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Surface-Concrete Decontamination Equipment Developed by Pacific Northwest Laboratory

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August 1982

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SURFACE CONCRETE DECONTAMINATION EQUIPMENT
DEVELOPED BY PACIFIC NORTHWEST LABORATORY

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SUMMARY

A major problem associated with nuclear facility decontamination and decommissioning is how to economically demolish and dispose of contaminated concrete. Removing only the contaminated portion of the concrete can substantially reduce costs. Evaluation of various methods for removing concrete surfaces shows that several techniques presently used require excessive manpower, time, and energy. Many times more material is removed than necessary, increasing the quantity of waste that must be handled under controlled conditions. These evaluations generated the basic criteria for developing a suitable concrete removal technique:

- Provide a convenient method for cleaning surfaces (such as those contaminated by a small spill).
- Reduce the contaminated waste volume that has to be placed into controlled storage.
- Remove surfaces quickly.
- Minimize personal exposure to potentially harmful radiation or toxic materials.

Removal of 1/4 to 1/2 in. of contaminated surface layer is sufficient for cleanup of most facilities.

Two unique decontamination methods have been developed at the Pacific Northwest Laboratory (PNL): the concrete spaller and the water cannon. The concrete spaller removes concrete by exerting radial pressure against the sides of a shallow, cylindrical hole (~2 in. deep x 1 in. dia) drilled into the surface. Two operators using a platform model can remove approximately 100 ft² of concrete surface in an hour. An air-powered rotary hammer mounted on a track drills the holes while an operator follows with the hand-held spaller. A vacuum system removes the drilling dust to prevent the spread of contamination. The platform is designed to be handled by most forklifts available today. It is fast and convenient, and the rubble produced is moderately sized for easy handling.

Two types of water cannons were tested: a high-speed (rapid-fire) water jet and a modified .458 magnum rifle. It was thought that the high-speed jet would have a distinct advantage over the modified rifle, but because of its weight and size it had to be mounted on a backhoe, which resulted in very slow positioning times.

The .458 magnum water cannon fires a small glycerine stick that is formed into a high-velocity stream by a nozzle mounted at the barrel's end. Two operators, one loading the glycerine charges and the other firing the cannon, can remove 9.5 ft^2 of concrete surface in an hour. The total cost of using the .458 magnum water cannon was estimated as about $\$17.75/\text{ft}^2$ of concrete surface. The unit is compact, making it easy to handle, and useful on small surfaces in confined areas. Also, the glycerine tends to capture or encapsulate the dust, preventing most airborne contamination.

The concrete spaller is the most efficient technique: it removes the concrete surface faster than the water cannons and at a lower cost (as little as $\$3.00/\text{ft}^2$ of concrete surface). However, the .458 magnum water cannon may be well suited for small or hard-to-reach locations.

CONTENTS

SUMMARY	iii
INTRODUCTION	1
COMPARISON OF CONCRETE REMOVAL TECHNIQUES	3
WATER CANNON	7
.458 MAGNUM WATER CANNON	7
RAPID-FIRE WATER CANNON	8
CONCRETE SPALLER	13
TEST 1	16
TEST 2	19
TEST 3	22
TEST 4	22
TEST 5	24
REMOVAL RATE FOR AN 8-HOUR WORK SHIFT	26
CONCLUSIONS	28
WATER CANNON	28
CONCRETE SPALLER	28
REFERENCES	30
APPENDIX A - .458 MAGNUM WATER CANNON TEST SETUP AND RESULTS	A.1
APPENDIX B - EQUIPMENT OPERATING COST ESTIMATES	B.1
APPENDIX C - CONCRETE SPALLER BIT AND PUSH ROD DRAWING	C.1
APPENDIX D - CONCRETE SPALLER DATA PACKAGE LISTING	D.1

FIGURES

1	Impactor Mounted on a Backhoe Linkage	5
2	A Concrete Slab with Part of the Surface Removed by High-Pressure Water Jets	6
3	.458 Magnum Water Cannon Schematic	7
4	A Typical Water Cannon Spall	9
5	One Square Foot of Surface Removed by the Water Cannon	9
6	.458 Magnum Water Cannon Being Operated Without Vacuum	10
7	Schematic of Rapid-Fire Water Cannon	11
8	Water Cannon Mounted on a Backhoe Linkage	11
9	Concrete Spaller Schematic	13
10	Concrete Spaller Bit Ready to be Inserted into a Hole	15
11	Concrete Spaller Bit Expanded	15
12	Concrete Spaller Being Used	17
13	Spall Made by Concrete Spaller	17
14	Concrete Spaller Next to Spalled Test Panel	18
15	Spalling Done Around Rebar	18
16	Manually Positioned Air Drill	19
17	Manually Positioned Drill and Spaller in Operation	20
18	Concrete Spaller Supported by Elastic Cord	21
19	Motor-Actuated Air Drill	23
20	Automated Air Drill in Operation	23
21	Concrete Spaller in Operation	24
22	Control Module Used to Position the Drill	25
23	Motor-Actuated Air Drill with Limit Switches	25

24	Forklift-Mounted Drilling and Spalling Platform	26
C.1	Spaller Bit and Push Rod Drawing	C.1

TABLES

1	Comparison of Various Concrete Surface Removal Techniques	4
B.1	Cost Comparison of Water Cannon and the Two Concrete Spaller Systems for One 8-Hour Shift	B.2

INTRODUCTION

The concrete surfaces of many nuclear facilities have become contaminated with radioactive particles because of accidental spills or releases of vapors and fine particles. During the decontamination of these facilities it is desirable to remove only the portion of the concrete wall, floor, or ceiling that is contaminated, thereby reducing the quantity of contaminated rubble which must be handled and placed in controlled storage.

In some past decontamination operations all of the concrete contained behind a contaminated surface was treated as contaminated and placed in controlled storage. This was done because it was faster than removing only the concrete surface. However, the high cost of storage today requires that economical methods be developed and used for removing the contaminated material. This allows the remaining concrete to be removed and disposed of as is done with other noncontaminated concrete.

This report documents a project that the Pacific Northwest Laboratory (PNL) conducted to identify and develop techniques for removing contaminated concrete surfaces. The criteria used in selecting good techniques were:

- Provide a convenient method for cleaning surfaces (such as those contaminated by a small spill).
- Reduce the contaminated waste volume that has to be placed into controlled storage.
- Remove surfaces quickly.
- Minimize personal exposure to potentially harmful radiation or toxic materials.

Removal of 1/4 to 1/2 in. of contaminated surface layer is sufficient for cleanup of most facilities.

Two unique concrete surface decontamination techniques were investigated by PNL: the water cannon and the concrete spaller. Two versions of the water cannon were evaluated: 1) a hand-held rifle model that actually fires sticks of glycerine and 2) a rapid-fire water jet designed to be mounted on a backhoe.

Publications describing the PNL decontamination techniques were prepared while the work was in progress and were presented at three workshops and conferences (Halter and Sullivan 1979; 1980; 1981). One of the workshops, which was held in Seattle in May 1980, was devoted entirely to concrete decontamination (Currie 1980).

This report summarizes all of the data gathered to date. The information presented here will enable a potential user to decide if the equipment will be adequate for a particular decontamination job. A brief comparison of various surface removal techniques is first presented to illustrate the advantages of the PNL-developed equipment. Following this comparison are subsequent sections that describe the equipment, show how the equipment is used, and report the performance of the equipment observed during field tests. Conclusions about the performance of the water cannon and concrete spaller are given in the last section. Estimates of operating costs are detailed in an appendix.

COMPARISON OF CONCRETE REMOVAL TECHNIQUES

A comparison of various surface removal techniques along with the methods developed at PNL is presented in Table 1. In addition to the concrete spaller and the water cannon, the techniques include sand blasting, dry ice blasting, flame spalling, explosives, jack hammers, impactors, and scrubbers.

Sand blasting is a technique that is used to remove some surface contamination. It is effective only if the contamination is right on the surface, and it is a slow technique. The sand blasting medium becomes contaminated and so adds to the material needing to be placed in controlled storage. A blasting technique using dry ice pellets has been evaluated, but this technique was found to be even slower than sand blasting.

Flame spalling has not been tried because handling the by-products of combustion, which may be contaminated, is potentially more difficult. Explosives are a useful method which have been used to remove surfaces. Although the technique is fast, the structures need to be sturdy. Consideration must be made to handle the blast-produced dust, debris, toxic gases, and overpressures. Also, explosives experts are needed (Anderson 1980).

Jackhammers are fairly effective but are awkward to use on walls and ceilings and in tight, constrained areas. An impactor, a large jackhammer-like device which must be mounted on a backhoe, is limited to large, accessible areas. Operators can easily remove complete walls but find it difficult to remove only a 1/4 to 1/2 in. of the surface layer. Figure 1 shows an impactor in operation.

The scrubber, or scabbler, works well on floors but is slow by comparison to other techniques. In its present configuration the scrubber would be difficult to use on walls and ceilings.

A technique using very-high-pressure water jets is fast, removing 4 to 6 ft² per minute. In tests conducted on noncontaminated concrete for PNL by Flow Technology Company (Flow Technology Company 1981) the technique worked well with the following results:

TABLE 1. Comparison of Various Concrete Surface Removal Techniques

Technique	Limitation	Estimated Relative Speed with Which a Unit of Surface Area Can Be Removed
Sand Blasting	Grit Adds to the Contamination	Slow
Dry Ice Blasting	Very Slow Penetration	Slow
Flame Spalling	Heat May Cause Undesirable Chemical Reactions	Slow
Explosives	Generates Moderate Quantities of Dust which Must be Controlled	Fast
Jack Hammer	Awkward to Use on Walls	Medium Fast
Impactor Powered by Air or Hydraulics	Limited to Large Accessible Facilities	Fast
Scrubber	Awkward to Use on Walls	Slow
Water Cannon		
Handheld Modified	Gun Powder Combustion	Slow (5-6 min/ft ²)
.458 Magnum Rifle	Products are Produced	
Rapid-Fire Model	Limited to Large Accessible Facilities	Slow (3-4 min/ft ²)
Concrete Spaller with 38-Pound Air Drill to Make Holes		
Handheld		Medium Fast (50-60 sec/ft ²)
Semi-Automated on Platform		Medium Fast (35-40 sec/ft ²)
High-Pressure Water (30,000 to 60,000 psi)	May Produce Contaminated Water	Fast (10-15 sec/ft ²)

Source: Halter and Sullivan (1981)

FIGURE 1. Impactor Mounted on a Backhoe Linkage

1. The technique uses one gallon of water to remove 2 ft² of concrete surface. It is possible to filter out insoluble particulates and reuse the water.
2. A vacuum system is capable of collecting the concrete cuttings and used water. The contaminated concrete cuttings can be filtered out of the water and loaded into drums.
3. The technique lends itself to incorporation into concrete surface removal equipment that can be used on floors, walls, and ceilings.

The reused water may become contaminated with soluble compounds and thus recontaminate the surface being cleaned. This technique needs testing and additional development before it can be applied. Figure 2 shows a sample of concrete with the surface removed by high pressure water jets.

FIGURE 2. A Concrete Slab with Part of the Surface Removed by High-Pressure Water Jets

WATER CANNON

The water cannon removes surfaces by shooting very-high-pressure jets of liquid at the surface, causing it to spall (Exotech Incorporated 1975). The most desirable feature of the method is that no surface preparation is required.

Two versions of water cannons were evaluated^(a). One was a .458 magnum rifle which was fairly slow, requiring 5 to 6 minutes to remove 1 ft² of concrete surface. The second water cannon was a rapid-fire model capable of firing 4 to 5 shots per second.

.458 MAGNUM WATER CANNON

Figure 3 shows the .458 magnum water cannon in schematic form. A .458 magnum rifle was modified to shoot a high-velocity glycerine jet. The gun barrel was shortened, and a nozzle was attached to the end. Cartridge cases are primed and filled with gun powder, and a wax plug is added to retain the powder. Solidified glycerine sticks (2 in. long x 1/2 in. in dia) are

FIGURE 3. .458 Magnum Water Cannon Schematic

(a) Both concepts are patented by Exotech Incorporated.

fitted into the loaded cases. The altered cartridges are then chambered and shot. The glycerine is formed by the nozzle into a high-velocity stream which spalls the concrete surface on contact. The wax plug provides a seal between the burning gun powder and the glycerine. Each cartridge casing can be reused approximately ten times. A shield to which a vacuum system can be attached is placed around the nozzle to collect the by-products of combustion and the rubble.

A letter report prepared by Exotech, the water cannon developer, describes the construction and the use of the unit. This report is contained in Appendix A.

During May and June of 1978, tests of the water cannon were conducted on the concrete sides of the 1608F building located next to the 105F reactor building in 100F Area of the Hanford Reservation.

The .458 magnum water cannon typically made 2- to 3-in.-dia spalls as shown in Figure 4. The spalls were about $3/4$ in. deep at the center. Figure 5 shows a 1-ft^2 sample wall which was spalled in about 6 minutes using 24 shots. The darker area around the spall was due to the combustion products mixing with the glycerine. One cubic foot of concrete rubble is generated for every 24 ft^2 of surface removed. The glycerine coats the dust, preventing most airborne dust contamination. The compactness of the unit makes it useful for small areas and confined spaces. Figure 6 shows the .458 magnum water cannon being used.

The water cannon was capable of removing approximately 58 ft^2 of surface over an 8-hour shift. This was based on an average of 25 cannon shots to remove 1 ft^2 of concrete surface, four shots per minute, and a working team of two men actually using the water cannon for 6 hours of each 8-hour shift. One man loads the cases with the glycerine charges and passes the cartridges while the other man fires the cannon. Material and labor costs are estimated in Appendix B.

RAPID-FIRE WATER CANNON

The rapid-fire water cannon is conceptually different from the rifle water cannon. Instead of using gun powder to propel the glycerine, compressed gas

FIGURE 4. A Typical Water Cannon Spall

FIGURE 5. One Square Foot of Surface Removed by the Water Cannon

FIGURE 6. .458 Magnum Water Cannon Being
Operated Without Vacuum

is used to force a piston which impacts a small amount of water, projecting the water to the concrete surface. Figure 7 shows a schematic of the rapid-fire cannon.

The unit itself is cylindrical, approximately 25 in. tall, and 9 in. in diameter. The unit and a water pump mount on a backhoe, replacing the bucket. The nozzle of the cannon is positioned perpendicular to the concrete surface before firing.

The water cannon is powered by a hydraulic impactor. The force of the impactor compresses nitrogen gas. The nitrogen is then released at the right time to propel the piston, which forces the water out the nozzle. The water cannon is fastened directly to the end of the impactor where the tools would normally be attached. Figure 8 illustrates a rapid-fire water cannon being used.

The results of a water cannon test conducted by Exotech Incorporated are as follows:

1. Each "shot" removes approximately 4 in.².
2. Rubble varied from 1/8 to 1/2 in. diameter. Some pieces were as large as 1 in. x 1 in. x 1/4 in.

1. TARGET
2. JET
3. HIGH PRESSURE HEAD WITH NOZZLE
4. WATER FILLED AREA
5. PISTON
6. COMPRESSED GAS STORAGE AREA

FIGURE 7. Schematic of Rapid-Fire Water Cannon

FIGURE 8. Water Cannon Mounted on a Backhoe Linkage

3. Thirty-six shots will remove $\sim 1 \text{ ft}^2$ of material.
4. One square foot of surface can be removed in 15 minutes.
5. Each shot requires $\sim 1 \text{ in.}^3$ of water.
6. Each shot exerts a surface force of 800 to 900 lb.

It was decided that this unit had no particular advantage over the .458 magnum cannon.

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bottom of the hole, it forces the wedges away from the bottom, causing an average 8-in.-dia spall. Figures 10 and 11 show the bit in the initial position and in the expanded position, respectively. A dust shield is placed around the drill and is used in conjunction with a vacuum cleaner to collect the drilling chips generated when the hole is drilled.

The hydraulic cylinder is powered by a 10,000-psi pump. An electric four-way valve controls the flow of hydraulic oil to the main or return side of the cylinder. Two push buttons on the spaller handle allow the operator to select whether the bit wedges are to expand to make a spall or to contract in preparation for the next spall. A connecting section of any length between the hydraulic cylinder and the spaller bit can be used to obtain the desired stand-off distance.

To select the best drill for making the spaller holes, numerous preliminary tests were made on old concrete foundations. In particular, three types of drills were evaluated: 1) an electric rotary hammer, 2) an air-powered rotary hammer, and 3) an electric core drill. The amount of time required to drill a 2-in.-deep, 1-in.-dia. hole was the determining factor for these drills. The electric rotary hammer was tested first and found to have a drilling time between 30 and 45 seconds. The air-powered rotary hammer was tested next with a drilling time of 5 to 7 seconds. The last unit tested was an electric core drill. A core drill was tried in an attempt to reduce the amount of drilling chips generated, compared to the other two drills. The core drill took three minutes to drill the 2-in. hole. It also produced very fine drilling chips that would be more difficult to contain than the larger chips produced by the two other drills. The air-powered rotary hammer was used in the following tests because of its speed.

Five tests were conducted on typical Hanford concrete found in the 100F Area and in the 300 Area between May of 1978 and August of 1980. The building and test dates are listed below:

- Test 1. Outside wall of 1608 Bldg. - May-June 1978
- Test 2. Outside wall of 105 Bldg. - November 1978
- Test 3. Decontamination of 303C Bldg. - July 1979
- Test 4. Outside wall of 108 Bldg. - Aug-Sep 1979
- Test 5. Outside wall of 108 Bldg. - August 1980

FIGURE 10. Concrete Spaller Bit Ready to be Inserted into a Hole

FIGURE 11. Concrete Spaller Bit Expanded

TEST 1

Test 1 was performed at ground level using the hand-held spaller and the hand-held, air-powered drill. Six 3-ft x 3-ft panels were laid out on previously painted walls. One-inch-diameter holes were drilled to a depth of approximately 2 in. with the air-powered rotary hammer drill. They were spaced 8 in. apart in a triangular pattern. A predrilled plywood template was used to locate the holes.

The spaller was inserted into each hole and activated to spall the concrete surface (see Figure 12). Approximately 60 ft^2 of surface were removed per hour.

A spall produced by the concrete spaller is shown in Figure 13. The spaller and a spaller panel are shown in Figure 14. Occasionally small areas of surface were left intact. These areas were then redrilled and spalled again. Note that the rubble produced by spalling is conveniently sized so that handling was easy and much of the surface layer remained intact. The rubble can then be scooped into boxes for disposal. If spreading airborne contamination is a problem, water mist can be sprayed over the rubble to contain any dust generated by the spalls.

The thickness of the surface removed is nominally 1 in. The depth ranges from 2 in. at the drilled hole to approximately $1/4$ in. at the edges of the spall. If at that depth contamination is still found, the spalled surface can be redrilled and spalled as many times as necessary. Approximately 1 ft^3 of rubble was generated for each 10 ft^2 of surface removed during the first removal pass.^(a)

The concrete spaller can successfully be used to remove the surface of concrete made with reinforcing steel (rebar) as shown in Figure 15. The outer layers of concrete can be removed down to the rebar. If contamination is still deeper, spalling can be done around the rebar so that the rebar can be removed also.

(a) The volume of the rubble produced during the test was measured by loading it into buckets of known size.

FIGURE 12. Concrete Spaller Being Used

FIGURE 13. Spall Made by Concrete Spaller

FIGURE 14. Concrete Spaller Next to Spalled Test Panel

FIGURE 15. Spalling Done Around Rebar

TEST 2

Test 2 featured the use of a platform to support and position the spall-er and drill. This model was conceived to reduce operator fatigue that was especially noticable during the drilling operation. The air drill and concrete spaller were mounted on tracks allowing four feet of lateral motion and forward and backward motion. This setup increased the hole drilling rate from 2-1/2 holes per minute to 5 and 6 holes per minute. The drill and spaller were positioned manually by the operator. Figure 16 shows the track-mounted, manually positioned drill, and Figure 17 shows the platform being used on a forklift.

FIGURE 16. Manually Positioned Air Drill

FIGURE 17. Manually Positioned Drill and Spaller in Operation

More time was required than desired to position the track-mounted spaller. It became much easier and faster to manually pick up and move the spaller from one hole to the next. Therefore, the spaller was removed from the track and hung above the track on elastic cord as shown in Figure 18.

FIGURE 18. Concrete Spaller Supported by Elastic Cord

A surface removal rate of 100 ft² per hour was obtained with the manually positioned drill and spaller. Operator fatigue was reduced and the removal rate was increased; however, it was felt the operator workload could be further reduced and the system made easier to operate by using motors to position the drill.

TEST 3

The handheld concrete spaller was used during decontamination of the 303-C facility on the Hanford Reservation during July 1979. Approximately 30 ft² of painted concrete floor with smearable contamination were reduced from 30,000 disintegrations per minute to background radiation level with one pass of the spaller. Previously tried detergent, strippable, and solvent-based decontamination agents were not able to bring the floor area to a nonsmearable condition.

TEST 4

In Test 4, motors and a control system were added in an attempt to further increase the drilling rate. Figure 19 shows a diagram of the motor-actuated air drill. The shield around the end of the drill bit was used to collect drilling chips with a vacuum system.

The width of the track was also increased, so an 8-ft-wide strip could be covered each time the platform was positioned. The concrete spaller was hung on a cable and held within operator reach by a pivoting, telescoping arm. The tension on the supporting cable was controlled by an adjustable tensioning module. Figure 20 shows the drill in operation. Figure 21 shows the wall being spalled. Motorizing the drill added some problems, the most important being that the drill has to be backed up and repositioned manually when it hits rebar. Because of the need to reposition the drill manually, the plan to use automation on the drill and let it work its way across the wall while the operator was spalling had to be abandoned. Normally rebar is 3-in. deep, which would pose no problem for the first pass of the spaller.

The operator monitored the automatic drilling until an 8-ft pass was completed, intervening to reposition the drill if rebar was hit. He would then spall the surface using the holes previously drilled.

**CONCRETE DRILL POSITIONER
AND ACTUATOR**
WITH MANUAL AND AUTOMATIC CONTROL

FIGURE 19. Motor-Actuated Air Drill

CONCRETE SPALLER
ATTACHED TO PIVOTING
OVERHEAD ARM

AIR DRILL

FIGURE 20. Automated Air Drill in Operation

FIGURE 21. Concrete Spaller in Operation

The electronic control system for the drill did not work well. If the drilling cycle was interrupted because of shallow rebar, it was difficult to move sideways an inch and restart the cycle. Also, transient electrical signals would cause the controllers to change directions or stop out of phase.

TEST 5

Modifications were made to the control system to make up for the deficiencies in the previous test. The system was retested in August 1980. The drilling sequence could be stopped and started again from any position. If rebar was encountered, the drill was easily moved to a new position and started again. Transient electrical signals were no longer a problem. Figure 22 shows the drill control module, and Figure 23 shows the drill with motors and with limit switches that signal the control module when a boundary is reached. The drill and spaller platform mounted on a fork-lift is shown in Figure 24.

A removal rate of 100 ft^2 per hour was obtained as in Test 2. Although an increase in removal rate was not obtained, the operator now only had to monitor the drill operation and to work the concrete spaller, which required little physical exertion.

FIGURE 22. Control Module Used to Position the Drill

FIGURE 23. Motor-Actuated Air Drill with Limit Switches

FIGURE 24. Forklift-Mounted Drilling and Spalling Platform

A design package containing the fabrication drawings for the concrete spaller and the mounting platform has been prepared. Appendix D contains a listing of the drawing titles and reference numbers.

REMOVAL RATE FOR AN 8-HOUR WORK SHIFT

The hand-held concrete spaller is capable of removing approximately 300 ft² of surface per shift. It is assumed that 1) 3-1/3 holes and spalls are required to remove 1 ft²; 2) 60 ft² of surface can be removed in an hour; 3) the equipment is used by two men for five hours each shift (the reduced man output per shift is because of the physical effort required to use the air drill).

Because of the faster drilling rate, the platform-mounted concrete spaller is capable of removing approximately 600 ft² of surface per shift. About 100 ft² of surface can be removed each hour by two men working 6 hours over

an 8-hour shift. The second man could assist one or two other spalling operations in the same area or perform other tasks while the first man is operating the drill and spaller. Material and labor cost estimates for the hand-held and platform-mounted spallers are listed in Appendix B.

A video tape was prepared which shows the equipment in operation (Pacific Northwest Laboratory 1980).

CONCLUSIONS

Two concepts for removing concrete surfaces have been tested by PNL. A summary of the results follows.

Of the two concrete surface removal techniques developed by PNL, the concrete spaller is the most efficient: it removes the concrete surface faster than the water cannon and at a lower cost. However, the compactness of the hand-held rifle (.458 magnum) version of the water cannon makes it useful for small areas or confined, hard-to-reach locations.

WATER CANNON

In addition to its compactness, the water cannon requires no preparation of the concrete surface. With the .458 magnum version, glycerine encapsulation of dust particles prevents most airborne dust contamination. Undesirable combustion by-products can be collected along with rubble by an attached vacuum system. Based on the removal of $\sim 58 \text{ ft}^2$ of concrete surface over a two-man, 8-hour shift (6 hours of actual use), the total cost of the .458 magnum water cannon is about $\$17.75/\text{ft}^2$ of surface. The rapid-fire water jet showed no particular advantage over the .458 magnum version of the water cannon.

CONCRETE SPALLER

The concrete spaller best fulfilled the criteria for efficient removal of contaminated concrete surfaces. Use of the spaller is convenient because it is moderately fast and can be limited to a small area of contamination. The concrete spaller limits the volume of contaminated waste by a well-controlled spall that removes the surface layer to a depth of ~ 1 in. The rubble produced is moderately sized for easy handling. The controlled volume and size of the contaminated rubble would help minimize personnel exposure to the materials, as would the spaller's moderately fast speed relative to other decontamination techniques. Based on the removal of $\sim 300 \text{ ft}^2$ of concrete surface over a two-man, 8-hour shift (5 hours of actual use), the total cost of using a hand-held concrete spaller is about $\$3.55/\text{ft}^2$ of surface. Based on the

removal of $\sim 600 \text{ ft}^2$ of surface over a two-man, 8-hour shift (6 hours of actual use), the total cost of using a platform-mounted concrete spaller is about $\$3.00/\text{ft}^2$ of surface. These costs include labor, equipment rental, and equipment costs amortized over their useful lifetimes.

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APPENDIX A

.458 MAGNUM WATER CANNON TEST SETUP AND RESULTS

APPENDIX A

.458 MAGNUM WATER CANNON TEST SETUP AND RESULTS^(a)

The .458 magnum water cannon was developed for PNL by Exotech Inc. of Gaithersburg, Maryland. The following is a report Exotech^(a) prepared describing equipment setup, changes they made to the equipment so it would function reliably, and the results of testing they performed.

TEST SET-UP

1. Assemble barrel extension and nozzle to the gun barrel. Torque metal-to-metal joints tight.
2. Assemble gun into holding apparatus and shield assembly.
3. Standoff from nozzle tip to target should be approximately one and one-half inches.
4. Load cartridges: 35 grains of "Unique" powder^(b) in a .458 magnum cartridge with a No. 250 primer. Push in wax plug to the mouth of the cartridge followed by a cardboard "nitro wad" (45 caliber). Push the wax and wad to just touch powder without packing it. Insert a 2-inch length of glycerine into the cartridge until it touches the wad. Place another 2-inch length of glycerine into the breech of the gun. Insert cartridge and glycerine forcing the first glycerine length into the barrel. Close the breech. Pull trigger with a lanyard. Glycerine should be kept below 85°F for best results. Keep time of glycerine in the barrel to a minimum.

REWORK THE BARREL TO NOZZLE JOINT

The barrel to nozzle joint(s) have been made by using a metal-to-metal seal similar to a "lens ring" configuration. With the joint between the barrel

(a) Letter report from Exotech, Incorporated.

(b) "Unique" powder is a product of E. I. Dupont Company.

and barrel extension and the barrel extension and nozzle tightened (approximately 50 ft-lb) there has been no problem of either leakage or loosening. The extension to nozzle joint may exhibit a very minor leakage over a number of shots. This is due to the extreme hardness of the metals used in these two parts and has not been a problem in performance. Relief ports prevent any pressure buildup at this joint.

The erratic nature of the previous tests at Battelle were found to be caused by the gun barrel swelling under the pressure developed by the glycerine. As the glycerine was compressed in the nozzle, the glycerine remaining in the barrel overcame the yield strength of the barrel. The gun barrel, a typical gun steel of hardness R_C 25-30, was unable to retain the glycerine pressure after a number of firings. The nozzle is a maraging steel with a much higher yield strength. By placing a hardened barrel extension between the barrel and nozzle, the extension was able to sustain the pressure pulse caused by the compressed glycerine. After approximately 65 firings, the extension bore diameter of .450 in. remains unchanged.

EFFECT OF NOZZLE DIAMETER

Two nozzles of .171-in. diameter are furnished with the units. Tests conducted using nozzle diameters of .118-in., .155-in. and .175-in. have shown the .171-in.-diameter nozzles to be the most consistent. They give the best small crater and are the least expensive to manufacture as far as internal bore is concerned. Depending upon the concrete target, the craters formed will have a diameter of 4 in. $\pm$ 1 in. This number is a result of test targets used at Exotech. Stronger concrete may reduce this figure. The nozzle exit of the nozzle used was fabricated at .171-in. diameter; after approximately eighty tests, the exit diameter remained at .171-in. with no signs of wear.

EFFECT OF POWDER LOADING

The recommended powder load of 35 grains of "Unique" was arrived at after testing loads ranging from 25 to 40 grains. The crater diameter and depth

increase from 35 to 40 grains is not significant enough to warrant the added gun wear expected at the higher loading. The crater size varied from an average of 3 in. at 25 grains to 4 in. with 35 grains.

EFFECT OF NOZZLE-TO-TARGET DISTANCE

With the current equipment, standoff does not seem to affect the crater size between 5/8-in. and 2-in. All tests in this range fell within the 4-in. $\pm$ 1-in.-diameter crater.

EFFECT OF FIRING ANGLE ON CRATER SPALL

Tests fired into the target at an angle seemed to decrease the effectiveness of the jet. Tests at both 60° and 45° to the target resulted in the crater diameter being lessened. The "cross-breaking" into a previous crater by attacking it at an angle did work, but slightly less well than a normal jet perpendicular to the target. Again, the shots were made against a concrete floor. Tests against a pneumatically deposited concrete or "shot-crete" wall may give different results.

EFFECT OF GLYCERINE SOFTENING ON PERFORMANCE

Firing of heated glycerine appears to cause the crater to jump around in diameter. Heated conditions may result from heating of the glycerine from environmental conditions or heating of the barrel from rapid firing or the environment. In either case, keeping the glycerine below 85°F in a tightly capped container will help to stabilize the results. Also, the barrel will heat up if firings are made at intervals of one minute or less. Some sort of barrel cooling will help results if this is necessary. In any case, try to keep the glycerine time in the heated barrel to a minimum.

COMMENTS

1. Check cartridges you have to assure the mouths are round with an outer diameter of .481-in.
2. Wax should be cut to a diameter of approximately .460 in. to .470 in. by 3/8 in. to 1/2 in. long.

APPENDIX B

EQUIPMENT OPERATING COST ESTIMATES

APPENDIX B

EQUIPMENT OPERATING COST ESTIMATES

WATER CANNON

The material costs for the water cannon rifle as shown in Table B.1 were based on \$0.31 per shot. This included gun powder, primers, glycerine, cases (reused 10 times), labor to load the cases and mold the glycerine, and the costs of the water cannon and the vacuum system amortized over their useful lives. The breakdown by item is shown below:

Item	Cost
Powders, primers, and glycerine	\$0.25/shot
Cartridge cases (used 10 times at \$.30/each)	0.03/shot
Gun	0.02/shot
Vacuum	<u>0.01/shot</u>
Total	\$0.31/shot

An average of 1440 shots will be required to remove 58 ft² of surface. With labor costs of \$560 per day, the cost to remove 1 ft² of surface is approximately \$17.75.

CONCRETE SPALLER

The material costs for the hand-held spaller and drill were based upon \$0.45 per spalled hole. The costs include the amortized costs for drill bits, the drill, spaller bits, the hydraulic pump, cylinder, hoses and handle, and a vacuum cleaner with absolute filters. The breakdown by item is shown below:

Item	Cost
Spaller Bit (\$150 each used for 400 holes)	\$0.38/hole
Drill Bit (\$70 each used for 5000 holes)	0.02/hole
Drill (\$1300 each used for 2 x 10 ⁵ holes)	0.01/hole
Pump & Cylinder (\$2000 each used for 2 x 10 ⁵ holes)	0.01/hole
Vacuum Cleaner (\$500 each used for 2 x 10 ⁴ holes)	<u>0.03/hole</u>
Total	\$0.45/hole

An average of 1000 spalls are required to remove 300 ft² of concrete. Rental costs were included for an air compressor to power the drill and vacuum cleaner. The cost to remove 1 ft² of surface was \$3.55.

The materials costs increased to \$0.49 per spalled hole with the addition of the platform and a forklift. With the more rapid removal rate, the cost to remove 1 ft² of surface is reduced to \$3.00. The cost will be somewhat less if the second man is used only part time.

TABLE B.1. Cost Comparison of Water Cannon and The Two Concrete Spaller Systems for One 8-Hour Shift

<u>Technique</u>	<u>Surface Removed (ft²)</u>	<u>Labor Cost (2 men at \$35/hour)</u>	<u>Equipment Cost</u>	<u>Equipment Rental Cost Per Day</u>	<u>Removal Cost/ft²</u>
Water Cannon	58	\$560	\$ 466	--	\$17.75
Concrete Spaller					
Hand Held	300	\$560	\$ 450	\$ 50	\$ 3.55
Platform	600	\$560	\$1030	\$210	\$ 3.00

APPENDIX C

CONCRETE SPALLER BIT AND PUSH ROD DRAWING

C.1

① PUSH ROD
MATERIAL: CARPENTER S2 TOOL STEEL
SEE NOTE #7

② BIT
MATERIAL: CARPENTER S2 TOOL STEEL
SEE NOTE #7 & 8

GENERAL NOTES

(UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONS & TOLERANCES ARE IN ACCORDANCE WITH ANSI Y14.5 1973
2. TOLERANCES: DECIMAL $\pm .015$
3. ALL MACHINED SURFACES $\frac{32}{1}$ SURFACE TEXTURE TO BE IN ACCORDANCE WITH ANSI B46.1
4. ALL DIMENSIONS ARE IN INCHES
5. ALL MATERIAL TO BE AS SHOWN OR APPROVED EQUAL
6. REAM CENTER HOLE IN TIP OF BIT TO .185 ϕ AFTER TAPER HAS BEEN MACHINED BUT PRIOR TO CUTTING SLOTS
7. HEAT TREAT TO 1600°F IN A NEUTRAL ATMOSPHERE, WATER QUENCH, TEMPER @ 300°F FOR 1 HOUR, AIR COOL, REF HARDNESS SB-S9 RC
8. TO AVOID WARPING DURING HEAT TREATMENT TIE FLUTED END WITH 8 HANG PARTS IN FURNACE
9. HANG BIT BY WIRE FROM THE BIT END - HEAT TREAT - DIP IN OIL QUENCH THREADED END FIRST TEMPER IMMEDIATELY AFTER QUENCH

SK-2-3779	2204	BY-GATE	FOR	BY-GATE	FOR	REV	DATE	DESCRIPTION	REV	DATE	DESCRIPTION
<p>NOTE 9 & 38 A) WAS .400 & GC (B) ADD</p>											
<p>REVISIONS</p>											
<p>REFERENCE DRAWINGS</p>											
<p>DWG NO. 2204</p>											
<p>COMMENT PRT ISSUE NO. 2 DATE 7/10/79</p>											
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APPD	OPERATED BY BATTTELLE MEMORIAL INSTITUTE		
APPD	J. M. Hatter	7-10-79	SPALLER BIT & PUSH ROD
BY	J. M. Hatter	7-10-79	
SCALE	FULL SIZE		
CLASSIFIED BY	CONCRETE DECONTAMINATION HARDWARE		
CLASSIFICATION	NONE REQUIRED		
DWG NO.	SK-2-3779	INDEX NO.	2204
SHEET NO.	1	TOTAL SHEETS	1

APPENDIX D

CONCRETE SPALLER DATA PACKAGE

APPENDIX D

CONCRETE SPALLER DATA PACKAGE

The drawings listed below describe the concrete spaller, peripherals, and mounting platform. Copies can be obtained from:

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<u>Drawing Number</u>	<u>Sheet Number</u>	<u>Title</u>
SK-2-3770	1	Spaller Assembly
	2	Spaller Details
	3	Spaller Details
SK-2-3772	1	Drill and Spaller Assembly - Plan and Section
	2	Drill Support - Sub Assembly
	3	Drill Support Details
	4	Drill and Spaller Support Details
	5	Drill and Spaller Support Details
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SK-2-3773	1	Drill and Spaller Work Platform - Plan and Section
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SK-2-3774	1	Drill Dust Collector Assembly
	2	Drill Dust Collector Details
SK-2-3775	1	Drill and Spaller Platform Isometric
SK-2-3778	1	Spaller - General Arrangement Hydraulic and Electrical
SK-2-3779	1	Spaller Bit and Push Rod
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