Design of the M-9 Firing Facility Containment Vessel for Los Alamos National Laboratory

by

Michael A. Polcyn
Edward D. Esparza
Southwest Research Institute

Mark G. Whitney
Wilfred Baker Engineering

Abstract

Los Alamos National Laboratory Group M-9 has been performing tests of high explosives at their open facilities. Southwest Research Institute was contracted to design, fabricate, and test a containment vessel which will be installed at the M-9 facility. It is required that the vessel contain blast and fragments from routine explosives tests using charge weights up to 10 kg of TNT equivalent.

The vessel is fabricated from a 11.5 foot diameter steel cylindrical section with 2:1 elliptical ends. The cylinder is made of 1.5 inch thick HY100 steel and the heads are made of 2 inch thick HY100 steel. A 4 inch thick HY100 steel plate door is placed in one head, and seats against a 6 inch thick steel frame. Fragment shields constructed with 0.5 inch thick steel are placed against the cylinder walls. The floor is concrete with steel plates along the surface. Penetrations through the vessel are provided for an air inlet and outlet, electrical and gas penetrations, viewports, and a drain. This paper contains a discussion on the need for a contained firing facility at Los Alamos. The design approach, including loads prediction and dynamic structural response calculations, is presented. Drawings of several details of the vessel are also included.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1992**	2. REPORT TYPE	3. DATES COVERED **00-00-1992 to 00-00-1992**
4. TITLE AND SUBTITLE **Design of the M-9 Firing Facility Containment Vessel for Los Alamos National Laboratory**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Southwest Research Institute,6220 Culebra Rd,San Antonio,TX,78238-5166**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADA261116, Volume IV. Minutes of the Twenty-Fifth Explosives Safety Seminar Held in Anaheim, CA on 18-20 August 1992.**		
14. ABSTRACT **see report**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**20**	

1.0 Introduction

Los Alamos National Laboratory Group M-9 has been performing routine explosion testing at their outdoor facility. The principal purpose for these tests is to gain technical advantages in advanced experimentation on shocked materials, mainly in detailed investigations of the initiation and detonation of high explosives, and of the reaction rates that govern these processes. The experimental methods presently used include high-speed streak photography, electronic pin-contactor and gauging measurements, and laser velocity interferometry. The possibility exists to add flash x-ray, framing photography, and dynamic spectroscopic measurements.

Utilizing the generous available space at Los Alamos, and following good practice in handling explosives and barricading against blast and shrapnel, the users have developed a long record of very safe practice of open firing. The products of the detonation of high explosives are rather benign, so the program has had relatively little detriment to the environment. There are some modest environmental, health and safety advantages to a contained firing facility, not the least of which is that regulatory zeal in these areas may someday limit tests to contained firing as the only means to continue this type of work. One of the major motives for developing the contained firing facility has been to build an experience base for such a contingency.

There are a number of operational advantages to contained firing. The containment vessel enables greater proximity and multiple access with optical, electronic and electo-optical instrumentation. The greater ability to combine many channels of mixtures of the various diagnostic methods used in each experiment will both enhance the technical efficiency of the program and will allow more definitive experiments when several simultaneous measurements are helpful. Additionally, many of the techniques are improved through the use of shorter signal cables and optical paths than are feasible in open firing.

The work at Los Alamos involves an increasing number of experiments on cryogenic or heated specimens of explosives and other energetic materials. The heated explosives experiments are mainly motivated by weapons safety problems. These tests typically involve several hour cooling or heating cycles, with remote operation of the specimen conditioning system. In open firing, these tests are subject to complications, and occasional aborted procedures, from suddenly varied weather conditions. The conversion to contained firing provides operational advantages by moving the tests indoors, and reduces the amount of supplemental apparatus sacrificed in the current shots.

The new contained firing facility will be located within an easy walking distance to the staff offices and support laboratories, thus providing better access for the users. Also, the new facility will be located adjacent to a long-existing and recently improved gun facility. It is hoped that both facilities will benefit from convenient exchange of instrumentation, hardware, technology, and perhaps personnel.

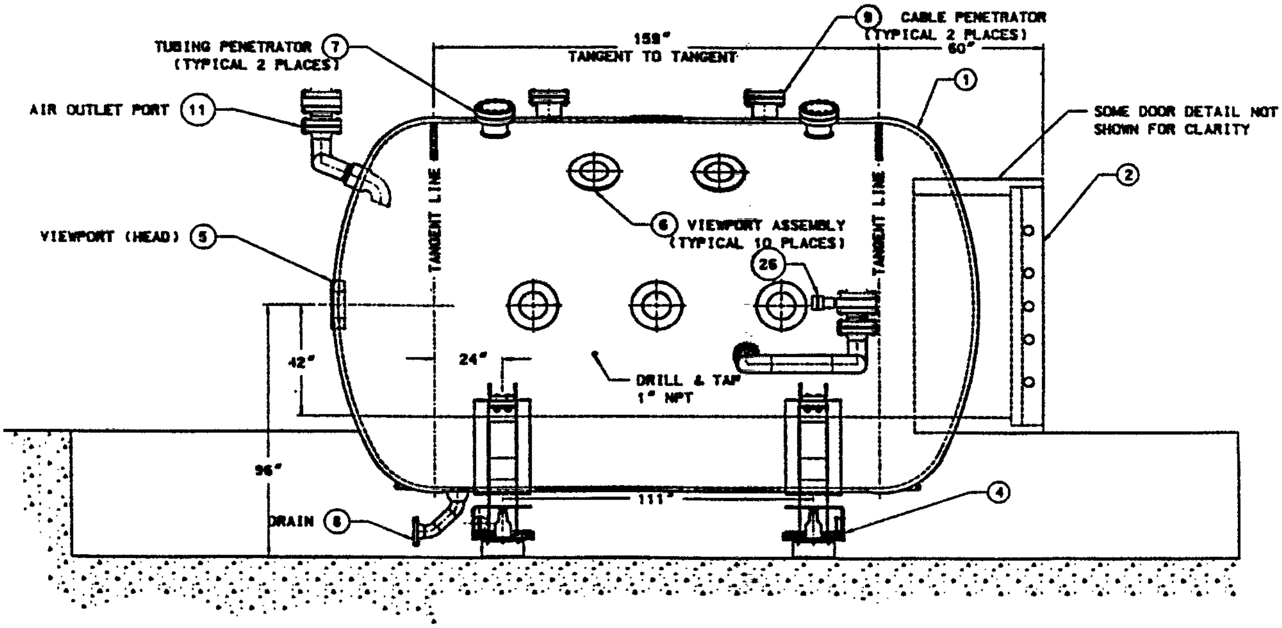
2.0 Design Requirements

Los Alamos National Laboratory contracted Southwest Research Institute to design, fabricate, and test a containment vessel for performance of explosive tests. Figure 1 shows exterior views of the vessel.

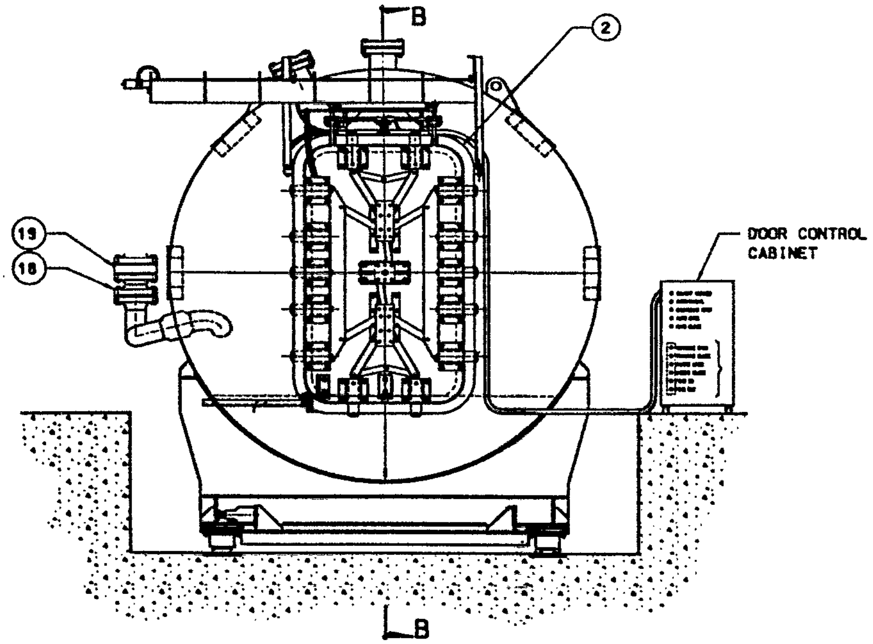
The vessel was designed to contain blast, fragments, and residual gases from repeated detonations of up to 10 kg TNT equivalent centered in the vessel.[1] It is also required to provide for the use of smaller charges at off-center locations as determined by analysis.

The vessel was designed to meet the following additional requirements:[2]

- The vessel shall have a minimum inner diameter of 11.5 feet and a minimum inner length of 19 feet.
- The weight of the vessel should be minimized and shall not exceed 75 metric tons (165,000 pounds)
- The vessel is to provide a lifetime of 1500 full charge shots or 10 years of installed operational use, whichever comes first. Maintenance and component replacement is acceptable as further specified.
- The vessel shall have a floor located 3.5 feet below the centerline of the vessel. It shall be designed to survive 100 full charge shots without replacement, and allow for easy removal for vessel maintenance.
- The vessel shall be fabricated with a minimum of four roller assemblies to allow the vessel to be rolled into and out of the facility. Also, a jacking mechanism shall be provided to adjust the vessel height and orientation.
- A door, 4 foot by 7 foot minimum, shall be provided in one end of the vessel. The door shall be designed for a cycle life of 100 openings and closings between required lubrication, 1500 openings and closings between major system maintenance, and 1500 shot cycles before door replacement. The door shall be power operated with a manual back-up operating system.
- The vessel shall have one air inlet connection and one air exhaust connection. The fixtures shall be equipped with valves that can maintain the vessel containment requirements during repeated tests with minimum lifetimes of 100 shots between maintenance and 500 shots before replacement.



a) Side View



b) End View

Figure 1. Containment Vessel

- Eleven 10-inch diameter viewports shall be provided in the vessel. The design shall allow for easy protection of the viewports not used during a test, and for easy replacement of the clear material between tests.

- The vessel shall have two cable pass-through fixtures with fragment shields to protect from line-of-site damage from fragments during tests.

- The vessel shall contain pass-through fixtures for gas and vacuum lines.

- A drain shall be provided to remove liquids from the vessel during cleaning.

3.0 Loads Prediction

Blast loads in the vessel consist of both a shock loading phase and a quasi-static, gas loading phase. The quasi-static load can be predicted with confidence using empirically based curves which are available from a variety of references. The shock loading is much more difficult to predict due to the reverberation of the shock waves within the chamber.

Shock loads were predicted using a combination of blast predictive methodologies and test data from a similar vessel at the DOE Mound Laboratory.[3] The approach involved the following steps:

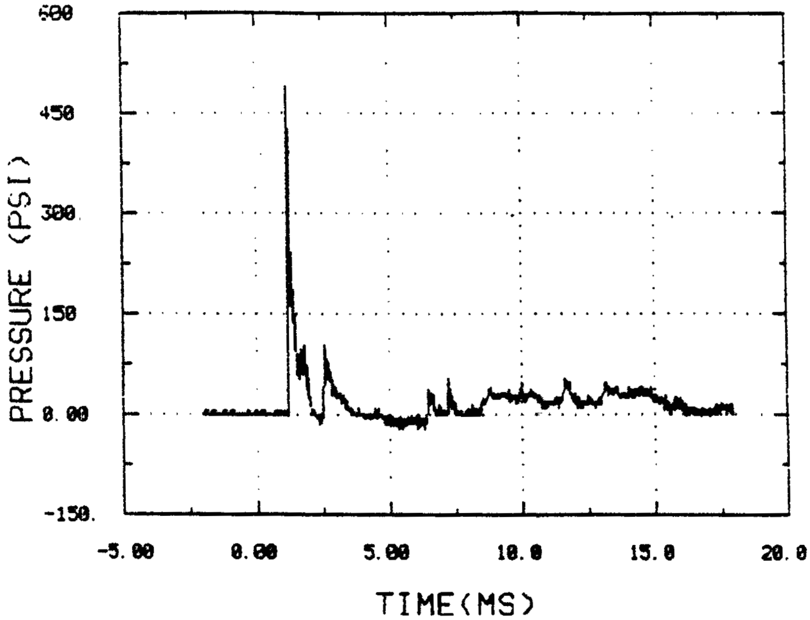
- A close review of the Mound data was made, concentrating on measured loads at the vessel sidewall (center) and at the middle of the elliptical endcap.

- Predictions of these measured loads in the mound vessel were made. Several methods were attempted, including the use of standard airblast curves and the computer code BLASTINW.[4]

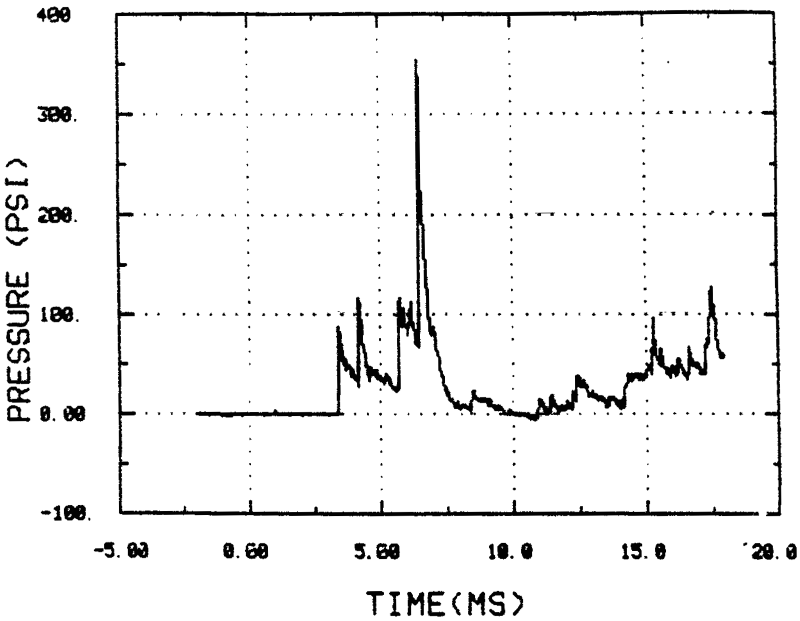
- Comparisons of the Mound predictions and measurements were made. Adjustments to the predictions were implemented to account for differences, and predictions were repeated.

- Once reasonable correlation between predicted and measured data were obtained for the Mound vessel, the final predictive procedures were repeated for the LANL vessel geometry and charge weight.

Typical blast pressure traces from the Mound tests are shown Figure 2 for locations at the cylinder wall directly adjacent to the charge and at the center of one end. Note that at both locations, the load history is defined by more than one significant pressure pulse. The shock loading phase normally consists of a large initial pulse from the expanding shock wave and later, smaller pulses from the reflection of the shock wave off adjacent surfaces. This type of loading was demonstrated in Figure 2a on the cylindrical shell. However, Figure 2b shows that the loading on the head is



a) Cylinder



b) End

Figure 2. Typical Mound Test Data

different. The shock wave expands spherically from the center until it reaches the confining cylinder wall, reflects, then moves toward the center. This reflected wave is not planer. It approaches the cylinder axis and forms a very strong, focused wave which is directed against the endcaps. This strongly focused reflected wave reaches the endcaps after the initial blast wave from the explosion, and the data indicate that this second pulse will have a greater peak pressure and more specific impulse than the first pulse.

Comparisons between the Mound data and several blast predictive methods indicated that a combination of the methods were required. Peak pressures were calculated using standard airblast curves. An equivalent charge weight to account for the confinement provided by the vessel was determined. The total impulse was based on calculations made with BLASTINW for an approximate geometry. The distribution of the impulse in multiple pulses was based on the data from the Mound tests. The times of arrival for each pulse were based on "image" charge methods. Time histories used for design of the LANL vessel are shown in Figure 3.

4.0 Primary Structure

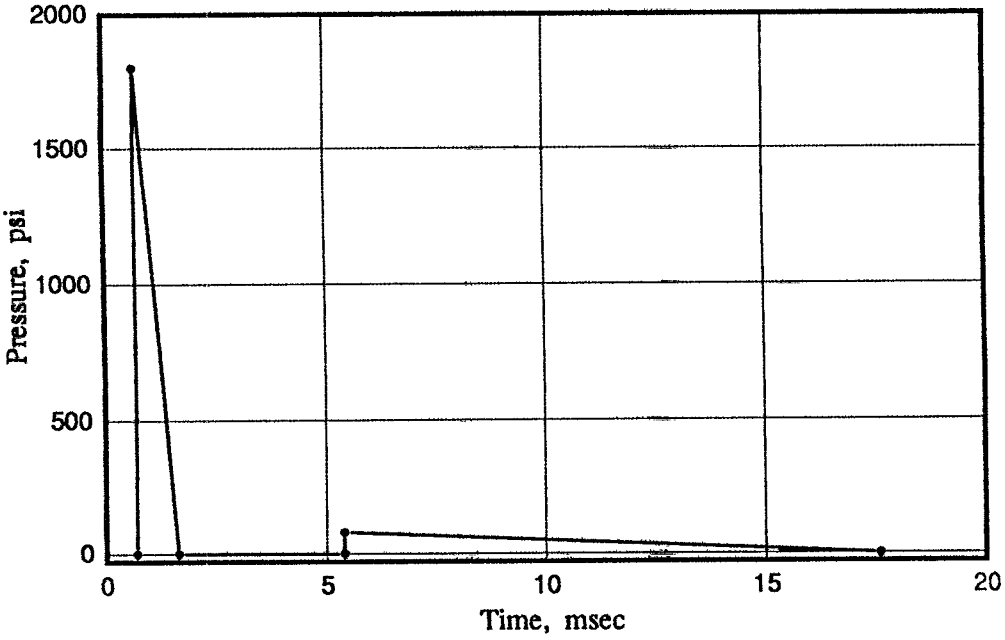
The primary structure consists of the cylindrical shell, the heads, the door, and the door frame. The vessel was designed to be totally elastic. The type of analysis used for each component of the vessel was selected based on the complexity of the component response. Equivalent static load analyses were used to design support components and secondary components such as pins, viewports, viewport frames, etc. Single-degree-of-freedom (SDOF) analyses were used to design the door, the shell, and the head of the vessel without the door. A multiple-degree-of-freedom (MDOF) analysis was used to design the head of the vessel with the door and the door frame. Also, maximum stresses were checked against ASME fatigue design requirements assuming 1500 charge detonations and a conservative damping factor. The following sections contain a description of each of these components and a summary of the design approach.

4.1 Cylindrical Shell

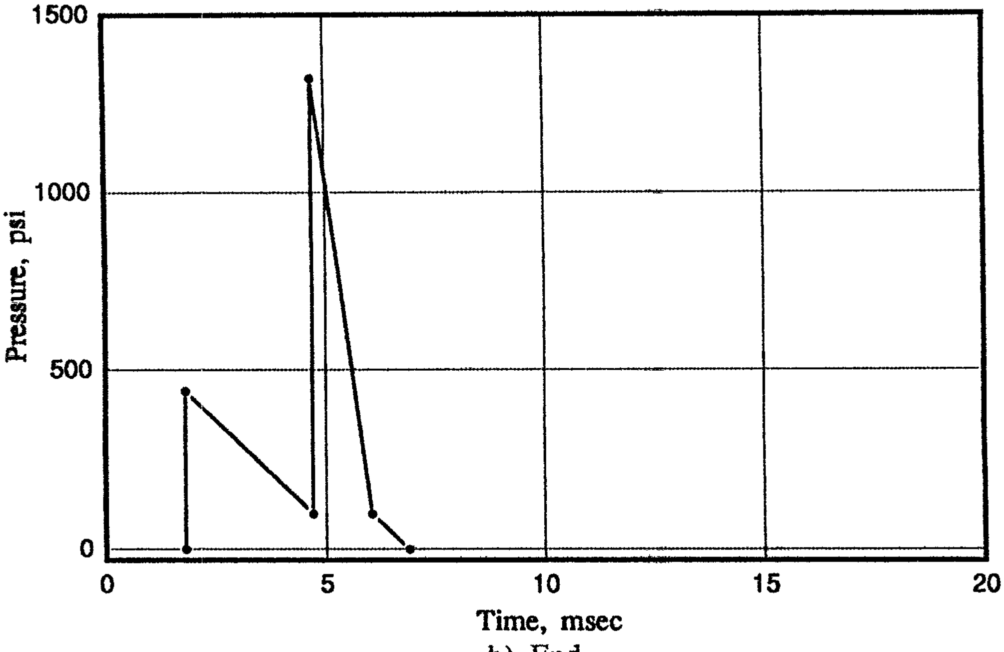
The cylindrical shell was analyzed using SDOF methods to account for the hoop response of the shell. Materials of varying strengths were considered, including A514 Grade 70, A588, HY80 and HY100. One and one-half inch thick HY100 was chosen. Although HY100 is more expensive than the other materials and requires more stringent welding procedures, the high strength ($f_y = 100$ ksi) allows for thinner material, thus reducing the vessel weight. Also, the thinner material requires smaller welds, somewhat offsetting the increased fabrication costs.

4.2 Head Without Door

The head opposite the door was analyzed using SDOF methods. A 2:1 elliptical head was chosen for both heads. The stiffness and deformed shape of the head were determined by performing



a) Cylinder



b) End

Figure 3. LANL Design Loads

a finite element analysis using ABAQUS.[5] The analysis showed that a 1-1/2 inch thick HY100 will adequately resist the blast loads. The head was fabricated from 2 inch thick steel to provide resistance to fragments.

4.3 Head with Door Frame and Door

The head with the door is shown in Figure 4. The head is a 2:1 elliptical head, identical to the head at the opposite head. An opening was cut into the head for the door opening. The sides, top, and bottom of the door frame were fabricated from 6 inch thick A572 Grade 50 plate. The corners were cut from a HY100 forged cylinder.

Initially, static finite element analyses were performed to estimate stresses in the head and door frame. Regions of high stress were identified in the head near the door frame corners. Gussets were added to strengthen the head and reduce the stresses.

The door plate is 4 inch thick HY100 plate. The door opens outward so as not to limit working space inside the vessel when the door is open. Because of this outward opening door, restraining pins were designed to resist the loads from the door reactions due to motion in the direction of the loads. The plate is latched in the closed position by 5 pins on each side of the door and 2 pins on the top and bottom of the door. All pins are 3-1/2 inch diameter, heat treated 4340 alloy steel, and are mounted on the door in pin blocks. Pin insertion into the door frame is accomplished simultaneously by remotely activating a hydraulic rotary actuator and its associated connecting linkage hardware to the pins, all of which are mounted on the door plate as shown in Figure 1. Also shown is the overhead structure containing a carriage-like arrangement which rolls on a track positioned such that the door can translate away from the frame, and then to the left, clear of the door way. Carriage movement is provided by DC motor-driven, rodless cylinders which are remotely operated by a programmable microprocessor based controller.

Final analysis of this head involved a combination of finite element analysis and Multi-Degree-of-Freedom dynamic analysis. Initially, the finite element analysis was used to determined the deformed shape of the head and the stiffness of the components of the head. The head system was modeled as a 3 degree-of-freedom system as shown in Figure 5. This model considered the motion of the vessel in the axial direction by accounting for elongation of the shell, radial motion and bending of the head, and bending of the door plate. The door frame was assumed to be rigid. The peak resistance developed in the springs of the model was used to develop equivalent static pressures for the finite element analysis, which allowed calculation of the stresses in the head.

5.0 Secondary Components

5.1 Floor System

Two types of floors were considered for the vessel: a solid floor and a grate floor. The grate floor uses lighter sections which eases removal and replacement of sections. However, debris

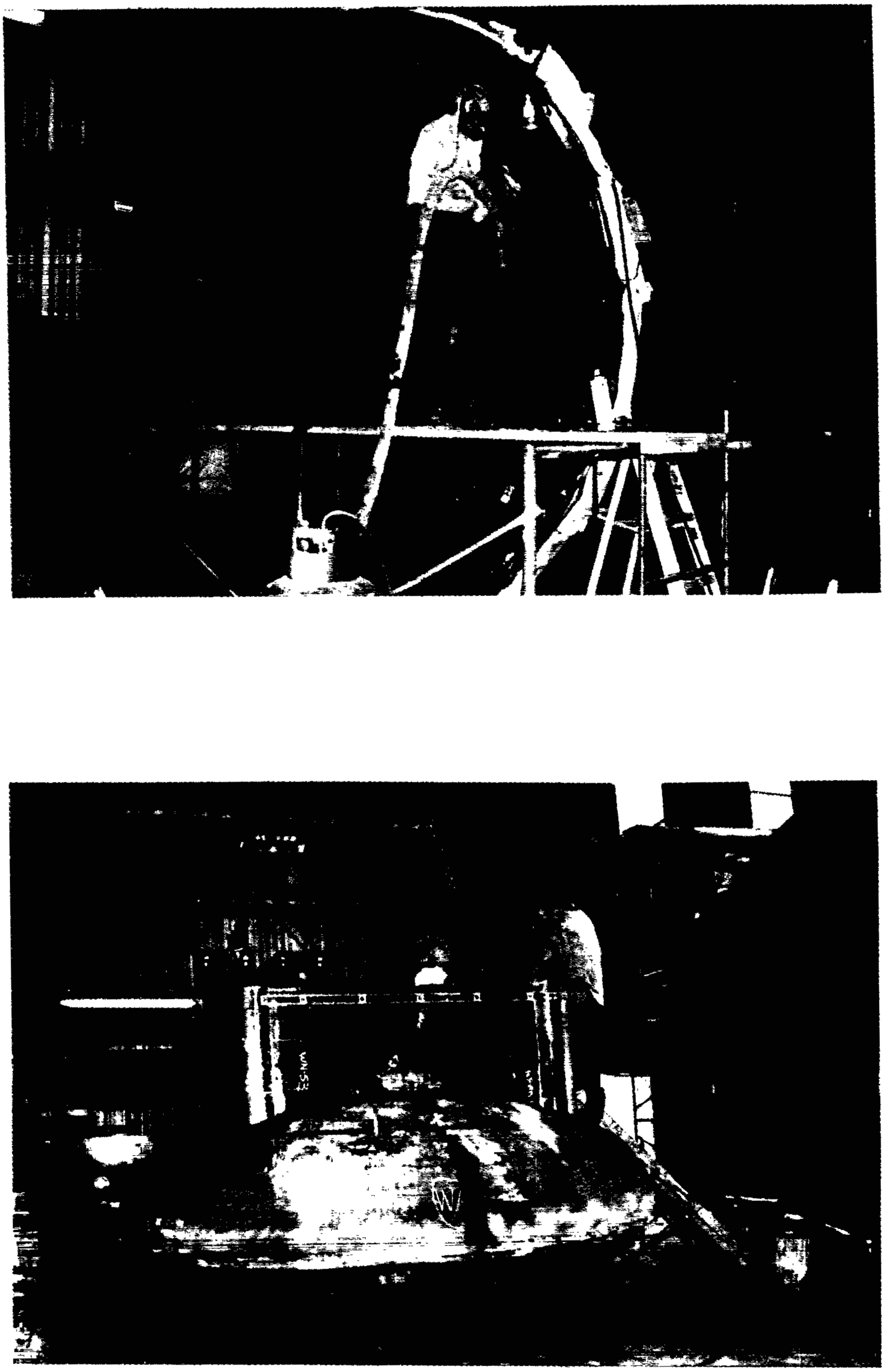


Figure 4. Head with Door Frame During Fabrication

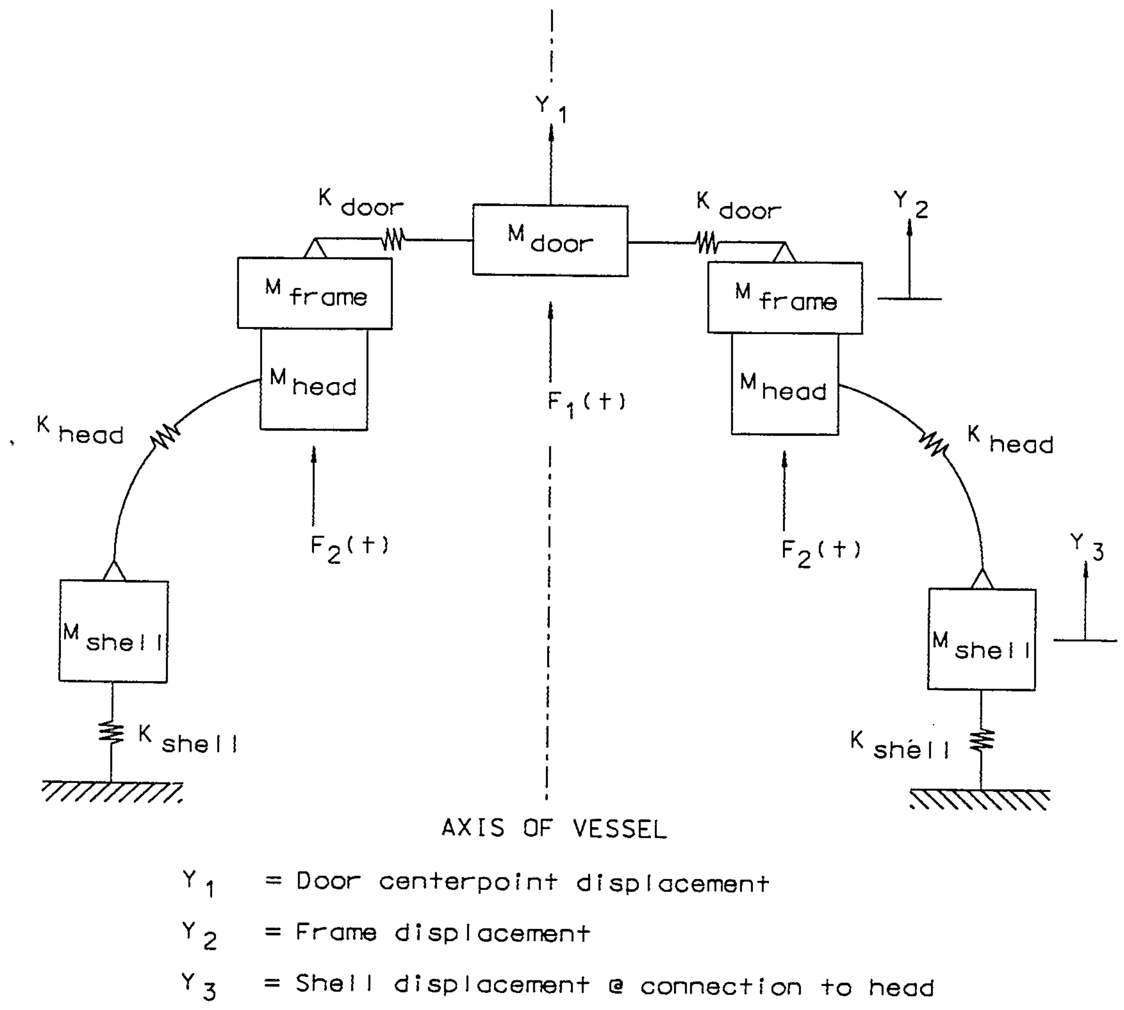


Figure 5. Three-Degree-of-Freedom Model of the Head with the Door

from the tests can pass through the openings in the floor which could be a maintenance problem. There was an additional concern that connections could loosen during tests which would require tightening before proceeding with subsequent tests.

A solid floor eliminates these problems and also provides a much smoother work surface inside the vessel. A concrete floor was chosen with steel plates at the surface to provide protection from fragment impacts and local concentrated blast pressures. The system is shown in Figure 6. The plates are placed in two layers of 0.5 inch thick steel, each separated by 1/8 inch neoprene. Two layers are used to simplify replacement by reducing the weight of the sections. The top layer consists of sixteen "tiles" which are plug welded to the lower plates. Smaller tiles are located in the center of the vessel where the larger charge weights will be detonated. The lower layer consists of twelve tiles which are plug welded to embedded structural steel.

5.2 Fragment Shields

Most of the shot configurations planned for the vessel use considerable amounts of metal. Internal barricading around the shot will be used to provide protection for the vessel; however, complete protection is not expected. Therefore, fragment shields are provided around the cylinder. The heads and door do not have attached shields and will be protected by the barricades around the shot.

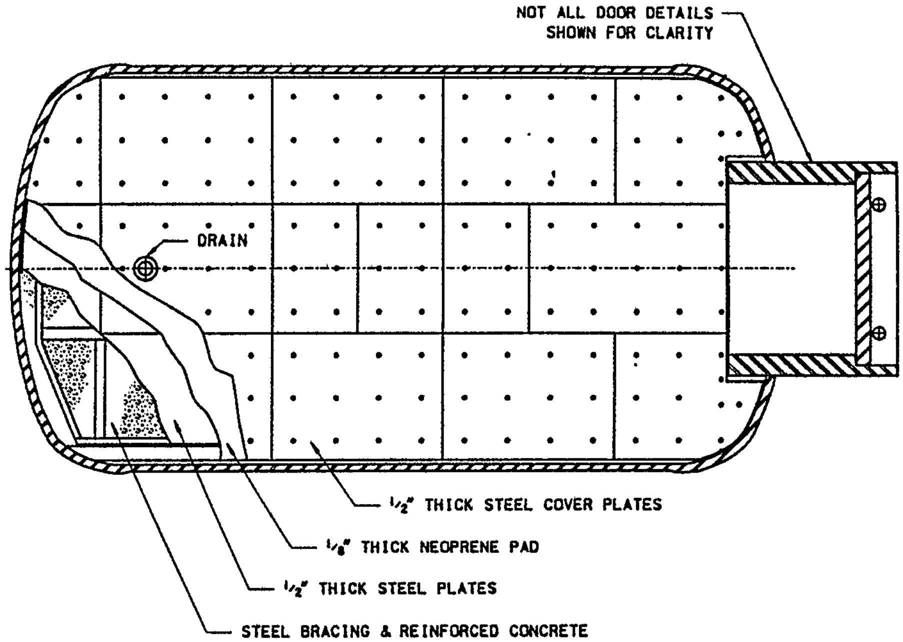
The fragment shields on the cylindrical section are approximately 12 inch by 12 inch square, 1/2 inch thick steel plates backed by 1/8 inch thick neoprene. Each plate is attached to cylinder with four 1 inch threaded studs.

5.3 Viewports

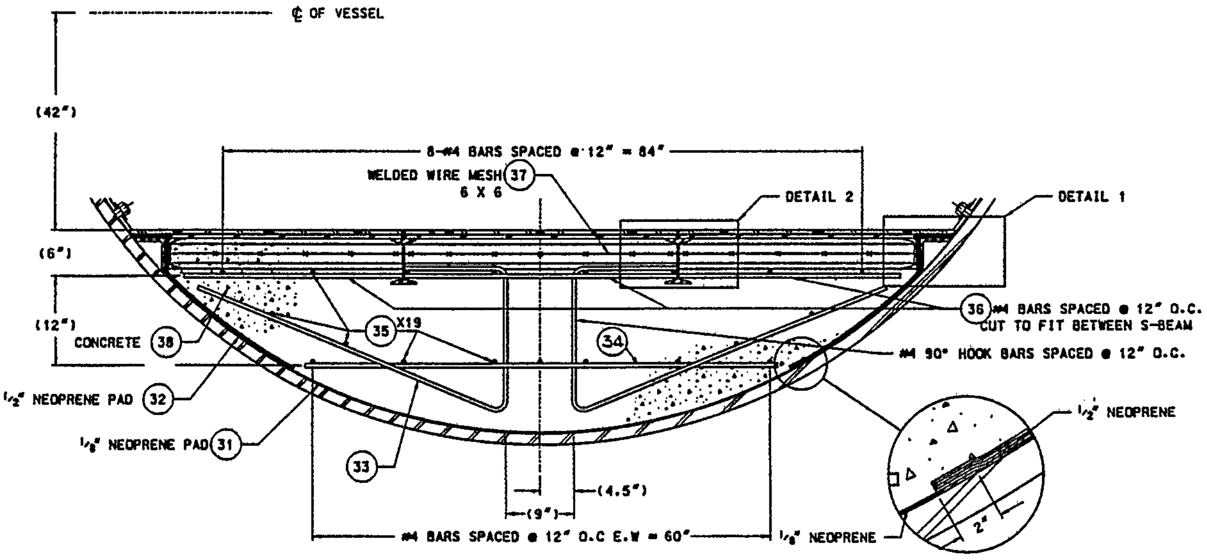
The viewport system is designed to meet three operational requirements:

- Provide a clear window to provide light inside the vessel and for users to look into the vessel before and after the test.
- Provide a high optical quality glass window for photography and other data collection as required for various tests.
- Accept a shield when the windows are not required for the tests.

The viewport system shown in Figures 7 meets these requirements. The frames were machined from HY100 forgings and are designed to accept a circular 3 inch thick thermally tempered glass window or 6061 T651 aluminum plate. Inserts were fabricated to accept 5 inch diameter high optical quality glass. The glass is secured in the insert, and the insert is placed in the viewport frame.



a) Plan



b) Cross Section

Figure 6. Vessel Floor

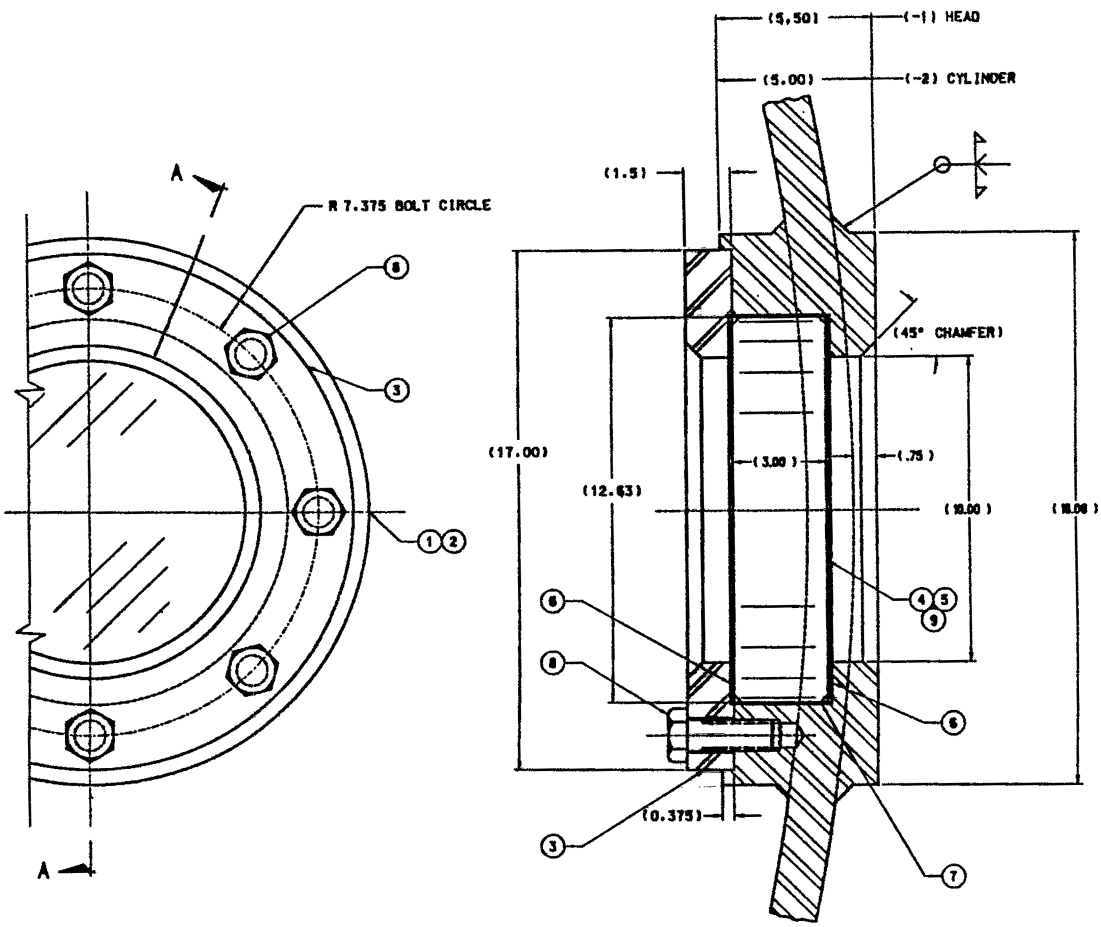


Figure 7. Viewport

5.4 Air Inlet and Exhaust

Following a test, the products from the explosion must be vented from the vessel. The vessel design includes a 6 inch air inlet near the forward end of the vessel and a 6 inch air outlet at the aft end of the vessel. A prefilter and valve is provided at the exterior end of the piping. The valves are 6 inch butterfly valves with pneumatic actuators and position sensors. The valves will be connected to the HVAC system constructed with the building, and will provide protection to the building HVAC system upstream and downstream from the vessel during tests. The prefilter contains a duocel metal foam filter core inside a filter housing. The prefilter will catch larger particles which may be passed through the ventilation system and will reduce shock loads on the valves.

5.5 Other Penetrations

Additional penetrations through the vessel are required for cable ports, gas and vacuum ports, and a drain. These are shown in Figures 8.

The cable penetration includes a blind flange which the users will drill and tap as necessary to provide for cable pass-throughs. A cover plate will be placed on the inside of the vessel to protect cable connectors from blast and fragments.

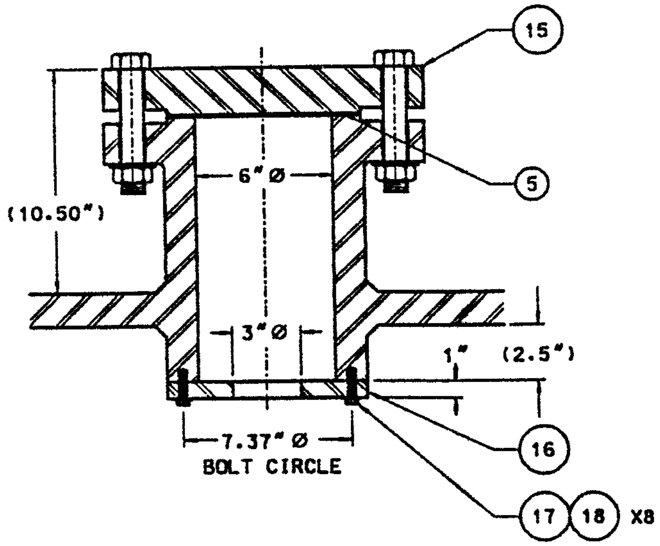
The penetrations for gas and vacuum lines are similar to the cable penetrations. The fittings will be attached to the outside of a plate attached to the penetration; therefore, a shield is not needed.

6.0 Proof Testing

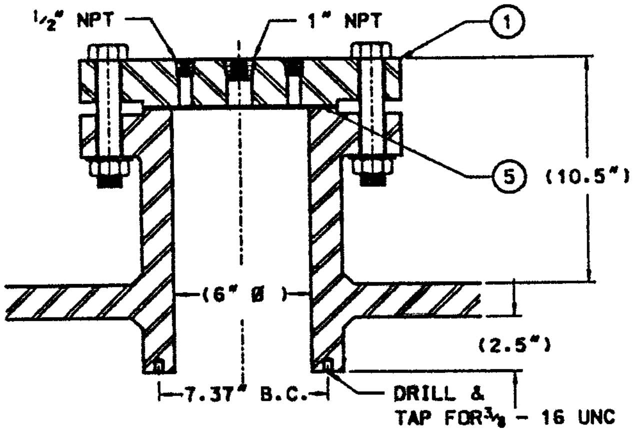
Three types of tests are required for proof testing of the vessel: hydrostatic, pneumatic and explosion. The hydrostatic test will confirm the "equivalent" static capacity of the dynamic loads on the vessel. The pneumatic air leak tests will show that the vessel is tight and free of leaks up to 125% of the estimated quasi-static gas pressure generated by the 10 kg TNT equivalent charge. The pneumatic tests will be performed before, during, and after the explosion proof tests. The explosion proof tests will show the performance of the vessel at its rated capacity. A summary of the tests in the order in which they will be performed is as follows:

1) Hydrostatic test to an internal pressure of 780 psig. This test will be done prior to the floor being installed in the vessel.

2) Air leak test No. 1 will be conducted after the vessel fabrication is completed and before the first explosion test takes place. The test will show that the chamber is tight and free of leaks for 4 hours from the gas pressure rise of the explosive detonations. For the proof test charge weight of 10 kg, the peak gas pressure rise is estimated to be 125 psig. The pressure for the leak tests will be 125% of this value, or 156 psig.

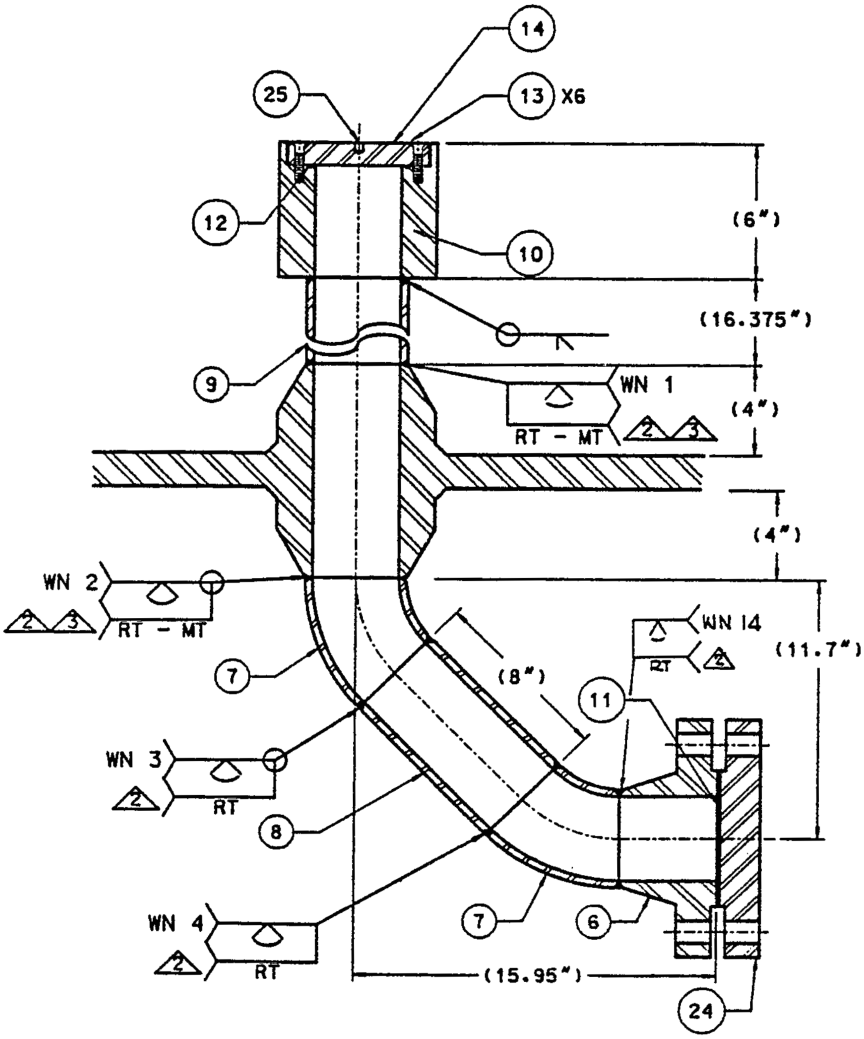


a) Cable Penetration



b) Gas and Vacuum Penetration

Figure 8. Miscellaneous Penetrations



c) Drain

Figure 8. Miscellaneous Penetrations (Continued)

3) A minimum of 3 preliminary explosion tests will follow leak test No. 1. These preliminary tests will use TNT explosive weights of about 5 and 10 pounds, will serve as operational checks on the measurement systems, and will provide blast load and response data to evaluate the chamber design prior to the explosion proof tests.

4) Explosion proof test No. 1 will consist of firing a 10 kg spherical charge after the data from the preliminary tests indicate the expected results. Again, the response of the chamber and the blast pressures generated by the charge will be measured by strain gages and pressure transducers, respectively.

5) Air leak test No. 2 will follow the first explosion proof test.

6) After completion of the second air leak test, explosion proof test No. 2 will be conducted in a similar manner to the first test.

7) Proof testing of the vessel will be completed by performing air leak test No. 3.

Testing of the vessel is scheduled to begin in late September of this year.

Acknowledgements

The authors extend their gratitude to all those individuals at Los Alamos National Laboratory and Southwest Research Institute who contributed to the design, fabrication, and review through the course of the project. Especially noted are Mr. Jerry Wackerle of Los Alamos, who provided review throughout the project and provided information on the use of the vessel and current testing at Los Alamos, and Mr. Wendel Seitz, who was the program manager for Los Alamos. Also Acknowledged are Mr. Francis Caroline, who supervised the fabrication of the vessel at Southwest Research Institute and Ms. Shirley Demel, who prepared this manuscript and processed the records for the project.

References

1. "M-9 Firing Facility Containment Vessel One Hundred Percent Design Basis Document," prepared for Los Alamos National Laboratory Group M-9 under Subcontract 9-L51-D9320-1, August 1991.

2. Statement of Work for the M-9 Contained Firing Facility Containment Vessel, February 2, 1990.

3. Esparza, Edward D. and White, Robert E., "Blast Pressure Measurements in Containment Test Cells," 23rd Department of Defense Explosives Safety Seminar, August 9-11, 1988.

4. Britt, J.R., Drake, J.L., Cobb, M.B., and Mobley, J.P., "BLASTINW User's Manual," ARA 5986-2, Final Report 2, Contract DACA39-86-M-0213, with U.S. Army Waterway Experiment Station, April 1986.

5. "ABAQUS User's manual," Version 4.8, Hibbitt, Karlsson & Sorensen, Inc., Copyright 1989.