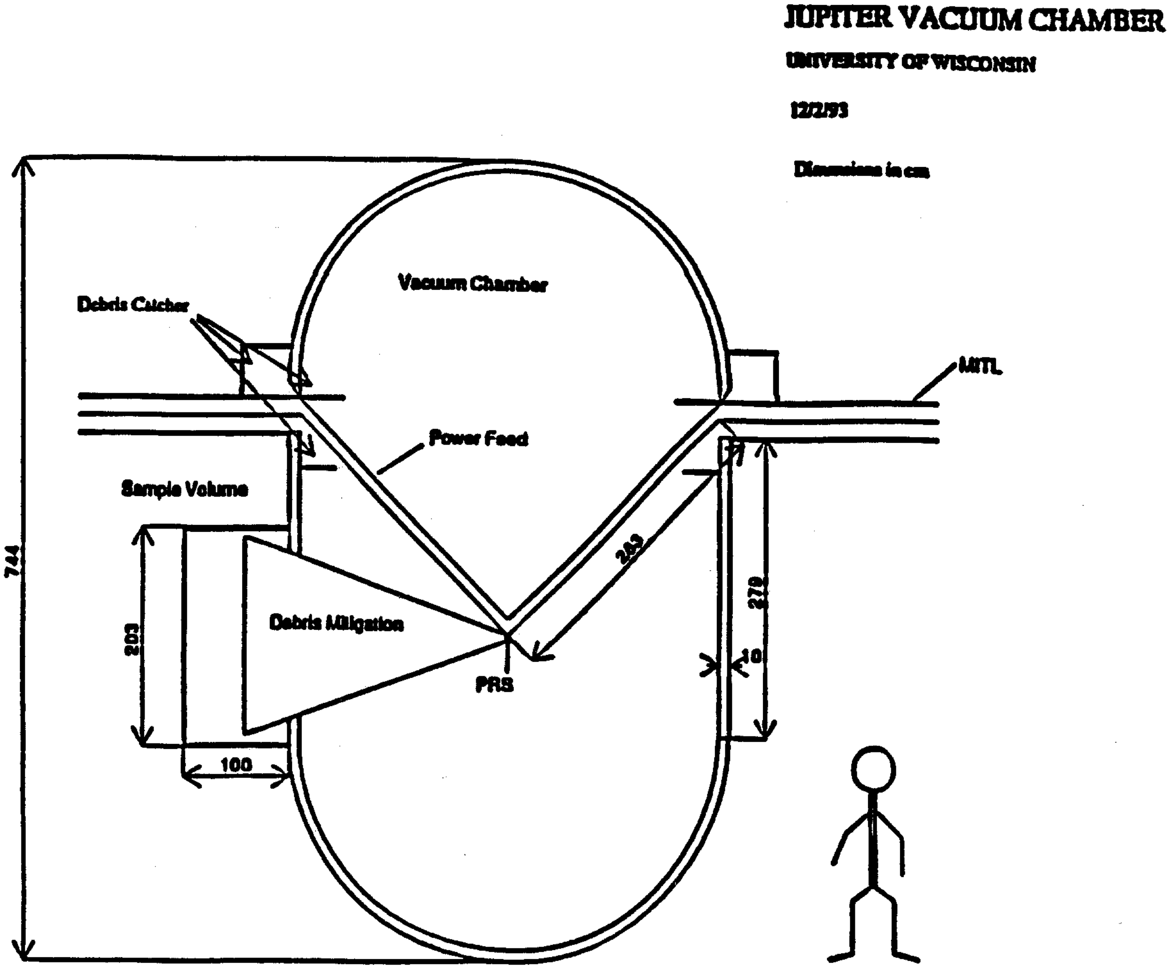

Figure 1. Schematic picture of Jupiter target chamber

Table 3. Vaporization Parameters per Shot

	LMF	Jupiter	X-1 (0)	X-1 (1000)
Vaporized Areal Mass (mg/cm^2)	1.1	0.71	1.42	1.1
Total Vaporized Mass (g)	1221	357	714	1221
Vaporized Thickness (μm)	6	0.90	1.80	6
Peak Pressure on Wall (GPa)	75	22.1	44.2	75
Impulsive Pressure at Wall (Pa-s)	84.5	20.1	40.2	84.5
Transient Pressure in Gas (MPa)	0.33	0.5	1.0	0.33

Table 4. Recommended Wall Thicknesses

	LMF	Jupiter	X-1 (0)	X-1 (1000)
Min. Thickness: Al (cm)	4.9	3.2	6.4	4.9
Min. Thickness: Steel (cm)	2.0	2.5	5.0	2.0

Table 5. Time for Hands-on Dose Rate to Drop to 2.5 mrem/hr

	LMF	Jupiter	X-1 (0)	X-1 (1000)
Cool Down Time: Al (days)	14	0	0	14
Cool Down Time: Steel (days)	4000	0	0	4000

Chamber Structural Response

The vaporization parameters in Table 3 can be used to predict the first wall response. Using the information from the Jupiter and LMF studies, assuming that the thickness are proportional to the impulsive stress, the minimum wall thickness is estimated and shown in Table 4. Aluminum thicknesses were only calculated for the LMF; to get them for Jupiter the same ratio between aluminum and steel thicknesses that was observed for LMF was assumed.

Neutron Activation

The cool down times are shown in Table 5. There is no neutron activation without yield and beam activation in Jupiter was found to be minimal, so the cool down time is zero. LMF activation calculations were performed for both Al-5086 and 2 1/4 Cr - 1 Mo steel. If a dose rate of 2.5 mrem/hr is taken as the maximum allowable, the cool down times in Table 5 are obtained. There is an obvious huge advantage for an aluminum alloy chamber, even though the structural response requires a thicker Al chamber. Steel is preferable without yield.

Conclusions

A list of issues important to the X-1 target chamber has been presented. The needs, database and proposed analysis methods have been given for each issue. Finally a very crude set of parameters has been scaled from past experience. All of the scaled parameters need to be calculated in detail, but they show that:

- The target emanations need better definition.
- Chamber response (melting and vaporization) drives the target chamber design and needs detailed analysis.
- 2 or 3-D gas dynamics calculations are needed for pressure loading and vapor venting considerations.
- Shrapnel can be a very serious problem and needs detailed analysis.
- Fatigue or yielding from vaporization driven vibrations determine the wall thickness. Holes and support structures play an important role in the minimum thickness.
- Activation by neutrons makes steel chambers impractical for the X-1 option with target yield.

Acknowledgment

This work has been supported by Sandia National Laboratories.

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