The U.S. Department of Energy (DOE), Division of Environmental Control Technology, requested Nuclear Energy Services to prepare a handbook for the decontamination and decommissioning (D&D) of DOE-owned and commercially-owned radioactive facilities. The objective of the handbook is to provide the nuclear industry with guidance on the state-of-the-art methods and equipment available for decommissioning and to provide the means to estimate decommissioning costs and environmental impact.

This paper will summarize the methods available for concrete decontamination and demolition to provide an overview of some of the state-of-the-art techniques to be discussed at this workshop. The pertinent information on each method will include the selection factors such as the rate of performance in terms of concrete removal per unit time (cubic yards per day), manpower required by craft, unit cost (dollars per cubic yard) and the advantages and disadvantages.

The methods included in this overview are those that have been routinely used in nuclear and non-nuclear applications or demonstrated in field tests. These methods include controlled blasting, wrecking ball or slab, backhoe mounted ram, flame torch, thermic lance, rock splitter, demolition compound, sawing, core stitch drilling, explosive cutting, paving breaker and power chisel, drill and spall, scarifying, water cannon and grinding.
1. INTRODUCTION

Concrete is universally used in all nuclear facilities such that nearly every decommissioning program must address itself to either the demolition or surface decontamination of concrete structures. Certain structures become radioactive during the operating period of a nuclear facility either through direct activation or surface contamination. Activated concrete represents the most difficult concrete removal activity due to the relatively high radiation dose and potential for release of radioactive particulates during demolition. Radioactive fluid leaks may contaminate floor or wall surfaces of a facility which, because of the porosity of concrete, prove to be resistant to nondestructive cleaning methods. Although non-radioactive concrete structures do not represent any unique demolition difficulty, the volume of such concrete coupled with significant reinforcement represents a formidable dismantling task.

Concretes typically encountered include biological shields which may be 2 to 10 ft thick standard (140-150 lb/ft\(^3\)) or high density concrete (magnetite or metal aggregate, 250-325 lb/ft\(^3\)). Reactor basemats or facility footings can be as much as 25 ft thick.

Contamination on floors and walls can be removed without demolishing the structures. This may be advantageous if the facility is to be converted to other uses.

This paper provides an overview of concrete demolition and scarifying processes for various concrete types and thicknesses. The following sections present a tabulation of available processes and detailed information important to the selection of a method.

2. PROCESS SELECTION

The selection of a specific process should be based on the experience learned from the conventional demolition industry, and applicable experience...
from actual decommissioning programs. Table 1 presents a tabulation of processes that may be used for all concrete types and thicknesses. The detailed information on each process provided in the following sections will aid in selection of the optimum process.

3. DETAILED DESCRIPTION OF PROCESSES

3.1 CONTROLLED BLASTING

3.1.1 Description of Process

Controlled blasting is ideally suited for demolition of massive or heavily-reinforced, thick concrete sections. The process consists of drilling holes in the concrete, loading them with explosives and detonating using a delayed firing technique. The delayed firing increases fragmentation, and controls the direction of material movement. Each borehole fractures radially during the detonation. The radial fractures in adjacent boreholes form a fracture plane. The detonation wave separates the fractured surfaces and moves the material towards the structure's free face. Figure 1 illustrates a typical "blasting round" for massive concrete demolition, and explains the terminology used in designing a blast; for example, the burden is the distance from the free face.

Blasthole design is based on a range of geometric relationships from which the blast design can be developed using an incremental powder loading per borehole. Pages 19-28 of Reference 1 provide guidance on standard blasting ratios. Under no circumstances should the user embark on a blasting demolition program without the services of a certified blasting technician.

Drilling methods for blast hole preparation include percussion air-operated drills, electric, pneumatic or diesel driven rotary drills or diamond-core abrasive drills. Percussion drills are the most versatile and can economically drill 1\(\frac{1}{4}\) in. to 2 in. diameter holes over a wide range of hardness or abrasiveness. Typical percussion drilling equipment is capable of drilling a 6 foot deep hole in 3\(\frac{1}{2}\) minutes. Rotary drills are much larger in diameter (6 in. to 9
TABLE 1. Concrete Removal Methods: Summary of Applications and Relative Costs

<table>
<thead>
<tr>
<th>Process</th>
<th>Concrete Thickness Application</th>
<th>Feasibility</th>
<th>Relative Equipment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled Blasting</td>
<td>2 ft</td>
<td>Excellent</td>
<td>High</td>
</tr>
<tr>
<td>Wrecking Ball</td>
<td>3 ft</td>
<td>Excellent</td>
<td>Low</td>
</tr>
<tr>
<td>Air and Hydraulic Rams</td>
<td>2 ft</td>
<td>Good</td>
<td>Low</td>
</tr>
<tr>
<td>Flame Cutting</td>
<td>5 ft</td>
<td>Fair</td>
<td>Low</td>
</tr>
<tr>
<td>Thermic Lance</td>
<td>3 ft</td>
<td>Poor</td>
<td>Low</td>
</tr>
<tr>
<td>Rock Splitter</td>
<td>12 ft</td>
<td>Good</td>
<td>Low</td>
</tr>
<tr>
<td>Bristar Demolition</td>
<td>1 ft</td>
<td>Fair</td>
<td>Low</td>
</tr>
<tr>
<td>Compound Wall &amp; Floor Sawing</td>
<td>3 ft</td>
<td>Good</td>
<td>Low</td>
</tr>
<tr>
<td>Core Stitch Drilling</td>
<td>2 ft</td>
<td>Poor</td>
<td>High</td>
</tr>
<tr>
<td>Explosive Cutting</td>
<td>2 ft</td>
<td>Good</td>
<td>High</td>
</tr>
<tr>
<td>Paving Breaker</td>
<td>1 ft</td>
<td>Poor</td>
<td>Low</td>
</tr>
<tr>
<td>Chipping Hammer &amp; Chisel</td>
<td>3 in.</td>
<td>Poor</td>
<td>Low</td>
</tr>
<tr>
<td>Drill &amp; Spall</td>
<td>2 in.</td>
<td>Excellent</td>
<td>Low</td>
</tr>
<tr>
<td>Scarifier</td>
<td>1 in.</td>
<td>Excellent</td>
<td>Low</td>
</tr>
<tr>
<td>Water Cannon</td>
<td>2 in.</td>
<td>Fair</td>
<td>High</td>
</tr>
<tr>
<td>Grinding</td>
<td>0.25 in.</td>
<td>Poor</td>
<td>Low</td>
</tr>
</tbody>
</table>

(1) Bench height
(2) Free face
(3) Burden
(4) Spacing
(5) Powder column
(6) Stemming
(7) Subdrilling
(8) Working floor of cut
(9) Collar

FIGURE 1. Blasting Round
in.) and are best suited for light concrete without reinforcing rods. Diamond-core abrasive bits are more expensive than percussion drills but bit life is longer. When cutting through reinforcing rod, abrasive drilling is slower and diamond loss is common.

Various types of explosives are available for use in demolition applications. The selection of the best type of explosive requires an evaluation of the properties of the explosive and of the concrete itself. A blasting expert is qualified to select the best explosive for the purpose. The major types of explosives include PETN 85% high velocity gelatin dynamite, cast TNT, liquid explosives, water gel explosives and high strength ammonia dynamite (Ref. 1, 2).

When blasting massive concrete sections with multiple charges, delayed detonation is used to direct the muckpile (rubble) and improve fragmentation. The first row of charges directs the burden perpendicular to the borehole plane. Subsequent burden plane charges would direct movement towards the vertical unless delayed sufficiently to allow forward movement of preceding burdens. A delay period of approximately one millisecond-per-foot of burden provides sufficient time for free face movement, and allows subsequent burdens to fragment perpendicular to the boreholes.

3.1.2 Applications

Controlled blasting is the concrete demolition method recommended for all concrete greater than 2 feet in thickness provided noise and shock in adjacent occupied areas are not limiting. The process is well suited to heavily-reinforced concrete demolition because with proper selection of the blast parameters a high degree of fragmentation may be achieved. The exposed reinforcing bar may then be cut with an oxyacetylene torch or bolt cutter.

The Elk River Reactor dismantling program used controlled blasting to demolish the 8 foot thick steel-reinforced radioactive biological shield. A blasting mat (composed of automobile tire sidewalls tied together) was placed over the blast area. Continuous fog sprays of water were used before, during and after the blast to hold down dust. Alternatively, a spray mixture of water and 5%-by-weight sodium silicate (water glass) may be used for dust control.
3.1.3 **Performance and Cost Factors**

Typical concrete removal rates and approximate costs in 1979 dollars are shown in Table 2. The removal rates include drilling, loading, shooting, rebar cutting and loading the muckpile into hauling equipment. The unit cost includes crew cost, materials (explosives and dust control measures) and subcontractor overhead and profit. Shipping and disposal are not included. A typical blasting crew consists of the blasting expert, six laborers, one iron worker and one equipment operator.

**TABLE 2. Concrete Removal Rates and Costs Using Controlled Blasting**

<table>
<thead>
<tr>
<th>Concrete Type</th>
<th>Removal Rate $yd^3$/day</th>
<th>Removal Cost, $/yd^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Massive Reinforced Standard Concrete (Non-Radioactive)</td>
<td>100-400</td>
<td>100</td>
</tr>
<tr>
<td>2. Massive Non-reinforced Standard Concrete (Non-radioactive)</td>
<td>250</td>
<td>13</td>
</tr>
<tr>
<td>3. Massive Reinforced Standard Concrete (Radioactive)</td>
<td>4-6 *</td>
<td>400</td>
</tr>
<tr>
<td>4. Lightly Reinforced Standard Concrete (Non-radioactive)</td>
<td>200</td>
<td>35</td>
</tr>
<tr>
<td>5. Non-reinforced High Density Concrete (Radioactive)</td>
<td>6-8*</td>
<td>35</td>
</tr>
<tr>
<td>6. Lightly Reinforced Standard Concrete (Radioactive)</td>
<td>6-8*</td>
<td>200</td>
</tr>
</tbody>
</table>

**References**

* Actual removal rates including inefficiency due to personnel and area contamination control and radiation work area control.

** Higher removal rate possible if adequate space is available to use large capacity loading and hauling equipment.
3.2 **WRECKING BALL OR WRECKING SLAB**

3.2.1 **Description of Process**

The wrecking ball is typically used for demolition of non-reinforced or lightly reinforced concrete structures less than 3 feet in thickness. The equipment consists of a 2-to-5 ton ball or flat slab suspended from a crane boom. The ball may be used in either of two techniques to demolish structures. The preferred method is to drop the ball from a height of 10-to-20 feet above the structure. The maximum height of structure is limited to about 100 feet. A 5-ton ball would require a 200 ton crane for the maximum height (Ref. 6). This method develops good fragmentation of the structure with maximum control of the ball after impact. The second method is to swing the ball into the structure using a suck line for recovery after impact. The structure height is limited to about 50 feet because of the crane instability during the swing and after impact. The latter method is not recommended because the target area is more difficult to hit and the ball may ricochet off the target and damage adjacent structures while putting side loads on the crane boom. The flat slab may only be used in the vertical drop mode, but offers the advantage of being able to shear through steel reinforcing rods as well as concrete.

3.2.2 **Applications**

The wrecking ball or slab is recommended for non-radioactive concrete structures less than 3 feet in thickness. It would be virtually impossible to control the release of radioactive dust during demolition due to the access needed for the crane to drop or swing the ball. For non-radioactive structures, the wrecking ball is an effective method and provides good fragmentation to expose reinforcing rods.

A wrecking ball was used in dismantling the Elk River Reactor containment building cylinder and dome after the outer insulation and steel shell were removed, and after all radioactive material had been removed from within the structure.
3.2.2 **Performance and Cost Factors**

Typical concrete removal rates with a wrecking ball are shown in Table 3, exclusive of loading or disposal. The unit cost includes crew cost, equipment rental and subcontractor overhead and profit. The range in costs reflect the accessibility to move large equipment to the muckpile for loading and hauling. Shipping and disposal are not included in these costs. A typical wrecking ball crew consists of the crane operator, one crane oiler, two laborers and a fore-

<table>
<thead>
<tr>
<th>Concrete Type</th>
<th>Removal Rate, yd³/day</th>
<th>Removal Cost, $/Yd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightly Reinforced Standard Concrete</td>
<td>40</td>
<td>18-34</td>
</tr>
<tr>
<td>Non-reinforced Standard Concrete</td>
<td>50</td>
<td>12-25</td>
</tr>
<tr>
<td>Concrete Block Structures</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Heavily Reinforced Standard Concrete</td>
<td>Not Recommended</td>
<td>100</td>
</tr>
</tbody>
</table>

3.3 **BACKHOE MOUNTED RAMS**

3.3.1 **Description of Process**

Backhoe mounted rams are used for concrete structures less than 2 feet thick with light reinforcement. The method is ideally suited for low noise, low vibration demolition and for interior demolition in confined areas. The equipment consists of an air- or hydraulic-operated impact ram with a moil or chisel point mounted on a backhoe arm. The ram starts impacting as soon as there is resistance to the point and stops when breakthrough occurs or when the ram head is lifted. With the ram head mounted on a backhoe, the operator has approximately a 20 to 25 foot reach, and the ability to position the ram in limited access structures.
3.3.2 Applications

The ram is recommended for applications with limited access for heavy equipment such as a wrecking ball, and where blasting is not permitted. The air rams need to be modified to direct air exhaust away from the work area to prevent the spread of dust (nuisance and radioactive dust). The hydraulic ram recycles the hydraulic fluid, so no modification is necessary. Dust and contamination control is maintained with water fog sprays before and during breaking activities.

The air ram was successfully used for light concrete demolition at the Sodium Reactor Experiment (SRE) in Santa Suzanna, California (Ref. 8). However, at Elk River a hydraulic ram proved to be too slow in demonstration tests for use on the massive, heavily reinforced biological shield. The ram was replaced with the more favorable controlled explosive demolition.

3.3.3 Performance and Cost Factors

The backhoe-mounted ram can remove approximately 20 yd³/day of non-reinforced concrete. The approximate unit cost in 1979 dollars for ram breaking of concrete is $40/yd³ (Ref. 8). The unit cost includes crew cost, equipment rental and subcontractor overhead and profit. Shipping and disposal are not included in the costs. A typical crew consists of the ramhoe operator, one laborer and a foreman.

3.4 FLAME CUTTING

3.4.1 Description of Process

Flame cutting of concrete consists of a thermite reaction process whereby a powdered mixture of iron and aluminum oxidizes in a pure oxygen jet. The temperatures in the jet are approximately 16,000°F, which causes rapid decomposition of the concrete in contact with the jet. The mass flow rate through the flame cutting nozzle clears away the decomposed concrete, leaving a clean kerf. Reinforcing rods in the concrete add iron to the reaction to sustain the flame and assist the reaction.
The nozzle is mounted on a metal frame which straddles the area to be cut. The nozzle, with associated hoses, is tracked on the metal frame at a steady rate. The rate is dependent upon the concrete depth. A starting hole is cut through the concrete to prevent blowback of material and consequent torch damage. Once started, the torch is advanced along the workface by a variable speed electric motor controlled by the operator.

Heat and smoke may be removed with a 5 to 7 horsepower squirrel-cage blower, and directed through a flexible duct which houses a water fogger to hold down smoke particulate. The high gas temperatures preclude the use of HEPA filters for contamination control, making the flame cutting technique unsuitable for use on radioactive concrete without pre-cooling the effluent gas.

3.4.2 Applications

Flame cutting of concrete is used when vibration to the surrounding area is intolerable, and when the thickness of the concrete to be cut exceeds the capabilities of mechanical cutters such as diamond saws. Flame cutters are capable of cutting through a maximum depth of 60 inches with or without reinforcing rod (Ref. 9).

3.4.3 Performance and Cost Factors

The flame cutting speed is approximately 1 hour/ft$^2$ of cut area. The torch consumes approximately 800 ft$^3$ of oxygen, 14 lbs of iron powder and 6 lbs of aluminum powder per square foot of cut area. The approximate unit cost in 1979 dollars for flame cutting is $175 per square foot of cut area. The unit cost includes crew cost, equipment and subcontractor overhead and profit. Shipping and disposal are not included. A typical flame cutting crew consists of the torch operator and one laborer full time during cutting.
3.5 THERMIC LANCE

3.5.1 Description of Process

The thermic lance consists of an iron pipe packed with a combination of steel, aluminum, and magnesium wires through which a flow of oxygen gas is maintained. The thermic lance cuts utilizing a thermite reaction at the tip of the iron pipe, in which the constituents are completely consumed. Temperatures at the tip range from 4000 to 10,000°F, depending upon ambient conditions. The lance is ignited using an oxyacetylene torch, thermal igniter or electric arc. Typical lances are 10-1/2 ft in length and 1/4 in. to 3/8 in. in diameter. Two lances may be connected in tandem to increase burn time and to permit complete consumption of each lance.

A thermic lance set-up will consist of the lance, an oxygen supply (generally two or more cylinders connected in tandem), associated regulator equipment to maintain oxygen pressure at 70-125 psi, 3/8 inch diameter hose, and protective clothing and faceshield for the operator.

A thermic lance generates a large quantity of smoke and hot gases, the actual amount depending upon the material being cut. For this reason, a control envelope is necessary for radioactive concrete cutting to contain the vaporized material in order to prevent the contamination of the surrounding area.

3.5.2 Applications

The thermic lance will cut any material that is likely to be encountered in a nuclear facility. The reinforcing rods in the concrete speed the burning by adding more metal to the thermite process. Material further than 1 inch from the hole is not affected. The thermic lance can be used to cut holes, slits or openings in a wide variety of materials.

3.5.3 Performance and Cost Factors

The 10½ foot thermic lance will burn for at least 6 minutes, and can burn a 2 inch diameter hole through reinforced concrete to a depth of 1½ to 3½ feet. The
lance holder costs approximately $50.00, and the 10½ foot lance is $7.00 each. Oxygen supply cost about $6.00 per 100 ft⁵ at STP.

3.6 ROCK SPLITTER

3.6.1 Description of Process

The rock splitter is a method for fracturing concrete by hydraulically expanding a wedge into a pre-drilled hole until tensile stresses are large enough to cause fracture. The tool consists of a hydraulic cylinder which drives a wedge-shaped plug between two expandable guides (called feathers) inserted in the pre-drilled hole. Figure 2 shows a schematic of the splitter operating principle.

The unit is powered by a hydraulic supply system, and operates at 7100 psi pressure. When the plug is extended and fracture occurs, an automatic pressure relief valve lowers the pressure to 900 psi. With the unit in neutral position the pressure drops to 50 psi.

Units are available to develop splitting forces approaching 350 tons. The maximum lateral expansion of the feathers is approximately 0.75 inches. Concrete may be separated at the fracture line using a backhoe mounted air ram or similar equipment. The reinforcing rod in reinforced concrete must be cut before separation is possible. For heavily reinforced concrete, additional holes and fractures will be necessary to expose the reinforcing rod.

3.6.2 Applications

The splitter is ideally suited for fracturing concrete in limited access areas where large air rams cannot operate. The process is silent (except for hole drilling) and is used extensively for demolition near hospitals and other densely populated areas. Hole sizes range from 1-3/16 to 1-3/4 inch, and depth of 12 to 26 inches, depending on the size of the unit selected. For massive concrete sections, holes are drilled from 1 to 3 feet apart to establish a fracture line.
Reinforced concrete sections up to 8 feet thick may be cut with a single large unit. Reinforced concrete sections of 10 foot thickness will require two or more large units operated simultaneously.

3.6.3 Performance and Cost Factors

For reinforced non-radioactive concrete, removal rates of 250 yd³/day have been demonstrated. Drilling and splitting time requires approximately 5 to 10 minutes per hole. The approximate cost of the rock splitter and power unit range from $6500 to $8000 from the smallest to largest cylinder available. Cost per unit of output are dependent on the geometry and working conditions of the application.

![Schematic of Rock Splitter](image)

**FIGURE 2. Schematic of Rock Splitter**

3.7 **BRISTAR* DEMOLITION COMPOUND**

3.7.1 **Description of Process**

Bristar concrete demolition compound is a chemically expanding compound which is poured into pre-drilled holes and causes tensile fractures in the concrete upon hardening. Bristar is a proprietary compound of limestone, siliceous material, gypsum and slag. The powdered compound is mixed with water and kneaded to a fluid paste. The paste is filled into holes drilled in a fracture line of predetermined burden, spacing and depth. Within 10-20 hours, Bristar pressure will develop to over 4300 psi. Concrete tensile strength ranges from 200 psi to approximately 425 psi, such that low grade concretes are likely to fracture

* Registered trade name of Onoda Cement Co., Ltd., Tokyo, Japan (Ref. 10).
easily. Cracks will form and propagate along the fracture line. The crack width will range between 1/4 inch after 10 hours to almost 2 inches after 15 hours. The fractured burden may then be removed with a paving breaker, backhoe or bucket loader. If reinforcing rod is encountered, it must be cut separately. The compound is not classified as a hazardous substance and can be readily stored and handled. There is no noise or vibration (except for drilling holes), or flyrock, dust or gas release. Contamination control is only required during drilling and removal.

3.7.2 Applications

Bristar is suited for use on massive non-reinforced concrete structures where noise, vibration, flyrock, dust or gas must be avoided. It is not recommended for slabs of concrete less than 12 inches in thickness. The compound can be used with reinforced concrete provided the holes are located along the plane of reinforcing rod so the fractured surface will expose the rods.

3.7.3 Performance and Cost Factors

The rate of removal of massive non-reinforced concrete is dependent on the crack formation time (10-20 hours) and the quantity of concrete to be removed. For small jobs the removal rate will be slow because of the time to fracture. For large jobs, drilling may be continuous with mucking out following hole loading by about 20 hours. In this manner the removal rate may approach that of controlled blasting for the same material.

The quantity of Bristar required for a 2 inch diameter hole per foot of hole depth is $2\frac{1}{2}$ lb/ft. The approximate cost for Bristar is about $80.00 for a 44 pound container.

3.8 WALL AND FLOOR SAWING

3.8.1 Description of Process

Wall and floor sawing is generally used when disturbance of the surrounding
material must be kept to a minimum. A diamond or carbide wheel is used to 
abrasively cut a kerf through the concrete. The blades can cut through rein 
forcing rods although the rods tend to break off the blade diamonds. The blade 
is rotated by an air or hydraulic motor. For most applications the saw will be 
mounted on a guide which also supports the saw's weight. The operator manually 
advances the blade into the work. The dust produced by the abrasive cutting is 
controlled using a water spray. The abrasive blade produces no vibration, 
shock, smoke, sparks, or slag and is relatively quiet.

3.8.2 Applications

Thicknesses up to 3 feet have been cut with concrete saws. The maximum 
thickness of cut is approximately equal to one-third of the blade diameter.

3.8.3 Performance and Cost Factors

The saw cuts approximately 150 in$^2$ per minute of cut surface, regardless of 
thickness. Cutting can be done either manually or remotely.

The approximate cost of floor sawing concrete is $8.00/ft^2$ of cutting 
surface for non-radioactive, non-reinforced concrete. Reinforced concrete cut-
ting costs are higher because of the additional replacement diamond saw blades 
necessary, and the increased time to cut through heavy rebar. The approximate 
cost of wall sawing is $22.00/ft^2$ of cutting surface for reinforced concrete up 
to a 7/8 inch-diameter reinforcing rod. The saw is operated by one operator 
with no helper.

3.9 CORE STITCH DRILLING

3.9.1 Description of Process

Core stitch drilling consists of close-pitched drilling of holes in con-
crete using a diamond or carbide-tipped drill bit in an electric or fluid-driven 
rotary drill. The center lines of the holes are located to correspond to the 
desired breaking plane in the concrete. The hole pitch is such that there is
very little concrete left between adjoining holes (less than \( \frac{1}{2} \) the radius of the holes). When a line of holes has been drilled along the breaking plane, the remaining concrete between the holes may be sheared by a hydraulic wedge, or by dropping a wrecking ball onto the piece to be removed.

3.9.2 Applications

Core stitch drilling produces no gases or smoke, thereby facilitating contamination control. The dust produced by the drilling is controlled by a water spray, which is also used to cool the drill bit. Core stitch drilling is used where surrounding material must not be disturbed, or where accessibility is limited. However, the slab to be removed must be accessible to the method of shearing the concrete (bar, slab or wrecking ball). The method is not recommended for reinforced concrete because the remaining reinforcing rod inhibits shearing.

3.9.3 Performance and Cost Factors

Concrete drills can cut a 4 inch diameter hole through 4 feet of concrete in 60 minutes. The pitch between holes is recommended to be no greater than \( \frac{1}{4} \) inch for 4 inch diameter drills. Accordingly, this process is very slow and costly for large volumes of massive concrete removal.

The core drilling costs range from $17.00/ft for 1\( \frac{1}{2} \) inch diameter holes, to $550.00/ft for 24 inch diameter holes. Drilling depths greater than 3 ft can increase these costs by a factor of 3 (Ref. 11). These costs include labor, drill bits, and drill motor costs.

3.10 EXPLOSIVE CUTTING

3.10.1 Description of Process

An explosive cutter consists of an explosive core such as RDX or PETN, surrounded by a casing of lead, aluminum, copper or silver. Cutting is accomplished by a high explosive jet of detonation products of combustion and deformed
casing metal. The jet forms a directed shock wave which severs the target material. The cutter is approximately 1 inch wide and chevron-shaped with the apex pointing away from the material to be cut. When detonated, the explosive core generates a shock wave which fractures the casing inside the chevron and propels the casing into the material to be cut.

The target material is cut, not fractured or snapped. In concrete, there would be some local fracturing and pulverizing of the surrounding area. In reinforced concrete, some of the deeper reinforcing rods will not be cut. In this case, either a reinforcing rod cutter or oxyacetylene torch can be used.

Other explosive types are available such as HNS, DIPAM, HMX, CH-6, HNAB, DATB, TATB, KHND and NONA, to accommodate higher temperature (up to 600°F) applications. Lead casings are most frequently used for the smaller sizes and core loadings, and aluminum, copper or silver used for larger sizes.

3.10.2 Applications

Explosive cutting is normally used either when the geometry of the object being cut is too complex to employ other methods, or when several cuts must be made simultaneously (e.g. removal of a large prestressed beam where it is impractical to shore up the ends for temporary support).

Explosive cutters are used for precision cutting rather than massive heaving or demolishing. Cutters have been used on concrete for removing buildings, salvaging bridges, and felling smokestacks.

3.10.3 Performance and Cost Factors

Typical prices of lead sheathed RDX explosive cutters range from $14.00/ft for 300 grains/ft to $64.00/ft for 2200 grains/ft (Ref. 12). These prices may be used as input for cost estimating purposes, but actual demolition should be estimated and directed by a demolition expert.
3.11 PAVING BREAKERS AND CHIPPING HAMMERS

3.11.1 Description of Process

Paving breakers and chipping hammers remove concrete (and asphalt) by mechanically fracturing localized sections of the surface. Fracturing is caused by the impact of a hardened tool steel bit of either a chisel or moil point shape. The bit is driven in a reciprocating motion by either a compressed air or hydraulic fluid pressure source.

Paving breakers (also called "jackhammer" and "pneumatic drill") weigh approximately 35 to 100 pounds and are intended for use on floors. The chipping hammer is similar in concept to the paving breaker but is light enough (15-35 lbs.) to be hand-held for use on walls or ceilings.

3.11.2 Applications

Paving breakers are recommended for use on floors to remove small areas that are inaccessible for heavy equipment. They may also be used to expose reinforcing rods after controlled blasting to permit cutting of the rods. The chisel point may be used to scarify surface areas of concrete floors where contamination may have penetrated several inches deep in localized areas. Contamination control may be accomplished using water or fog sprays. Chipping hammers are recommended for use on walls to scarify small areas where contamination may have penetrated several inches deep over localized areas. However, the limited removal capacity and significant weight (up to 35 pounds) make it impractical for use on large areas. Other techniques are better suited for this purpose.

3.11.3 Performance and Cost Factors

Concrete removal using paving breakers or chipping hammers is labor-intensive. The cost for removal of non-reinforced concrete by paving breakers is $32.00/yd³. The crew consists of one light equipment operator and two laborers. The crew has an output of 20 yd³/day.
For reinforced concrete, the crew consists of one light equipment operator, two laborers and one ironworker. The crew output is 12 yd$^3$/day at a cost of $62.00/yd$^3$.

Chipping hammer costs are essentially those of the hammer operator's hourly rate since the consumption of materials and power requirements is insignificant.

3.12 **DRILL AND SPALL**

3.12.1 **Description of Process**

The drill and spall technique was developed for the removal of contaminated surfaces of concrete without demolishing the entire structure. The technique consists of drilling 1 to 1½ inch diameter holes approximately 3 inches deep into which is inserted a hydraulically operated spalling tool. The spalling tool is similar in to the rack splitter, but uses shorter feathers. The holes are drilled on approximately 12 inch centers such that the spalled area from each hole overlaps the next.

3.12.2 **Applications**

The drill and spall technique is recommended for removing surface contamination that penetrates one to two inches into the surface. Removal of the surface radioactivity in this manner eliminates the need to dispose of large quantities of non-radioactive concrete as with other volume removal techniques. Contamination control while drilling is accomplished with a filtered vacuum system. Fog sprays may be used to wet the surface and reduce contamination and dust levels.

3.12.3 **Performance and Cost Factors**

The average removal rate is approximately 7.5 yd$^2$/hr for standard concrete. No detailed cost information is available yet on removal costs since the tool is still in the developmental stage. The equipment cost, exclusive of the
positioning equipment, is estimated to be about $10,000. A typical drill and spall crew would probably consist of one operator, one platform positioner operator, two laborers and a front-end loader operator.

3.13 SCARIFIER

3.13.1 Description of Process

The scarifier technique is best suited for the removal of thin layers (up to one inch in thickness) of contaminated concrete. The tool, marketed under the trade name of "Scabbler" by the MacDonald Air Tool Company, New Jersey, U.S.A., consists of pneumatically operated piston heads which strike the surface to chip off the concrete. The piston heads are available in either 5-point or 9-point tungsten carbide bit sizes depending on the degree of surface roughness allowable. The 5-point bit has 1/4 inch high points and the 9-point bit has 1/8 inch high points.

The pistons are mounted in a wheeled-floor chasis which is available in 5, 7 and 9 piston sizes. The chasis is pushed along the floor to remove the surface layer. The chasis can be modified to include a HEPA filtered vacuum exhaust system to capture contaminated dust. Other tool models include a 3-piston wall scabbler which may be spring counter-balanced to relieve the tool weight. Smaller hand-held units are available but are not intended for large surface area removal.

3.13.2 Applications

The scabbler tool is recommended for applications where the concrete surface is to be reused after decontamination. The scarified surface is generally level with coarse finish (1/4 to 1/2 inch peak-to-valley height) resulting from the 9-point bit. The coarse surface is suitable for bonding to a concrete finish cap, and the smoother surface suitable for epoxy, polymer and similar finishes.

A 7-piston floor model scabbler was used at the SRE decommissioning program to scarify slightly contaminated floors. An HEPA filtered vacuum exhaust system was fitted to the floor scabbler to control the release of contaminated dust.
3.13.3 Performance and Cost Factors

The concrete surface removal rate is 5 square yards per hour per bit (Ref. 13) for the floor scabbler, which represents 35 square yards per hour for a 7-piston unit. The three-piston wall scabbler will remove 8-12 square yards of surface per hour.

The approximate unit cost in 1979 dollars for floor and wall scarifying is $1.40/yd² for the 7-piston floor model, and $6.25/ft² for the 3-piston wall model. The unit cost includes operator cost, air consumption cost, dust and chip removal, subcontractor overhead, and profit. A typical crew consists of the tool operator and one laborer for chip removal.

3.14 WATER CANNON

3.14.1 Description of Process

Two types of high-pressure jet spalling devices have been developed under the common name of water cannon (Ref. 14): Type (1), the Glycerine Gun, fires solidified glycerine capsules in a modified 458 magnum rifle through a nozzle. Type (2), the Water Cannon, uses compressed gas to drive a piston which forces water through a small diameter nozzle.

(1) Glycerine Gun: The glycerine gun uses a 458 magnum rifle with a short smooth bore barrel. A nozzle is threaded onto the end of the barrel to reduce the diameter from 0.45 inches to 0.17 inches. A 9-inch diameter funnel-shaped shield is placed around the nozzle to protect the operator and collect chips and dust through a vacuum exhaust system. Rubble pieces are 0.5 inches to 0.75 inches in diameter, and are covered with glycerine which contains the dust. The shield extends one inch beyond the nozzle to provide the necessary standoff from the workspace. Figure 3 shows the glycerine gun.

The glycerine gun fires solidified glycerine capsules 2 inches long by a 0.45 inch diameter. The capsules are propelled by gun powder loaded into conventional cartridge cases. The glycerine is accelerated by the propellant, and is extruded through the nozzle at very high velocity. Wax is placed in the cartridge case to hold in the powder, and to create a moving seal around the
glycerine to prevent combustion gases from bypassing the glycerine.

(2) **Water Cannon:** The water cannon uses compressed gas to drive a piston and force a small quantity of water through a nozzle. Figure 4 shows a schematic of the water cannon components. A funnel-shaped shield is placed over the nozzle to protect the operators and collect debris through a vacuum system. The gas which propels the piston is compressed by a hydraulic impactor. Firing rates of up to 5 shots per second are possible. Water is injected into the chamber in front of the piston after each shot.

The unit is usually mounted on a back hoe or excavator and may be articulated to spall concrete walls, floors or ceilings.

**FIGURE 3.** 458 Magnum Water Cannon

**FIGURE 4.** Schematic of a Water Cannon Basic Components
3.14.2 Applications

The glycerine gun has been extensively tested, and has been shown to create spall craters 3 to 4 inches in diameter and 0.75 inches deep. The shots are fired about 3 inches apart in a triangular pattern. The glycerine gun is most effective when fired around and behind embedded aggregate. Shots at hard, round river gravel will result in small spalls.

3.14.3 Performance and Cost Factors

Tests in high-strength concrete required 24 shots to remove 1 ft$^2$ of surface and took 5 to 6 minutes (approximately 10 ft$^2$/hr). The glycerine gun can be positioned and held by hand, and can be fired as fast as the operator can reload and position the gun.

The water cannon generally exhibits slower rates of removal than the glycerine gun. Typical rates of 1 ft$^2$ in 15 minutes (4 ft$^2$/hr) have been demonstrated. The water jet serves to coat the rubble particles and thus helps to reduce the spread of contamination.

No detailed cost information is available yet on removal costs since these tools are still in the developmental stages at Battelle Pacific Northwest Laboratory. A typical crew would consist of the gun operator and one laborer.

3.15 GRINDING

3.15.1 Description of Process

The grinding process includes a large number of similar tools for the removal of thin layers of surface contamination from concrete. In many cases the contamination is limited to the paint coating or concrete sealer finish. The technique consists of abrading the surface using coarse-grained abrasives in the form of water-cooled diamond grinding wheels or multiple tungsten-carbide surfaced discs. Machines to power these abrasives are of the circular floor grinding type where the grinding head rotates parallel to the floor. Water required for cooling is injected into the center of the grinding head.
eliminating any possibility of dust. Supplementary contamination control can be accomplished through the use of HEPA filtered vacuum systems attached to or held near the machine. The surface may be moistened before and during grinding to hold down dust levels.

3.15.2 Applications

Grinding is recommended primarily for thin layers of contamination because of the rapid disintegration of the abrasives when in contact with concrete.

Floor and hand-held grinding machines have been successfully used at the San Onofre Unit 1 Nuclear Plant to remove surface contamination.

3.15.3 Performance and Cost Factors

Typical diamond grinding removal rates with disc type rotary floor grinders are capable of removing several thousand square feet (per day) of surface approximately ½ inch deep, and lesser areas to as much as 1 inch deep. The machine may be operated by one operator.

The approximate unit cost in 1979 dollars for concrete floor grinding is $36.00/yd² (Ref. 11). The approximate unit cost includes operator cost, grinding wheels and discs, electricity, dust removal and packaging, and subcontractor overhead and profit.

A typical crew consists of the machine operator and one laborer for dust removal and packaging.

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