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DNA/NBS/Crane NAD Barrier Tests

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Computer Systems Section
Computer Systems Engineering Division
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Technology
National Bureau of Standards
Washington, D. C. 20234

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Report for Period March 24 – 29, 1974

Prepared for

Defense Nuclear Agency
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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DNA/NBS/CRANE NAD BARRIER TESTS

by

R. T. Moore

1. INTRODUCTION

In discharging its responsibilities for the safety and security of special weapons, the Defense Nuclear Agency has sponsored a series of investigations to develop estimates of the penetration resistance of various barrier materials. In a number of instances these tests have been conducted on specimen panels and slabs or simulated structures which were specially constructed for the purpose of testing penetration resistance. While this report describes the results of further tests of this type, it also includes the results of tests on a high explosives magazine of a type which might be employed for the storage of special weapons.

2. DNA/NBS/CRANE NAD BARRIER TESTS

During the week of March 25, 1974, a series of barrier penetration tests were conducted at the Crane Naval Ammunition Depot, Indiana. The objectives of these tests were threefold:

(1) To obtain additional data on the penetration resistance of four reinforced concrete slabs which had been the subjects of an earlier test series conducted at the U. S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, Illinois in the fall of 1972.

(2) To obtain data on the resistance to penetration offered by a typical high explosives magazine against attacks directed against structural components other than the steel door, and to collect samples of the acoustical, ultrasonic and vibrational disturbances produced by these attacks.

(3) To develop preliminary estimates of the potential utility of chemical deterrents to forced entry through the simulation of pressurized grids of tubes or pipes which could be located inside a protective barrier and arranged to release their contents upon penetration.

3. TESTS ON CONCRETE SLABS

Concrete slabs numbered 3, 4, 5 and 6 were specimens which had been subjects of an earlier test series[1/]. Each was made from reinforced concrete eight inches thick. Slabs 3 and 5 were made with regular concrete, while slabs 4 and 6 were made with fibrous concrete. Slabs 3 and 4 were reinforced with two layers of 6.35 mm (1/4") welded steel mesh ((152.4 mm (6") mesh size)) and slabs 5 and 6 were reinforced with number five bars on 127 mm (5") centers both ways.

During the earlier tests, each of the slabs had been subjected to one or more linear-shaped charges, sizes JA-4 or JA-5. These had produced annular spalling on the outer face of the slab and some cracks on the inner face, but had not been successful in making a complete opening. Ninety-six square inch openings had been made in slabs 5 and 6 by other means, and drilling and burning bar tests had been conducted on slabs 3 and 4.

At Crane NAD, the four slabs were positioned vertically on a firing range and secured in position to short telephone poles on their down-range sides. It was planned to test slabs 3 and 4 using 20 mm projectiles and to use conventional tooling to complete openings in areas damaged by the linear-shaped charges on the other two slabs.

Several single- or double-shot rounds of 20 mm M-95 series APT were fired at slabs 3 and 4. These established that penetration was always complete and accompanied by sizable spalling from the rear surface of the slabs.

1/ Moore, R. T., Penetration Tests of Reinforced Concrete Barriers, NBSIR 73-101, December 1972.

Test 3L1

A relatively undamaged area was selected on slab 3 and marked as a target area. Than a 16 round burst of 20 mm APT was fired from a distance of approximately 150 m . Figure 1 shows the front and figure 2 shows the rear of the slab after this burst. Damage was such that it required only five blows with a sledgehammer to clear away the shattered concrete and expose the reinforcing. This was cut with bolt cutters and in only 0.44 minute working time an opening measuring 348 mm X 292 mm (13-1/2" X 11-1/2") was cleared as shown in figure 3.

Figure 1. 3L1. Slab 3 - front; attack results after 16-round burst of 20 mm APT

Figure 2. 3L1. Slab 3 - rear; attack results after 16-round burst of 20 mm APT

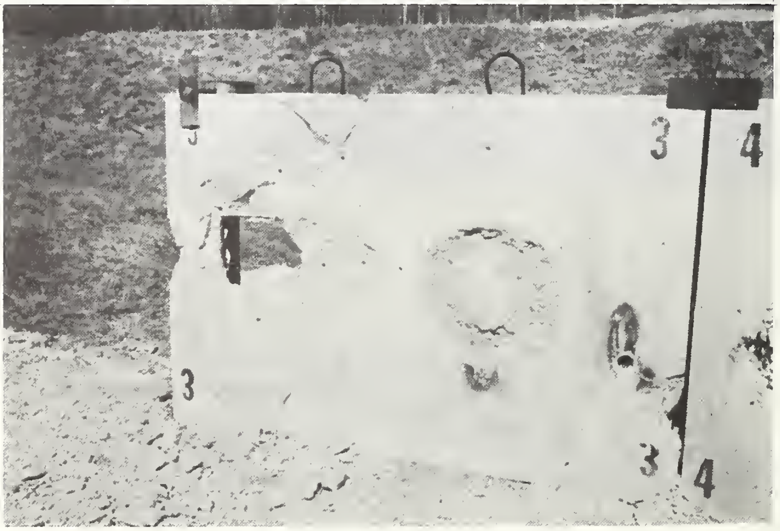

Figure 3. 3L1. Slab 3, front view of completed opening

Test 4L1

As in the preceding test, a target area was selected and then a 17 round burst of the 20 mm APT was fired at this target. Figures 4 and 5 show front and rear views of the resulting damage. The fibrous concrete in this slab was more difficult to clear away and 75 blows were required from a

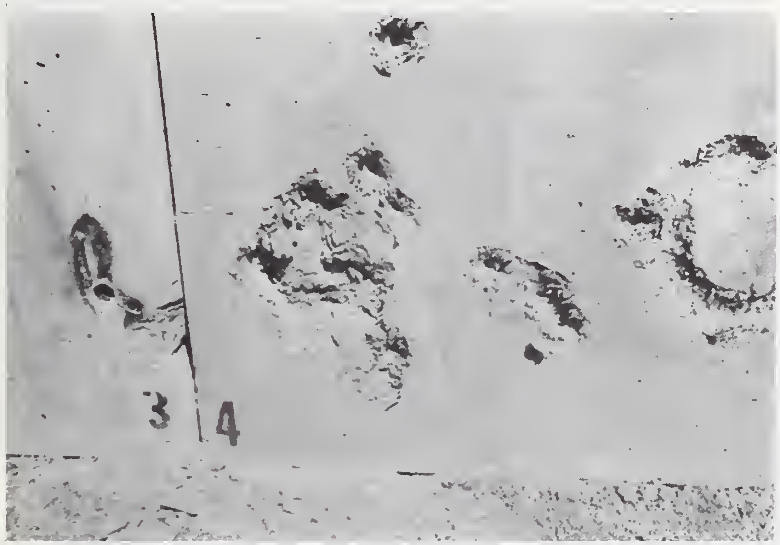

Figure 4. 4L1. Slab 4, front view of results of 17-round burst of 20 mm APT

Figure 5. 4L1. Slab 4, rear view of results of 17-round burst of 20 mm APT

4.5 kg (10-lb.) sledgehammer. These were followed by 15 cuts with bolt cutters which produced an irregular shaped opening of approximately 305 mm X 330 mm (12" X 13"). The total working time was 2.18 minutes. Figure 6 shows the finished opening.

Figure 6. 4L1. Slab 4, completed opening

A further unscheduled test was performed on slab 4. Three rounds of 40 mm HE were launched from a distance of about 75 m against the face of the slab. These exploded on impact leaving only the slight marks shown in figure 7.

Figure 7. 4L1. Slab 4, impact marks from 40 mm HE

Test 5E3

In the earlier test series[1/] on slab 5, a size JA-4 linear-shaped charge had produced a nominal 432 mm annulus of spalling to a depth of about 40 mm. Using a rotohammer, two 19.05 mm (3/4") holes were drilled to a depth of 88.9 mm (2-3/4") from the deepest part of the top and bottom of the annulus. These required 0.58 minute of working time.

1/ Moore, R. T., Penetration Tests of Reinforced Concrete Barriers, NBSIR 73-101, December 1972.

Then, using a bull-point punch and a 4.5 kg sledgehammer, the bottoms of these holes were spalled out with 34 blows delivered in 0.78 minute. This produced a spalled area on the rear surface of the slab that extended to the depth of the centered reinforcing bars over an area approximately 864 mm (34") high and 520 mm (20-1/2") wide. Then, 68 blows with the sledgehammer delivered in 1.05 minutes cleared away the remaining concrete fully exposing the reinforcing as shown in figure 8. Ten cuts with bolt cutters required 2.18 minutes and produced a clear opening approximately 356 mm (14") in diameter. The total working time was 4.60 minutes.

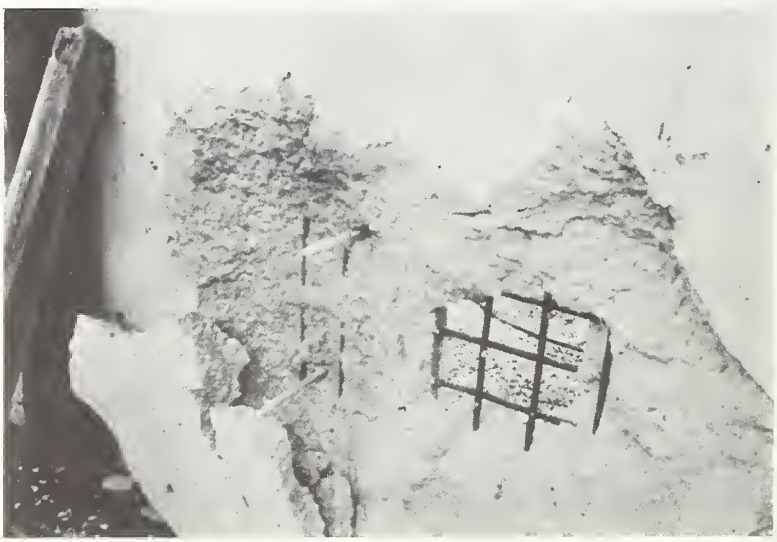

Figure 8. 5E3. Slab 5, rear view after reinforcing was exposed

Test 6E2

On the fibrous concrete of slab 6, an attack similar to test 5E3 was made, but with significantly different results. First it was found that spalling could not be done until a hole had been drilled to within about 51 mm (2") of the rear surface of the slab. Then, the spall itself would invariably be quite small, as shown in figure 9. As a result, it was necessary to drill holes along the bottom of the annulus at intervals of about 127 mm (5") to a depth of 127 mm. These were, in turn, spalled out and then a second series of holes were drilled to a depth of 76 mm (3") around the annulus midway between each of the first series of holes. This hole pattern is shown in figure 10, and figure 11 is a rear view of the slab after these holes had been spalled.

Figure 9. 6E2. Slab 6, rear view showing small spall

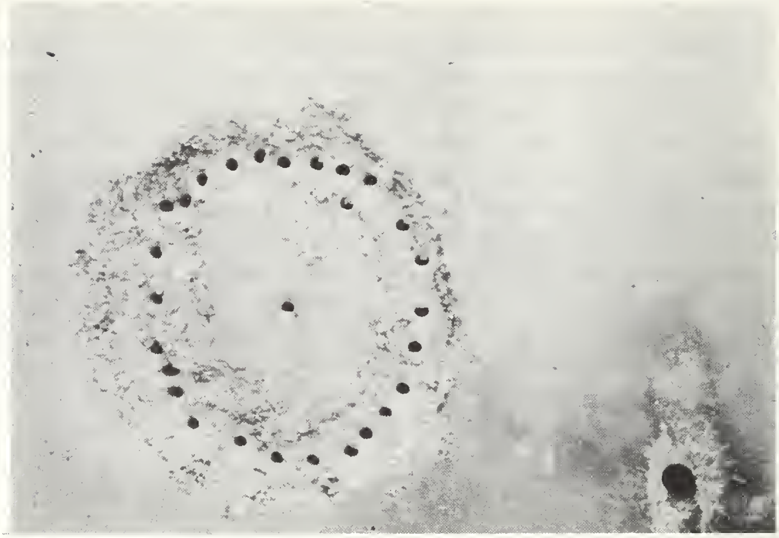

Figure 10. 6E2. Slab 6, front view showing drilling pattern

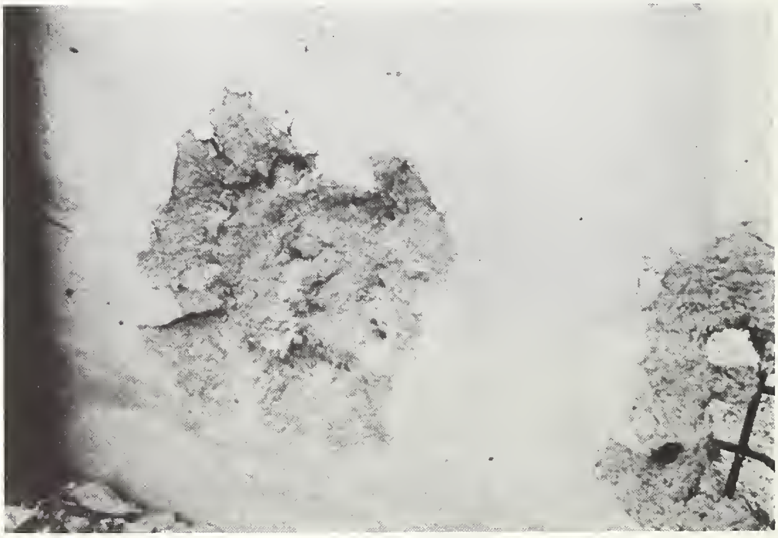

Figure 11. 6E2. Rear view of slab after second set of holes had been spalled

Next, four more holes were drilled partially through the slab near the center of the annulus. These were spalled and then a direct sledgehammer attack eventually produced a small central initial breakthrough. Using a combination of tapered punches and direct sledgehammer attacks, the peripheral holes were enlarged and spalled into the central breakthrough region. It required a total of 44.45 minutes of working time to make the opening shown in figure 12. It is estimated that it would have required at least two more minutes to cut the reinforcing bars with bolt cutters.

Figure 12. 6E2. Slab 6 after 44.45 minutes working time

This attack took maximum advantage of the damage previously produced by the linear-shaped charge. It is estimated that this damage reduced the required working time by about 10 to 15 minutes compared to that which might have been required to make a similar opening in an undamaged slab of this construction.

Fibrous concrete has demonstrated a greater cost-effective potential for use in highly penetration resistant barriers than any other material which has been tested to date by this author[2/,3/,4/].

Drilling Speed Tests

Sample holes were rotohammered in slab 5 to develop additional information on drilling rate as a function of drill size. The results are shown below:

Drill Size	Drilling Rate
19.05 mm (3/4")	2.28 sec./mm (5.8 sec./in.)
22.23 mm (7/8")	2.80 sec./mm (7.1 sec./in.)
31.75 mm (1-1/4")	4.00 sec./mm (10.18 sec./in.)
38.10 mm (1-1/2")	11.8 sec./mm (30.0 sec./in.)

From these data it appears that drilling rate is inversely proportional to the volume of material removed for drill sizes up to about 31.75 mm.

2/ Moore, R. T.; Acoustic, Ultrasonic and Vibrational Disturbances Resulting from the Penetration of Conventional Structural Barriers. NBS Report 10 682, January 1972.

3/ Moore, R. T., Penetration Tests on J-SIIDS Barriers. NBSIR 73-223, June 1973.

4/ Moore, R. T., Barrier Penetration Tests, NBS Technical Note 837, June 1974.

4. TESTS ON A HIGH EXPLOSIVES MAGAZINE

High explosives magazine No. 1421 was made available at Crane NAD as a test site. This magazine is an earth-covered concrete structure having an interior floor 23.77 m (78') long by 7.62 m (25') wide with an arched roof that was 3.38 m (11'1") high at the center. It had a straight ventilator located in the center of the arch near the back of the magazine. The ventilator shaft was 38.1 cm (15") inside diameter and was protected on the bottom by a grating of 6.35 mm (1/4") diameter metal bars spaced on 25.4 mm (1") centers, both ways, and with their ends embedded in the concrete of the arch.

The instrumentation arrangement was essentially as described in references 1, 3 and 4 and included two piezoelectric vibration transducers and a 6.35 mm (1/4") microphone.

Prior to the start of tests, the vibration transducers were attached to the interior of the magazine at the center of the arch; one was located approximately 1 m forward of the ventilator opening and the second was positioned approximately 3.2 m in back of the entrance door. Due to the cool, moist conditions which prevailed, some difficulty was encountered in cementing the transducers in place, and extended use of an electric heat gun was necessary. Apparently these efforts were not completely successful. At the end of the tests when the vibration transducers were removed, it was found that neither was firmly attached to the mountings. as a result, absolutely no confidence can be placed in any of the observed vibrational data. Samples of the observations are included in this report but their validity is extremely doubtful.

The microphone was mounted on a small tripod and positioned inside the magazine near the center of the floor plan. Its outputs, together with those of the vibration transducers, could be selectively displayed as the oscilloscopic output of a real-time spectrum analyzer. This was operated with a 500 Hz bandwidth swept over the frequency range from 0 to 50 kHz at a rate of 5 kHz per 30 ms. The output was logarithmic in amplitude, 10 dB per cm.

Sound pressure levels (SPL) were observed with a handheld meter using a c-weighted filter network. These are reported as values of dBc, together with the distance from the source of the disturbance.

The typical ambient, acoustical level inside the magazine is shown in figure 13. The low frequency peaks around 70 dB were confirmed by SPL readings and resulted from the diesel-powered generator which was used to provide electric power at the test site. A recording of the ambient vibrational disturbances is shown in figure 14.

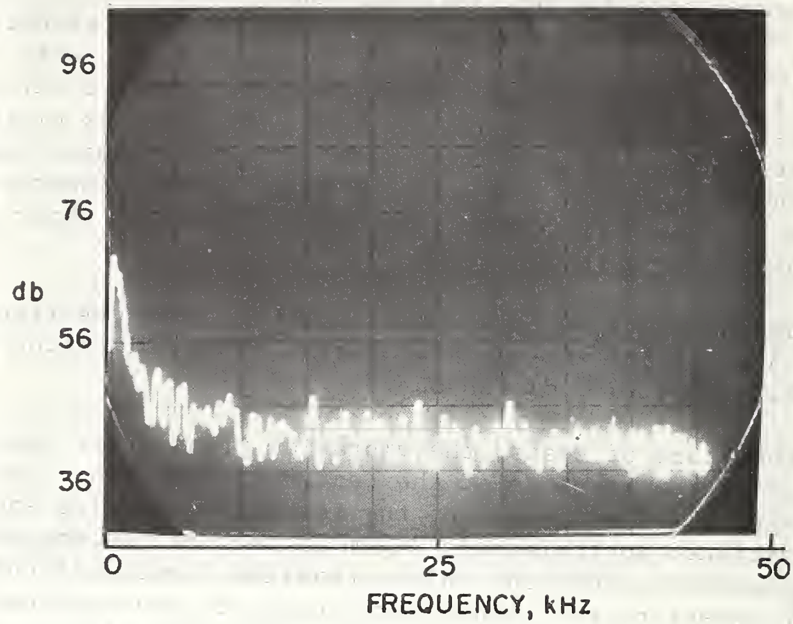

Figure 13. Typical ambient acoustical level inside magazine.

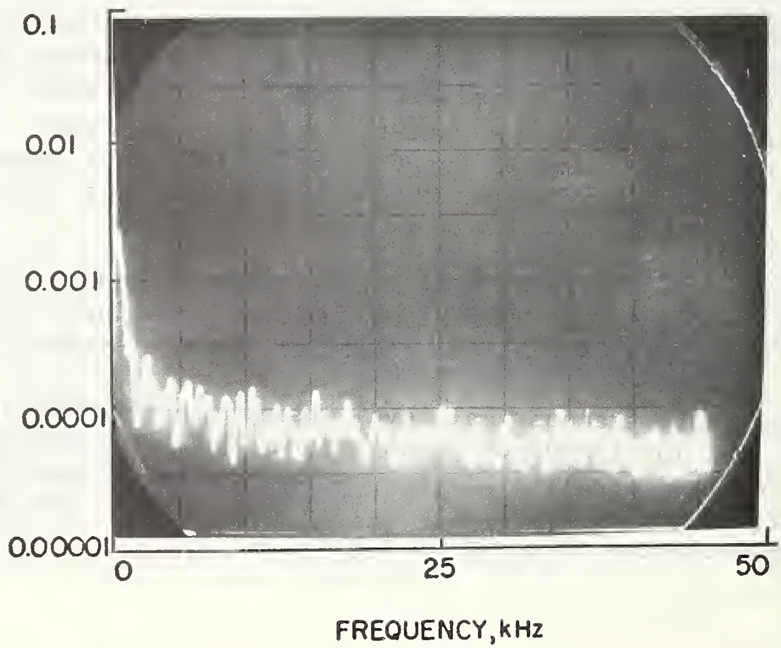

Figure 14. Typical ambient vibrational disturbances

Test 1421X1

The magazine ventilator was an obvious weak spot. The ventilator shaft was large enough to easily admit the passage of a man and was protected only by a rain cover which could be easily lifted off and by the grating of metal bars at its bottom. Since a battering ram, weighing approximately 113 kg (250 lbs.), was available, it was dropped down the ventilator shaft in the hope that it might knock the protective grating completely out of the shaft. If this had occurred, a man-passable opening would have been produced in less than 0.5 minute.

The battering ram broke through the grating bars and made a hole only about half the required diameter(see fig. 15), so the ventilator cover was replaced and the test was restarted using an alternative approach.

Figure 15. Test 1421X1. Interior view of grating

While the ventilator cover was again removed, a burning bar was ignited. The oxygen-acetylene torch used for this was quite small and ignition took 0.97 minute. Then the grating bars were burned away around the interior periphery of the ventilator shaft in 2.28 minutes working time, completing the opening in a total elapsed and working time of 3.25 minutes. Next, water was sprayed down the shaft to cool the burned area and one of the attack team put on air breathing apparatus in preparation for descending into the magazine. The breathing apparatus was necessary because dense smoke filled the interior of the magazine.

The breathing apparatus was jury-rigged. A belt was volunteered by one of the attack team and used to try to strap the pressure regulator of the breathing apparatus in such a position that the semirigid air supply line would not kink the hose between the regulator and breathing mask. When this had been done, the intruder was lowered to the interior floor of the magazine using belaying techniques as shown in figure 16. The bottom was reached after 8.70 minutes of working time and 11 minutes elapsed time.

Figure 16. Test 1421X1. Attacker being lowered through ventilator shaft

The jury-rigged breathing apparatus would not allow the intruder to climb back up and out the ventilator shaft so the magazine doors were opened to permit his exit.

Acoustical disturbances produced by the burning bar are shown in figure 17 and vibrational in figure 18. The latter were from the transducer mounted 1 m from the shaft, and, as previously noted, are of questionable validity.

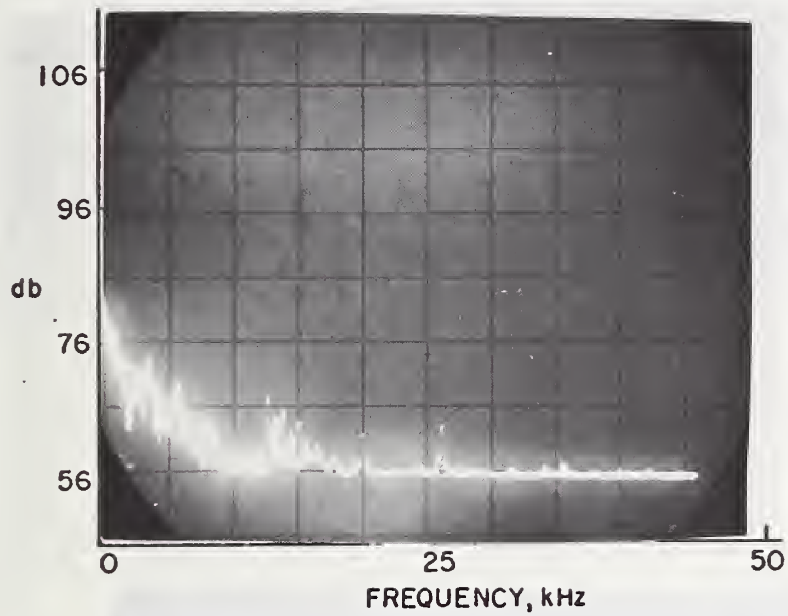

Figure 17. 1421X1. Acoustical disturbances produced by burning bar

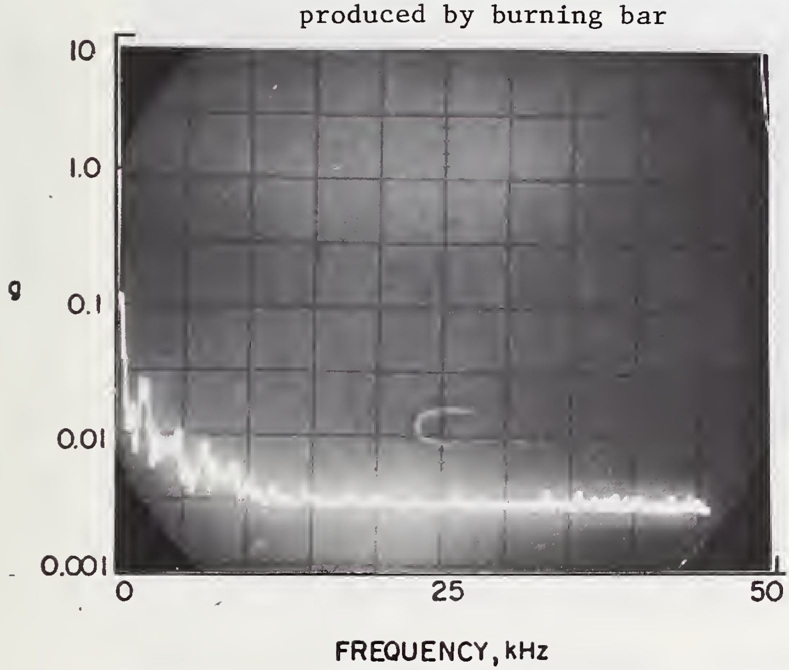

Figure 18. 1421X1. Vibrational disturbances produced by burning bar

After completion of test 1421X1, a grid work of plastic pipes was placed across the interior of the ventilator shaft and connected to a smoke generator. This was to simulate a proposed chemical forced entry deterrent system. The magazine was again closed and the pipe grids were cut with the burning bar. Smoke poured out of the ventilator, as shown in figure 19, and the interior of the magazine was filled with dense smoke. When the doors of the magazine were opened, it was several minutes before there was sufficient visibility to even find the fans which had been placed inside to facilitate forced ventilation and smoke removal. After they had finally been located and turned on, it took nearly half an hour to clear the magazine of smoke. It is believed that unless an invader had been trained to perform his mission in total darkness he could not have functioned in the environment of a closed magazine filled with such dense smoke even using breathing apparatus and portable lights.

Figure 19. Test 1421X1. Smoke from ventilator after burning grid

Test 1421N2

The site selected for this test was at the top of the earth-covered arch, approximately 10 meters from the door of the magazine.

A four-man attack team began shoveling away the moist, grassy fill. It took approximately 175 shovels full and 4.02 minutes working time to clear an area approximately 0.5 m in diameter on the membrane and extending out on one of the sloping sides of the arch, enough to provide room to operate a sledgehammer. The earth fill over the arch ranged in depth from 0.79 m(31") to 0.91 m(36") and the top of the hole was approximately 1.0 m wide and 2.0 m long. Shoveling produced SPL of 70 to 86 dBc at a distance of approximately 3.0 m. No disturbances above the ambient background were recorded from the transducers inside the magazine.

Using a template developed during the course of prior test series, a pattern of 14 holes was marked to outline a circular target area approximately 30.5 cm (12") in diameter. The marked locations were drilled 7.62 cm (3") deep with a 19.05 mm (3/4") drill in 2.98 minutes. This produced SPL readings of 78 to 85 dBc at a distance of approximately 3.0 m on the outside and acoustical disturbances as shown in figure 20 inside the magazine. Questionable data from a vibrational transducer located 6.1 m (20') from the attack point is shown in figure 21. This figure shows an uncharacteristic absence of high-frequency components of vibration from the rotohammering.

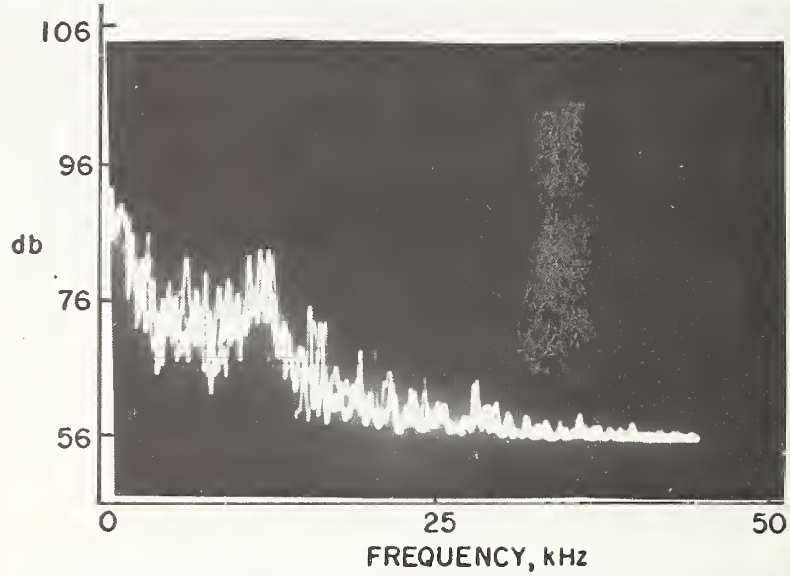

Figure 20. 1421N2. Acoustical disturbances produced inside magazine by rotohammer

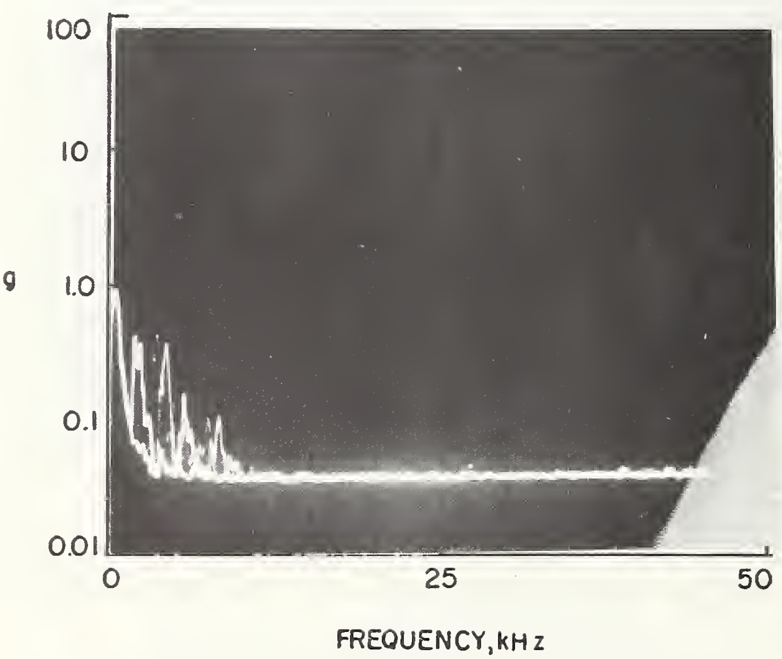

Figure 21. 1421N2. Vibrational disturbances from rotohammer

A bull-point punch was inserted in one of the drilled holes and 1.62 minutes of working time was expended in an unsuccessful attempt to spall out the bottom of the hole. The sledgehammering produced sound pressure levels of 78 to 95 dBc on the outside of the magazine at a distance of 3.0 m and 95 to 104 dBc inside the magazine at a similar distance from the attack point. Spectra of the acoustical and questionable vibrational disturbances are shown in figures 22 and 23.

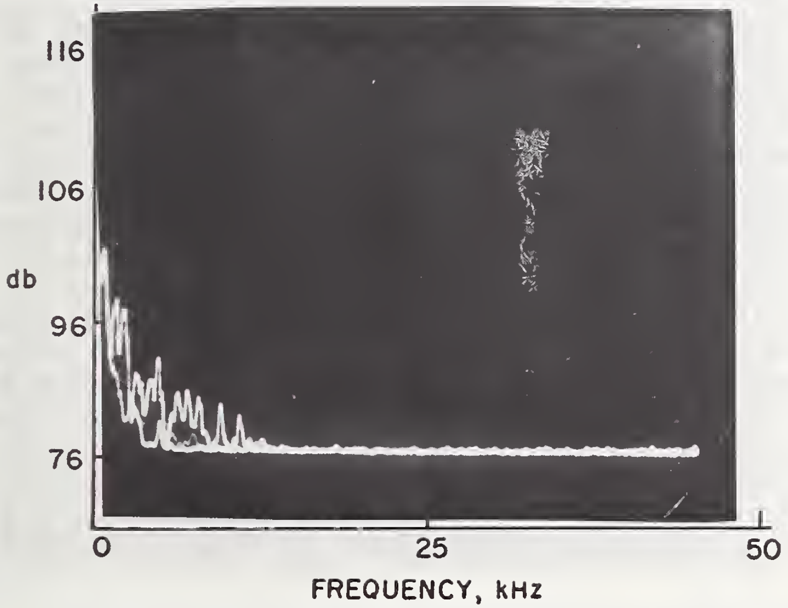

Figure 22. 1421N2. Acoustical disturbances produced by spalling

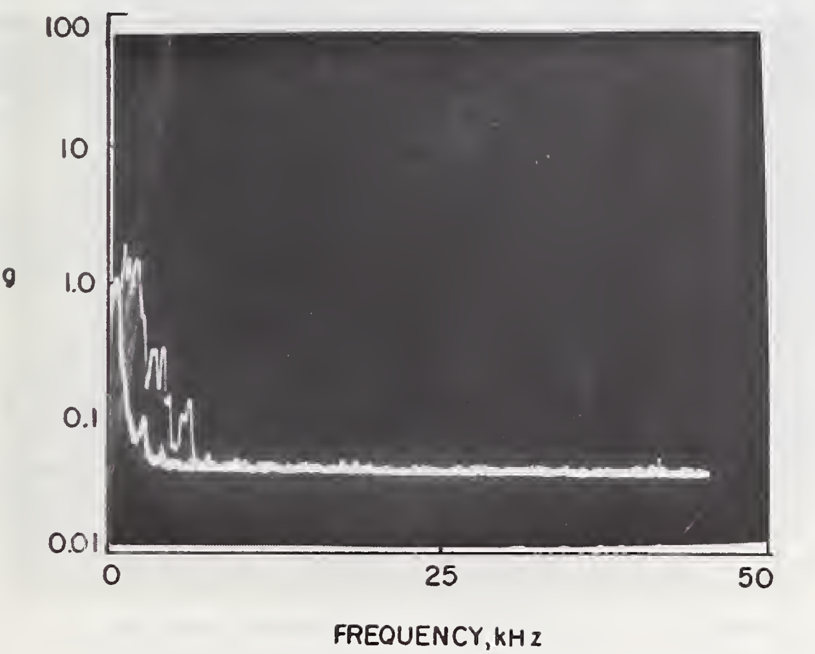

Figure 23. 1421N2. Vibrational disturbances produced by spalling

Failure to spall out the first hole suggested that the thickness of the concrete arch might be greater than the six inches shown on the drawings, so one of the holes was deepened to 12.7 cm (5") in 0.38 minute working time and this hole was spalled out in only 0.22 minute. The clocks were stopped and the thickness of the concrete was measured and found to be 20.3 cm (8").

When the attack resumed, the holes were enlarged to 22.2 mm (7/8") to provide better clearance for the bull-point punches as mud and concrete dust was getting back into the drilled holes. Alternate holes were also deepened to 12.7 cm (5"). These drilling activities took 3.13 minutes working time. The six deep holes were then spalled out in 1.18 minutes working time and 4.42 minutes additional working time was spent spalling out the shallower holes. It was necessary to clean the debris out of each hole with the rotohammer immediately before inserting the bull-point punch.

After the spalling had been completed, the remaining shell of concrete was knocked out in 3.25 minutes of direct attack with a sledgehammer and the reinforcing wires were cut in 0.63 minute using bolt cutters. The completed opening is shown in figure 24. The total working time was 21.83 minutes and the elapsed time 23.12 minutes.

Figure 24. Test 1421N2. Completed opening

It is believed that this penetration time was significantly lengthened by two factors. First, it was necessary to use two models of rotohammers. The drill bits for the heavy duty (and faster) model were not long enough for the required hole depths. Thus, it was necessary to switch to the lighter (and slower) model to finish out the holes. Secondly, the problem of debris clogging the holes was not adequately anticipated. This difficulty could have been avoided by simply reordering the attack plan and spalling out each hole as soon as it was drilled rather than doing all of the drilling prior to spalling. This would have prevented the concrete dust and mud from getting back into and clogging one hole while the next was being drilled.

In addition, at least two or three minutes were required to accommodate features of the magazine which were not in accordance with the design drawings. The thickness of both the overburden and the concrete arch were greater than expected. Taking all these factors into consideration, it is not unreasonable to expect that a penetration time on the order of 15 minutes working time could be realized.

Test 1421W3

The site selected for this test was on the top of the arch, approximately 7.62 m (25') from the entrance of the magazine. A grid-work of plastic piping was attached to the interior of the arch and connected to a water pump to simulate a forced entry deterrent system employing a liquid agent. Transducer locations were unchanged.

As in the preceding test, the four-man attack team shoveled away the overburden to provide a clear area on top of the arch approximately 60.9 cm (2') wide and 121.8 cm (4') long. This was somewhat larger than the hole made for test 1421W2 and required 7.15 minutes working time and 233 shovels full of earth.

There appeared to be a crack in the exposed concrete surface of the arch, so, on the off chance that it might go through, the 113 kg (250 lb.) battering ram was dropped three times from a height of about 76 cm (30"). No damage resulted.

A gasoline-powered clipper saw, equipped with a water-lubricated diamond blade, was then placed in the hole and two parallel cuts were made. These were about 56 cm (22") long, 11.4 cm (4-1/2") deep and 20 cm (8") apart. These required 7.66 minutes working time and produced the acoustical disturbances shown in figure 25 and the questionable vibrational disturbances of figure 26.

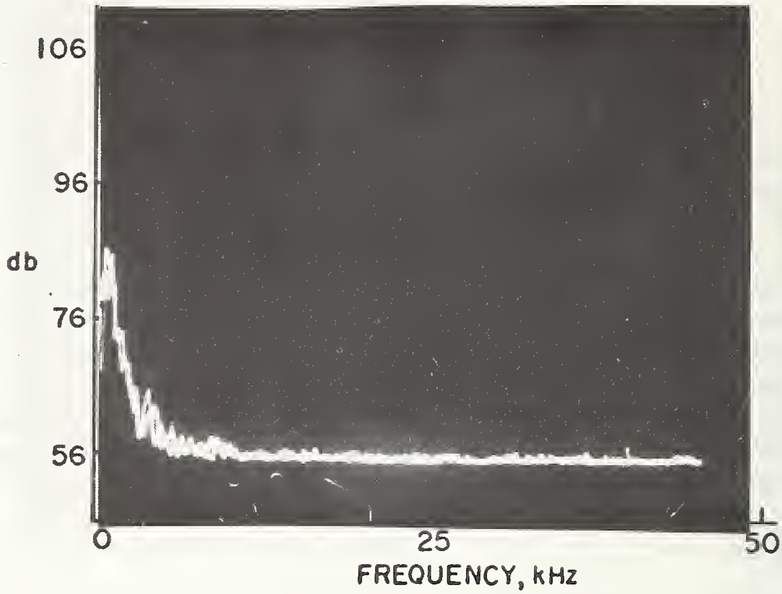

Figure 25. Test 1421W3. Acoustical disturbances produced by clipper saw

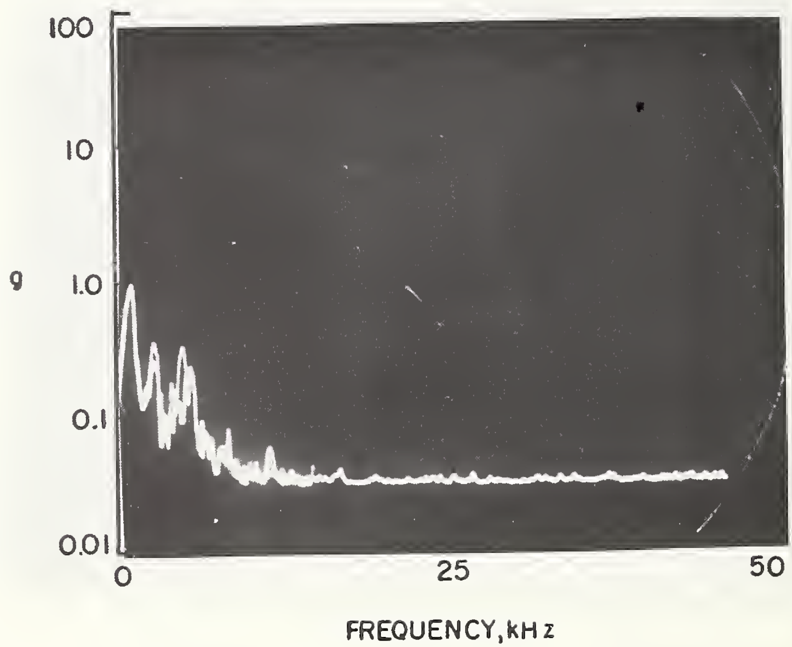

Figure 26. Test 1421W3. Vibrational disturbances produced by clipper saw

Then the battering ram was dropped 11 times in the area between the two cuts without useful results. The acoustical disturbance produced by the ram is shown in figure 27. The 11 drops required 1.35 minutes working time.

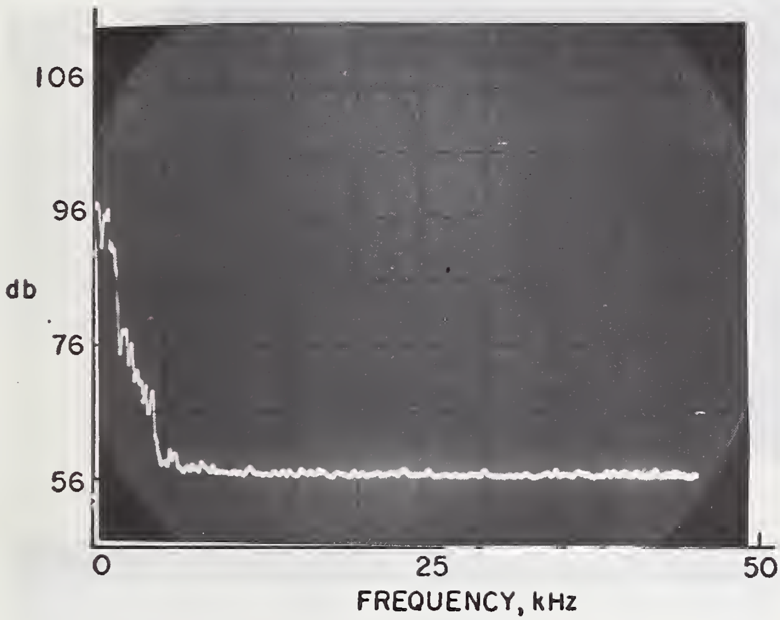

Figure 27. Test 1421W3. Acoustical disturbances produced by battering ram

Next, four holes 22.2 mm (7/8") in diameter were drilled to a depth of 11.43 cm (4-1/2") in a row extending between the two slits near their midpoint. This required 1.42 minutes and produced the acoustical disturbances shown in figure 28 and the questionable vibrational disturbances shown in figure 29.

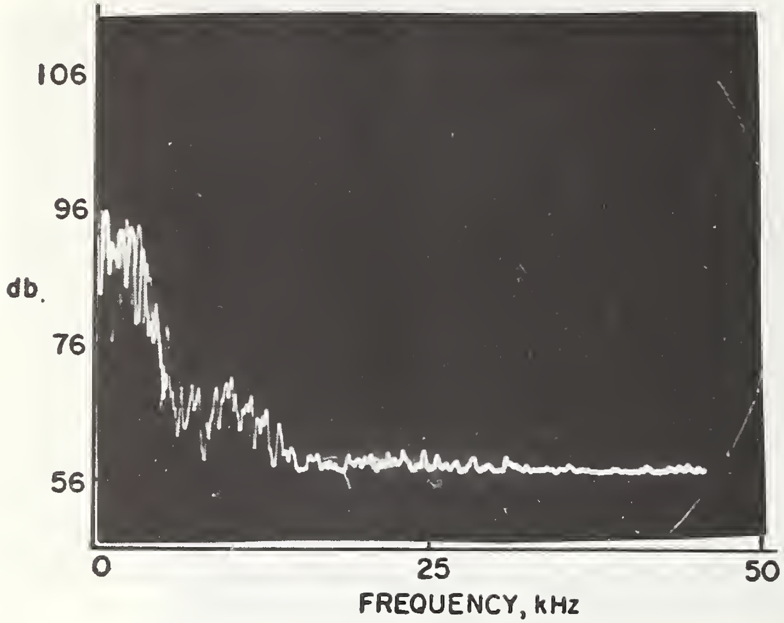

Figure 28. Test 1421W3. Acoustical disturbances from drilling

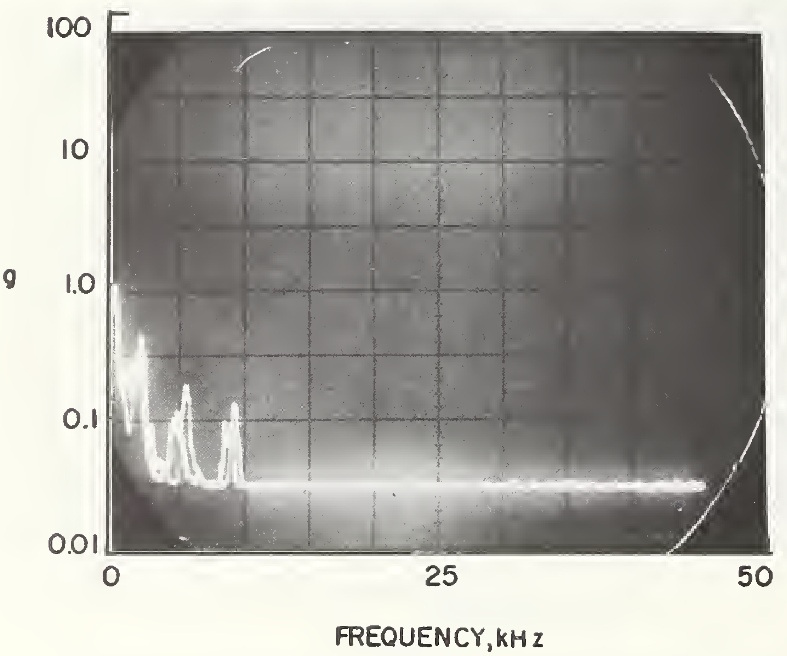

Figure 29. Test 1421W3. Vibrational disturbances from drilling

The battering ram was then dropped 20 times on the weakened area and again was ineffective. This required 1.50 minutes working time. It was clear that additional drilling and spalling would be necessary to complete this penetration, so a single 12.7 cm (5") deep hole and two 7.62 cm (3") deep holes were drilled in a row at each end of the pair of slits. The drilling was completed in 2.16 minutes working time. One of the deeper holes was spalled out using a bull-point punch and sledgehammer in 0.83 minute, but 0.85 minute later, while working on the next hole, the handle of the last sledgehammer was broken. Testing was suspended for the day with 22.92 minutes of working time.

The following day, the testing was resumed with a fresh supply of sledgehammer handles. The 7.62 cm (3") deep holes were extended to 12.7 cm (5") in depth and were spalled out in 3.95 minutes. On several occasions, punches came through the concrete in positions which threatened to penetrate the pipe grid work attached to the interior of the arch but in each instance the grid was merely bowed or deflected as shown in figure 30.

Figure 30. Test 1421W3. Interior grid work showing slight bowing

The ram was again dropped seven times without useful effects. This took an additional 0.80 minute.

Next, three equally spaced holes were drilled along each of the slits to a depth of 12.7 cm (5"). Each of these holes was spalled immediately after being drilled. The working time was 3.32 minutes.

Again the battering ram was dropped, and, on the tenth drop, after a working time of 1.17 minutes, about half of the concrete broke through. Then, 0.42 minute work with the sledgehammer cleared an opening 20.3 cm (8") wide and 54.6 cm (21-1/2") long. In the process, the pipe grid did not rupture but was torn loose from its hangars on one side and hung vertically as shown in figure 31. A final 0.57 minute of work with bolt cutters cleared the remaining reinforcing wires, completing the opening in a total working time of 33.15 minutes.

Figure 31. Test 1421W3. Unruptured pipe grid hanging loose from one side

After completion of the test, the pipe grid was reattached under the opening and cut with bolt cutters. The pressurized water flowed from the cut section into the interior of the magazine but did not spray up or wet the attack team.

5. CONCLUSIONS

The penetration tests conducted on magazine 1421 required somewhat greater working times than could be achieved by a skilled and well rehearsed attack team using optimum penetration techniques. While no tests were made of the magazine door, its vulnerability was judged to be considerably greater than that of the straight-through ventilator. It could probably have been opened in less than a minute.

The isolated location of this magazine and the infrequency of traffic in this portion of the Depot could be expected to greatly facilitate the opportunity for covert penetration. Even with the installation of intrusion detection sensors, it appears likely that the travel times required to respond to an alarm would preclude the maintenance of a high level of security at this site.

The simulation of Chemical Forced Entry Deterrent Systems (FEDS) did not provide conclusive results of their potential. They definitely show promise, however, and further research, development, test and evaluation of this concept is strongly recommended. There is little doubt that they can add to the time required to penetrate and/or operate within a protected enclosure, such as a magazine, if by no other mechanism than reducing visibility to virtually zero for a few minutes. Even with protective clothing and breathing equipment, an intruder would not be able to operate effectively within the magazine for this time interval.

They also offer an as yet unknown potential for an additional level of intrusion detection in the event that conventional sensors were defeated or disabled by a skilled attack team. This could come about through the inclusion in the FEDS materials of some component which could be readily detected at very low concentrations. Sensors surrounding the protected area, but at an appreciable distance from it, might be responsive to the release of the FEDS materials. This, together with knowledge of wind conditions, might provide a vector to the target under attack, and/or to the exit route taken by a successful penetration team. Such an array of sensors might be interconnected to a small computer which is also integrated with both the conventional intrusion sensor systems and the security communications systems to provide an enhanced level of security for special ammunition storage sites. Further study and investigation of this conceptual configuration is recommended.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

In discharging its responsibilities for the safety and security of special weapons, the Defense Nuclear Agency has sponsored a series of investigations to develop estimates of the penetration resistance of various barrier materials. In a number of instances these tests have been conducted on specimen panels and slabs or simulated structures which were specially constructed for the purpose of testing penetration resistance. While this report describes the results of further tests of this type, it also includes the results of tests on a high explosives magazine of a type which might be employed for the storage of special weapons.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Barrier penetration; intrusion resistance; physical security.

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