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`Explosive Components Facility Certification Tests*

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Abstract

Sandia National Laboratories has recently completed construction of a new Explosive Components Facility (ECF) that will be used for the research and development of advanced explosives technology. The ECF includes nine indoor firing pads for detonating explosives and monitoring the detonations. Department of Energy requirements for certification of this facility include detonation of explosive levels up to 125 percent of the rated firing pad capacity with no visual structural degradation resulting from the explosion. The Explosives Projects and Diagnostics Department at Sandia decided to expand this certification process to include vibration and acoustic monitoring at various locations throughout the building during these explosive events. This information could then be used to help determine the best locations for noise and vibration sensitive equipment (e.g. scanning electron microscopes) used for analysis throughout the building.

This facility has many unique isolation features built into the explosive chamber and laboratory areas of the building that allow normal operation of other building activities during explosive tests. This paper discusses the design of this facility and the various types of explosive testing performed by the Explosives Projects and Diagnostics Department at Sandia. However, the primary focus of the paper is directed at the vibration and acoustic data acquired during the certification process. This includes the vibration test setup and data acquisition parameters, as well as analysis methods used for generating peak acceleration levels and spectral information. Concerns over instrumentation issues such as the choice of transducers (appropriate ranges, resonant frequencies, etc.) and measurements with long cable lengths (500 feet) are also discussed.

Introduction

The ECF complex includes a single-story, main building of approximately 96,500 square feet, six explosive service magazines, and service drives and parking areas needed to make the complex self-contained. The main building is comprised of two main functional areas, laboratory/testing and administrative, both of which are under controlled access at all times. The ECF consolidates a number of ongoing activities relating to explosive components, neutron generators and battery research, testing, development, and quality control. Hazards addressed in the design and operation of the explosive area of the facility include explosives, pyrotechnics, propellants, lasers, micro-

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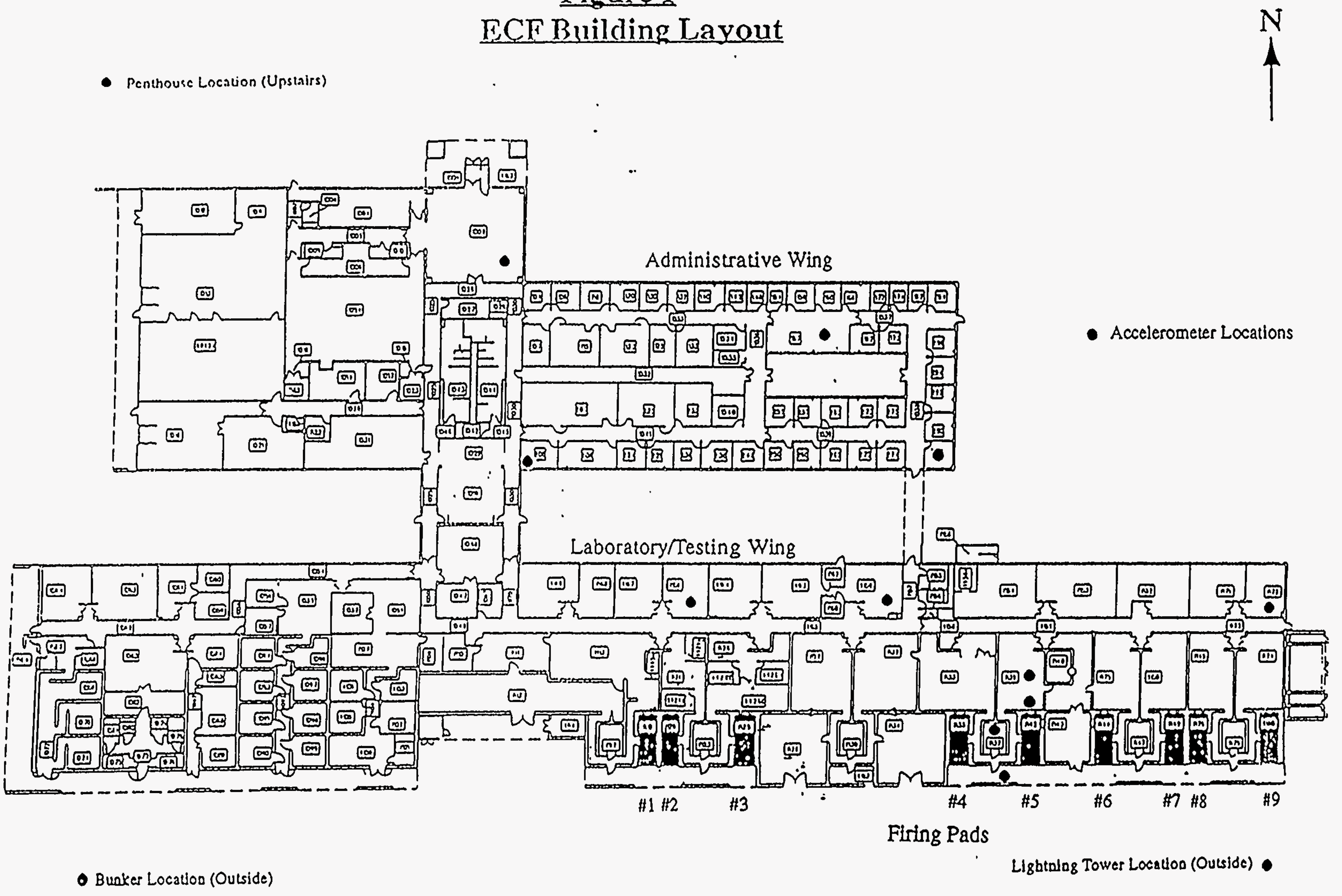
Figure 1
ECF Building Layout



waves, radioactive materials, neutrons, x-rays, toxic chemicals, reactive chemicals, hazardous waste, and conventional industrial safety hazards.

The laboratory/testing area is structurally isolated from the rest of the building to the extent that routine explosive tests will not generally be heard or felt in the administrative area of the building. The administrative portion of the building is actually a separate wing with a corridor connecting it to the laboratory/test areas. (Figure 1 shows the building layout). The south wing of the building houses the firing pads and laboratories used for testing in the facility. The testing laboratories in this section are isolated from the firing pads by a one inch foam joint in the concrete floor. This enables normal test activity in most laboratories while explosive tests are being performed in the firing pads. The area containing rooms 1164(GC/MS Lab), 1166(SEM Lab), and 1167(Image Analysis Lab) have an additional 3/4 inch isolation joint installed in the floor around their perimeter for additional vibration isolation of sensitive equipment. The laboratory spaces in the building are devoted to the routine testing of explosives and explosive devices, neutron generators and batteries. Laboratories are used for work with gas chromatography, mass spectroscopy, ultrasonics, component disassembly, propellant preparation, explosive analysis, explosive and pyrotechnic ignition studies, and laser diode ignition.

Nine enclosed firing pads and two high explosive chambers are located at the rear of the laboratory/testing area. The firing pads and chambers are designed to protect personnel from the overpressure, hazardous fragments, and thermal effects of planned detonations. The walls, roof, and floors of the firing pads are designed to accommodate repeated detonations without damage to the ECF structure. Two blast doors are used to provide access control and partial containment for each firing pad. The high explosives chambers are ASME code vessels which are designed to accommodate repeated detonations without damage to the chambers or the ECF structure. Six earth-covered explosive service magazines are located south of the southwest corner of the building. These service magazines contain non-propagating storage cabinets for explosives. The magazines are designed to prevent fragments and overpressures, due to accidental explosions, from spreading beyond the facility's boundaries. They are used for storage of materials being tested at ECF.

In developing an understanding of the operations conducted at the ECF, it is important to note this facility is a research and development facility which functions differently than a production facility. As a research and development facility, the descriptions of activities are generically grouped in terms of like operations rather than as a specific, well-defined, industrial process, even though there are individual differences in equipment, hazards, and personnel. All activities at Sandia involving the handling of hazardous materials require the use of written Operating Procedures (OPs). These procedures are developed by operating organizations and reviewed and approved by the various safety disciplines prior to commencing activities involving the handling of hazardous materials. The specific activities conducted in the ECF facility are as follows:

- Shipping, receiving, and storage of explosives, pyrotechnics, and propellants.
- Physical and chemical testing of explosives, pyrotechnics, propellants.
- Neutron device research, development, and testing.
- Battery research, development, and testing.
- Stockpile surveillance of explosives, pyrotechnics, and propellants.

The ECF is designated as a Department of Energy User Facility, meaning, industry has access to the testing capabilities and explosive expertise of personnel operating the facility. The ECF capabilities discussed in this paper are very general; detailed test plans for individual tests are developed between ECF personnel and customers within the appropriate time constraints of a desired test. The remainder of the paper discusses the vibration and acoustic tests performed for certification of the firing pads.

Vibration Test Setup

Vibration measurements were taken for multiple explosive weights (83 gram through 1049 gram range) of C4 explosive on nine firing pads in the facility. A total of 15 triaxial accelerometers were located at various points throughout the building for vibration characterization. Eleven of these locations were permanent, that is, accelerometers were kept in the same location for each shot on each firing pad. The other four measurements were made using accelerometers that were moved to specific locations around the individual pad being tested. These triaxial accelerometer locations typically included one approximately one inch from the pad wall, one in the assembly room, one in the operations room north of the pad, and one along the outside corridor. (Figure 1 shows the building layout with permanent accelerometer locations and the roving accelerometer locations for firing pad #5).

Three types of accelerometers were used for the tests. The primary concerns for the choice of accelerometers were the dynamic range (maximum g level) and the resonant frequency of the sensing element. The predicted acceleration levels for most locations, especially those closest to the firing pads, were vague at best. The final setup, after preliminary data ruled out other types of accelerometers, used a combination of three types of accelerometers with dynamic ranges from 10g's to 500 g's. An accelerometer capable of measuring the high acceleration levels on the firing pad walls and port covers was not readily available, therefore, no measurements were taken at these locations.

Accelerometers with a 10g dynamic range and a resonant frequency of 11 KHz were used at the majority of locations. These worked well because of the distance from the firing pads and the isolation built into the floor of the facility. High acceleration levels and frequencies approaching the accelerometer resonance were not a problem in these areas. Specific areas of concern for these parameters were the operation rooms adjacent to the north side of the pads, and, in particular, the assembly rooms located between each set of firing pads. The assembly rooms are located between each set of firing pads and share a common floor slab with the firing pads. For this reason accelerometers with a 50g dynamic range and a resonant frequency of 54 KHz were used in the assembly locations. These same accelerometers were also used in the operations laboratories adjacent to the north side of each firing pad because of the higher acceleration levels. Accelerometers with a 500g range and a resonant frequency of 80 KHz were used at the firing pad wall location in the operations room due to a shortage of the 50g accelerometers.

All accelerometers were mounted on aluminum blocks in a triaxial configuration using #10-32 studs; the blocks were attached to the concrete floor using dental cement. Two triaxial locations were outside away from the building - these accelerometers were mounted on concrete supports that are used as bases for lightning towers around the building. All instrumentation was connected to a central data acquisition system using a combination of RG-58 and microdot coaxial cable. Many of these locations involved long runs of cables which introduced their own unique problems to the test setup. These concerns and other problems are discussed in a later section of the paper.

Vibration Data Acquisition

The data acquisition system used was PC based using the HP3566A 48-channel software with an HP35650 mainframe for collecting data. A throughput module was used in the mainframe to allow time history data to be streamed directly to disk during the process. The maximum sampling rate the system would handle while acquiring 45 channels of data simultaneously (16384Hz) was used for all tests. To ensure this sampling rate was sufficient to capture peak values during an explosive event the number of discrete points sampled on the initial pulse at various accelerometer locations was checked for several shots. Worst case (shortest pulse duration) was the assembly room data which resulted in a sampling resolution of four to five discrete points over the shortest peaks. Data for locations outside of the floor isolation joint had longer initial pulse durations resulting in higher sampling resolution for peak values. Acquiring the raw time history data is advantageous in that it allows easy manipulation for peak acceleration levels as well as easy conversion to different forms of spectral data.

Problems Encountered

As with any remote test some problems were encountered during the initial phases of the setup and data acquisition. The first problem was physically stringing the BNC cables to the different locations throughout the building. The building was in the final stages of construction so the tests could only be performed on weekends when no construction personnel were present. This meant both stringing and rolling up 45 cables (200 to 500 feet in length) each weekend. This was resolved after the first test series with the purchase of large hose-reels that were used for each set of cables. The cables also presented a larger problem with a static charge buildup during the stringing process and discharging into the accelerometer once they were connected. We were unaware of this potential problem with the Endevco 7751 (10g dynamic range) accelerometers and during the initial tests it resulted in 11 data channels being inoperable. After discussions with Endevco it became evident the discharge was overloading and burning out parts of the semiconductor circuit internal to the accelerometer. The fix for the problem was to simply discharge (using a shorting connector) the cable before connecting it to the accelerometer or connect the cable to the conditioning amplifier first instead of the accelerometer. There was initial concern regarding the impact of a 500 feet cable on the amplifier voltage source driving the accelerometers. The concern was the increased cable impedance combined with a fixed voltage source would result in current levels that would be to low to properly drive the electronics of the accelerometer. This was checked by comparing calibrations on the same accelerometers using cables three feet and 500 feet in length. Maximum variance between the calibrations on five different accelerometers was just under 1.5 percent.

Vibration Data Analysis

The data of interest from these measurements were peak acceleration levels and the spectral content through the 100Hz range for all data channels. There was also a need to generate plots of each data channel for each shot for documentation and future reference purposes. Taking into account that data had been acquired for a total of 24 shots throughout the nine different firing pads and each shot had 45 channels of data associated with it, the data reduction process would involve over 1000 channels of data to analyze and plot. While the HP3566A software works well for data acquisition there are severe limitations on it's plotting and data manipulation capabilities. Based on this scenario it was determined that a more efficient method for generating plots and spectral information was necessary. Several MATLAB programs were developed in-house to address the documentation requirements.

The programs used converted the SDF (Standard Data Format) files from the HP system into a MATLAB file format. The SDF files were very large (over eight megabytes), so the resulting MATLAB files were written out as single channel files for easier data manipulation. Another set of programs allowed the user to choose a specific portion of a time history record (in this case the actual explosive event), convert that portion to spectral information (autospectra), and plot both the time history portion and the auto-spectra (amplitude vs. frequency plots) information for the X,Y, and Z directions of a triaxial accelerometer all on the same plot. (Figure 2 shows a sample of the data plots for each triaxial accelerometer location).

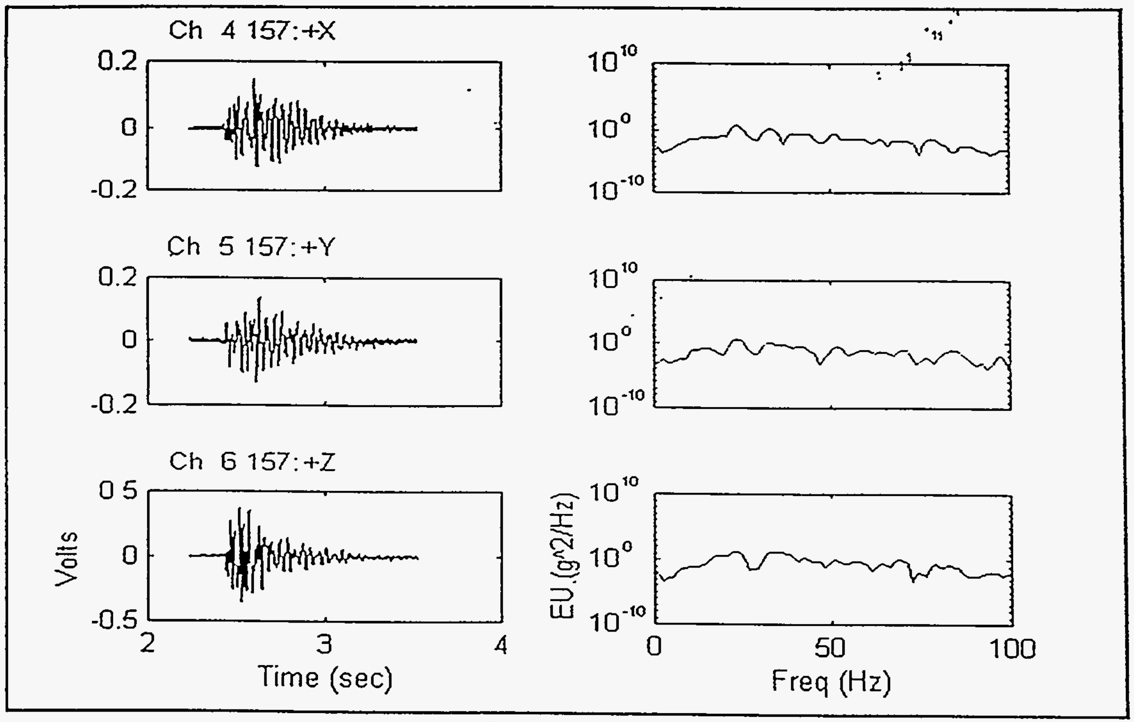


Figure 2
Time History and Autospectra Plots

Peak amplitudes exhibited reasonably consistent patterns, that is, the levels tend to increase as the location gets closer to the firing pad being tested. The office area accelerometers saw very low levels because of their location in the administrative wing of the building away from the firing pads. (75 feet to several hundred feet depending on the pad being tested). Room 1166 (SEM Lab) and Room 1159 (Liquid Chromatography Lab) tracked each other fairly closely which was surprising considering Room 1166 has an additional isolation joint in the floor around the perimeter. The penthouse accelerometer (upstairs) had some fairly large variances due to the different structural coupling between the upstairs and downstairs at different pad locations. (See Table 1 for peak acceleration levels).

The bunker accelerometer was located outside on the southwest corner of the building by the explosive service magazines used to store explosives for the facility. It was mounted with dental cement to a concrete slab used as a base for a lightning tower. The acceleration levels between this location and firing pads 1, 2, and 3 were quite high considering the distance (approximately 150 feet) and the fact the only coupling between the two is dirt. These levels decreased significantly for tests performed on Pad4 through Pad9.

The data shows large variations in amplitudes on the roving accelerometer locations, especially in the assembly rooms. As mentioned earlier, the assembly rooms share a common concrete floor with the firing pads. The levels in the assembly rooms compared to the levels in the adjacent rooms give some indication of how well the floor isolation joint works.

Table 1 represents eight measurement locations (5 permanent, 3 roving - the roving being in similar positions for each pad) for firing pads 1 through 5. The locations and their proximity to the different firing pads can be seen in Figure 1.

Table 1
Peak Acceleration

	Pad1Test1	Pad2Test2	Pad3Test2	Pad4Test2	Pad5Test2
Room 206 - Office Area	- 0.009 g + 0.010 g	- 0.005 g + 0.006 g	- 0.010 g + 0.008 g	- 0.003 g + 0.003 g	- 0.004 g + 0.003 g
Room 1166 SEM Lab	- 0.024 g + 0.021 g	- 0.031 g + 0.033 g	- 0.050 g + 0.037 g	- 0.011 g + 0.008 g	- 0.009 g + 0.008 g
Room 1159 Liq. Chrom. Lab	- 0.017 g + 0.024 g	- 0.032 g + 0.025 g	- 0.020 g + 0.036 g	- 0.028 g + 0.025 g	- 0.022 g + 0.038 g
Penthouse (Upstairs)	- 0.102 g + 0.099 g	- 0.177 g + 0.222 g	- 0.167 g + 0.150 g	- 0.045 g + 0.049 g	- 0.166 g + 0.242 g
Bunker (Outside)	- 0.302 g + 0.356 g	- 0.247 g + 0.227 g	- 0.249 g + 0.204 g	- 0.035 g + 0.043 g	- 0.028 g + 0.025 g

Table 1
Peak Acceleration

	Pad1Test1	Pad2Test2	Pad3Test2	Pad4Test2	Pad5Test2
Assembly Room	Rm 1123 - 4.61 g + 6.82 g	Rm 1123 - 21.33 g + 23.46 g	Rm 1123 - 33.86 g + 45.46 g	Rm 1137 - 27.07 g + 26.00 g	Rm 1137 - 19.90 g + 25.31 g
Adjacent Room	Rm 1113 - 0.273 g + 0.264 g	Rm 1121 - 0.776 g + 0.793 g	Rm 1126 - 5.00 g + 0.759 g	Rm 1133 - 2.41 g + 2.57 g	Rm 1139 - 2.18 g + 1.70 g
Floor 1 inch from firing pad wall	Rm 1113 No Data	Rm 1121 - 15.44 g + 20.73 g	Rm 1126 - 12.20 g + 14.33 g	Rm 1133 - 10.32 g + 9.04 g	Rm 1139 - 17.74 g + 16.63 g

Vibration Frequency Analysis

Frequency information was generated in the form of autospectra (frequency vs. amplitude) plots for each data channel. This provides the necessary information needed to calculate displacement amplitudes to help determine the best locations for vibration sensitive equipment. The 100 Hz cutoff is more than adequate considering any significant displacement in the floors of the building will be well below this frequency. The displacement algorithm used on the autospectra performs a double integration on the data in the frequency domain and normalizes it to the scaling method used in the HP3566A software.

Peaks at 23Hz, 33Hz, 52Hz, and 70Hz were common to most data channels. Other frequencies through the 100 Hz band varied significantly between locations. Areas closest to the firing pads and in the penthouse showed the largest variations. A concentrated effort to correlate structural resonances resulting from the explosive blasts to specific coupling paths will only be performed if some form of vibration suppression is needed to accommodate specific equipment requirements.

Acoustic Test Setup and Results

Industrial hygiene personnel from SNLA recorded sound pressure level measurements during the certification process that resulted in noise levels above $95dB_A$ in some areas of the building. Based on this preliminary data it was decided that a more thorough acoustical survey needed to be performed to better characterize noise problems associated with the firing pads. The primary goal of the acoustic test was to identify the noise paths from the firing pads and recommend possible solutions for noise reduction in these areas. This will hopefully reduce the "startle factor" experienced by facility personnel when blasts are detonated without prior warning. The goal is to be able to perform explosive tests without interrupting all facility personnel by implementing countdowns or other such measures. The test was designed and performed by Stuart Smith, Sandia National Laboratories, and Victor Wowk, Machine Dynamics Inc.

Separate tests were setup in firing pads 8 and 9 using a speaker with a broadband random input as a source. The source was located in the center of the room approximately 3 feet off the floor. Output levels of the speaker in the chambers during the tests were measured in the 95 to 98 dB_A range. Sound pressure level measurements were taken using a GenRad 1565-A sound level meter outside of each firing pad. The results in dB_A amplitude for Pad #9 are shown in Figure 3.

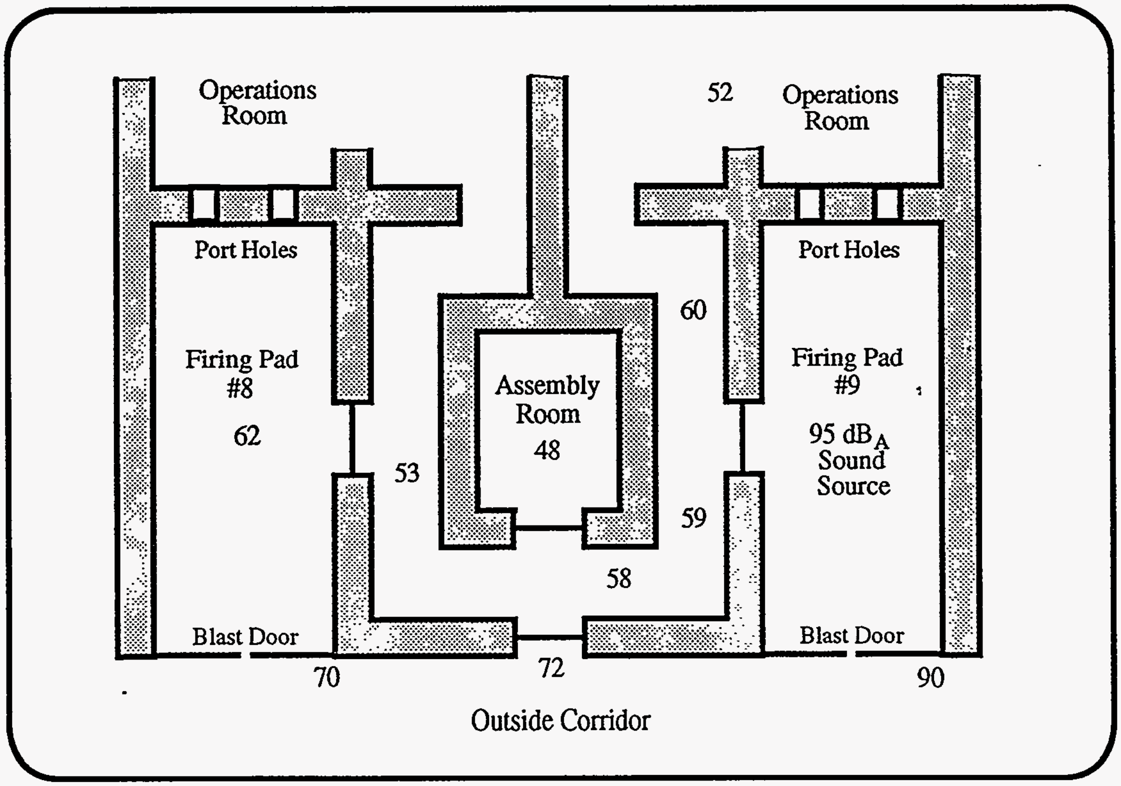


Figure 3
Acoustic Test Noise Levels

The test results indicated a variety of probable noise paths. The primary leakage source is the inner blast and outer blast doors. Methods for sealing around these doors are currently being developed. It was determined the steel plate (3/4 inch) used for the floor, walls, and ceiling at the explosive end of the chamber (see Figure 4) has air pockets in the floor between the plate and the concrete. During an explosion the resonant frequencies of this plate are excited resulting in higher noise levels than normal. Each firing pad has four conduit pipes (four inch diameter) running from inside the firing pad through the concrete floor to the operations room. Resonant frequencies of this conduit are also being excited during the explosive event resulting in higher noise levels.

Some of the simpler modifications were made immediately to see if they had any impact on the noise levels. The conduit sections extending up into the firing pads were cut off at floor level inside the firing pad and reattached with a rubber coupler for vibration isolation. Mufflers were then installed on the operations room end of the conduit to suppress noise levels transmitted through this path. Foam rubber was installed on the inside of the firing pad door panels for additional noise absorbtion. A similar test using a speaker in Pad #9 was repeated with output levels in the 105 dBA range this time. The source levels were purposely increased to ensure a noise floor well above the HVAC (heating, ventilation, air conditioning) environment found in the measurement locations. These simple modifications resulted in no significant reduction of noise in the surrounding rooms. It is still the contention of the personnel performing the acoustic tests that significant reduction levels can be achieved by properly sealing the doors and filling in air pockets under the floors with an epoxy grout type material. Options for implementing these modifications are currently being researched. Figure 4 shows the firing pad configuration with the steel plates and conduit located at one end.

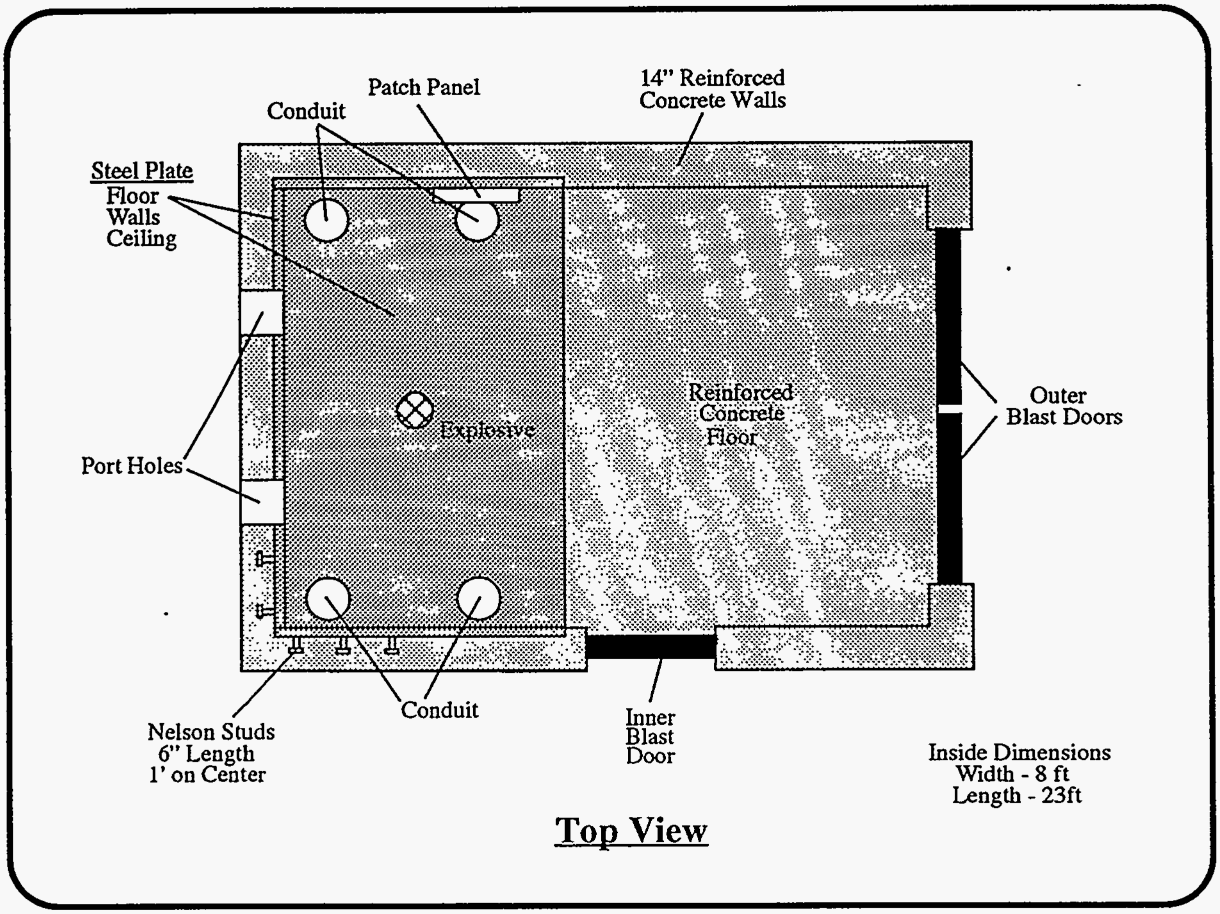


Figure 4
Firing Pad Construction

Current Facility Status

Additional acoustic tests are still being performed in the facility to help reduce noise levels in laboratories closest to the firing pads. The acceleration data has confirmed the benefits of the floor isolation design and is providing reference information to help locate vibration sensitive equipment in the building. The facility is still coming on-line in some areas - normal operation for all test environments is expected to be achieved by December, 1995.

Acknowledgements

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DISCLAIMER