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Concrete Decontamination by Electro-Hydraulic Scabbling (EHS)

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LIST OF ILLUSTRATIONS

LIST OF TABLES

TABLE

1.0 EXECUTIVE SUMMARY

The Electro-Hydraulic (EH) or Electro-Pulse (EP) Scabbling technology involves the generation of powerful shock waves by a strong pulsed electric discharge in a water layer at the concrete surface or in a concrete surface layer itself*. The high pressure impulse results in stresses which crack and peel off a concrete layer of a controlled thickness. The scabbling produces a relatively small volume of contaminated debris to be disposed off under controlled conditions leaving clean bulk concrete for reuse or conventional disposal.

The EP/EH technology has been explored for other industrial processes, such as coal comminution, well-hole boring, and concrete structure destruction but it had not been investigated as a means of removing thin surface layers. Textron, with the support of the Department of Energy under Contract No. DE-AC21-93MC30164, embarked on a program to develop a commercially competitive process based on application of electric pulsed power that would have several advantages over existing mechanical processes such as grinding, shot blasting or jack-hammers. Progress of the development is reflected in reports and papers Ref. 1-4, 12. The perceived potential advantages were**:

- Remote Operation - lends itself to robotics, operators not in contact with radioactive nibble
- Wet operation - no generation of contaminated airborne dust.
- Versatile - should be appropriate for small or large areas and with proper design could be used on vertical surfaces, e.g. tank walls.

It is appropriate to mention in this context, that the EP/EH scabbling is a non-traditional technology integration mechanical, flow and electric pulsed power components. The pulsed power technology itself began to enter the area of commercial applications (see, for instance, Ref. 5) only in last one-two decades when the electric pulsed power equipment (used in the past predominantly for military applications) of high reliability and lifetime became broadly available.

According to design, the program proceeded in three phases. In Phase I, the feasibility of using EP/EH technology for the controlled removal of a thin layer of contaminated concrete, i.e. scabbling, was demonstrated. In the experiments conducted over the concrete floors of Textron's industrial process development lab in Everett, MA, the scabbled swath was limited to a few inches by the design of the electrodes, but the effectiveness and control of the process were certainly evident.

* The term Electro-Hydraulic Scabbling (EHS) has been used in the title of this project and through Phase I and Phase II Reports. In fact, the electro-hydraulic effect and corresponding technique is a certain version of more general technology based on application of the electric pulse power. In this report we are using EH term where the electric discharge takes place in liquid (water), and EP term when the discharge occurs directly through solid (concrete).

** See also Figure 2.4.

In Phase II, the design, construction and testing of an integrated subscale unit was performed at Textron with the concluding tasks of tests and analysis being performed at a DOE site (Fernald). The objective of the Fernald tests were to show that the radioactivity of a contaminated floor could be significantly reduced by electro-hydraulic scabbling.

During this Phase, Textron:

- Made multiple changes in hardware and in operating parameters to improve scabbling performance and to prolong the lifetime of the components

- Explored the feasibility of an alternate super - high voltage (>100kV) EP scabbling system, testing associated power supplies and multi-electrode scabbling modules.

- Designed and tested several versions of a water recirculation/concrete debris separation subsystem

- Completed logistic and health/safety arrangements required for shipping operating and recovering equipment from the DOE Fernald site.

The tasks performed in Phase II led to the following conclusions:

(i) EHS can accomplish removal of between 1/4" and 1" of concrete surface layer in a single pass and that the depth of removal can be controlled by varying the pulse energy, frequency, and scabbling module travel velocity.

(ii) The width of the scabbled path can be preselected by changing the length of the electrodes. Path widths up to 26" were achieved in Phase II.

(iii) The electric power supply (pulser) and the rest of the integrated unit (scabbler) can be assembled using commercially available components.

(iv) The scabbling rate depends on the power input, scabbling depth and quality of concrete. For a 3/8" scabbling depth at 8 kW nominal AC power input, the net rate (not including set up and debris removal) was 16 ft^2/hr at the TSD site and 10 ft^2/hr at Fernald, where the floor was noticeably harder with finer gravel.

(v) EH scabbling significantly reduced the radioactivity to less than 10% of counts per minute or uranium content of the contaminated floor area scabbled. Uranium was removed not only from the flat floor areas, but also from cracks and indentations.

(vi) The uranium content in the debris/sludge and unfiltered water averaged between 400 and 800 ppm while in the filtered water it was less than 10 ppm.

In Phase III, the EH scabbling unit was reconfigured to increase its power and processing rate, and to make it more compact and "user friendly". Two different electric power supplies were incorporated to make the system more versatile, that is, a high voltage/low current system operating at high (15 Hz) frequency in a concrete breakdown mode and a lower voltage/higher current system operating at lower (5 Hz) frequency.

After rebuilding the unit (see Figure 1), it was tested and further modified during shake-down runs at Textron's laboratory and then shipped to DOE's site at Florida International University (FIU) for performance testing. During the shake-down runs, it was shown that when operated with the high frequency power supply, designated A-EP, was most effective in scabbling down to depths of to 3/8" whereas the low frequency combine, designated A-EH, was effective between 3/8" and 5/8". The performance tests at FIU were limited to the A-EP unit to provide shallow scabbling data for closer comparison to other processes that were only capable of shallow (2/10" to 6/10") concrete removal. In the FIU tests, the A-EP unit operated without any breakdowns or serious malfunctions and, once the proper utilities and facilities were obtained, the designated 700 ft^2 of concrete slab area was scabbled without incident.

Based on the results of Everett and FIU trials, estimates of capital, operating and total project costs were made. Recognizing that there are inherent uncertainties, we have projected for a first, moderate power/degree of automation, integrated (i.e. including scabbling as well debris removal) unit:

Scabbling rate -	50 ft^2 per hour *
Processing capacity-	70,000 ft^2 per year
Capital Costs -	$ 175,000 per unit
Operational Costs	$ 2 to 3 per sq. ft.

(including labor equipment, labor and utilities)

In reviewing the process cost projections and the market, as represented by DOE's 10 year D&D program, it is evident that the major cost items will be site preparation, health and safety compliance and labor. The cost of the units and the number required to complete the 10 year program would be relatively small. Thus, the prime business incentive for developing the EH/EP process is to engineering contractors that provide decontamination services and not companies, like Textron, that would manufacture the EH/EP units.

* After this report has been completed, we received results of recent experiments by a High Voltage Research Institute (Tomsk, Russia)/ ITAC Ltd., Japan. By using our EP scabbling approach and increasing the operating voltage to 260 kV they achieved much higher volume of crushed concrete removed per pulse. Under these conditions, rate of 1/2" deep scabbling should exceed 500 ft^2/hr, and the overall productivity will be limited mostly by the rate of rubble removal.

Textron has thus initiated a concerted effort to transfer the technology to an engineering contracting company active in commercial D&D. A video, describing the fundamentals of electro-hydraulic and electric pulse processing, the hardware design and the testing at Fernald and FIU, was made and distributed to interested parties. In addition, videos were sent to the Global Environmental Technology Enterprise (GETE) and Dawnbreaker, both contracted by DOE-EM as part of the Commercialization Assistance Program (CAP). Communications with these firms are continuing.

Figure 1 Electro-Pulse unit on a field test site
(Power supply cabinet shown as insert)

2.0 INTRODUCTION

2.1 CONCRETE SCABBLING

Contamination of concrete structures by radionuclides, hazardous metals and organic substances (including PCB's) occurs at many DOE sites. The contamination of concrete structures (walls, floors, ceilings, etc.) varies in type, concentration, and especially depth of penetration into the concrete. In many instances, only the surface layer of concrete is contaminated, up to a depth of one inch, according to estimates provided in the D&D ID document.[6] Then, removal of the concrete surface layer (scabbling) is considered to be the most effective decontamination method.

Scabbling effectively divides the entire contaminated concrete structure into two parts: the contaminated surface layer rubble, and the remaining clean bulk of the concrete structure. The contaminated surface layer rubble is of relatively small volume, meaning that only a relatively small amount of hazardous radioactive material requires restricted disposition, compared to the amount requiring disposition if the whole structure were demolished. The remaining structure can either be re-used, or disposed of as non-hazardous waste.

A successful concrete scabbling technique should provide:

- High productivity (high scabbling rate)
- Cost effectiveness (including cost of equipment, consumables, and labor)
- Scabbling depth control
- Low volume of restricted waste
- Ability to remove, transport, separate, and store the process waste
- Environmental protection and health and safety for operating personnel (e.g., remote control of the scabbling unit).

2.2 CONCEPT OF THE ELECTRO-HYDRAULIC (ELECTRO-PULSE) SCABBLING

Textron Systems Corp. (TSC) has developed a scabbling concept based on electro-mechanical phenomena accompanying strong electric pulses generated by applying high voltage at the concrete/water interface. Depending on the conditions, the electric discharge may occur either through a water layer or through the concrete body itself; both cases as well as an "intermediate" event where the discharge channel propagates along the interface, are illustrated **by Figure 2.1**. Whatever the channel propagation, cracks are formed, and spalling of concrete takes place (**see Figure 2.2**). Phenomena taking place in the first

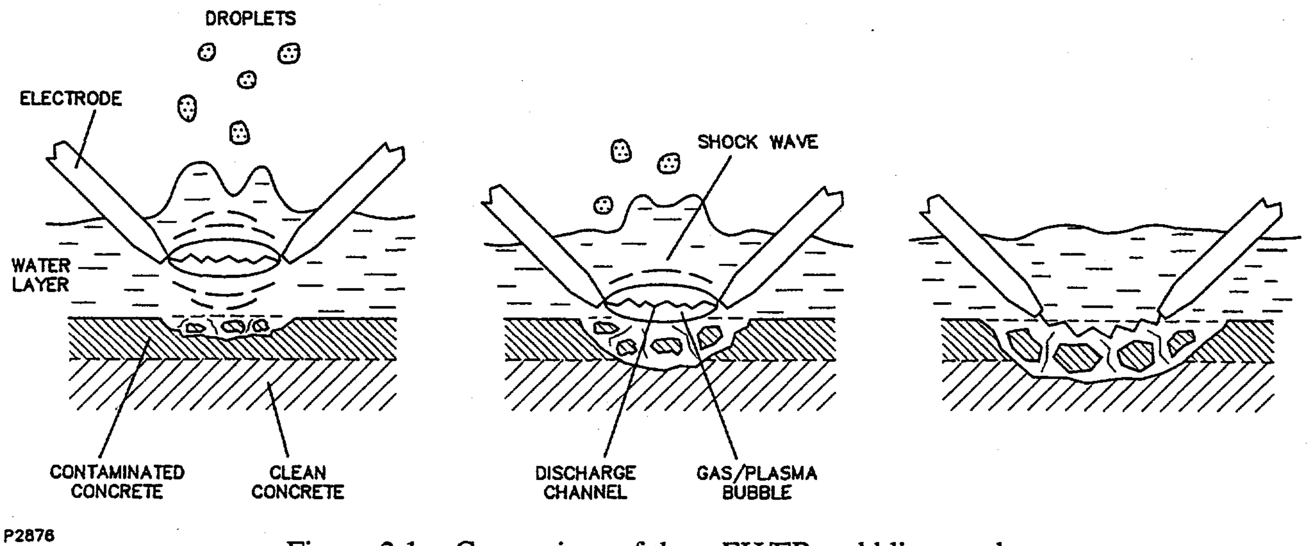

Figure 2.1 Comparison of three EH/EP scabbling modes

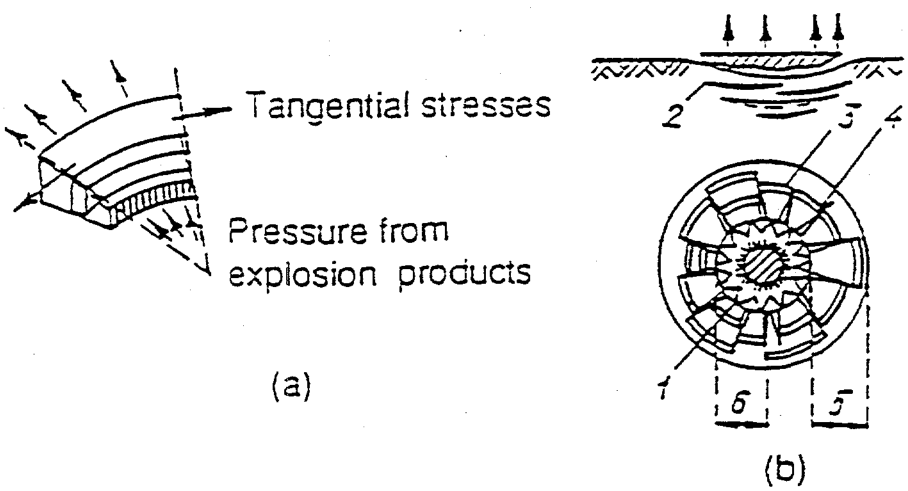

Figure 2.2 (a) Schematic of generation of tangential Sstresses in material under action of explosion

(b) Peeling of material at a liquid-solid interface (1 - location of breakdown, 2 - peeling, 3 - concentric cracks, 4 - radial cracks, 5 - cracking zone, 6 - compression /crushing zone) case (see **Figure 2.3** and description in Report I, section 2.3[1] are known as Electro-Hydraulic effects; hence, the term -Electro-Hydraulic Scabbling (EHS) is used as a name for the technology*.

A strong, spark-like discharge in liquid is accompanied by:

- Generation and propagation of an intense shock wave
- Generation and pulsation of a gaseous cavity formed by evaporation of the liquid
- Radiation of electromagnetic waves by the discharge channel.

The Electro-Hydraulic (EH) effect has found technical applications for crushing and grinding of minerals, rock drilling, metal forming, demolition of foundations, cleaning of surfaces, and decontamination/treatment of water.[1]

It is projected that under certain, rather broad range of conditions, EHS technology will provide significant improvement over other concrete decontamination techniques. The main advantages and benefits expected from the EHS technology developments are listed in **Figure 2.4.** To realize these advantages, a system integrating electrical, mechanical, flow components and controls has to be designed and integrated in a single mobile unit. A block diagram of a "generic" EHS system invented and developed under this project is shown in **Figure 2.5.**

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* A more generic term - Electric Pulse Scabbling - may be more appropriate for future use because it covers also events when the discharge channel is forming directly in a surface concrete layer, and shock waves generated by the rapidly expanding gas propagate through the concrete body.

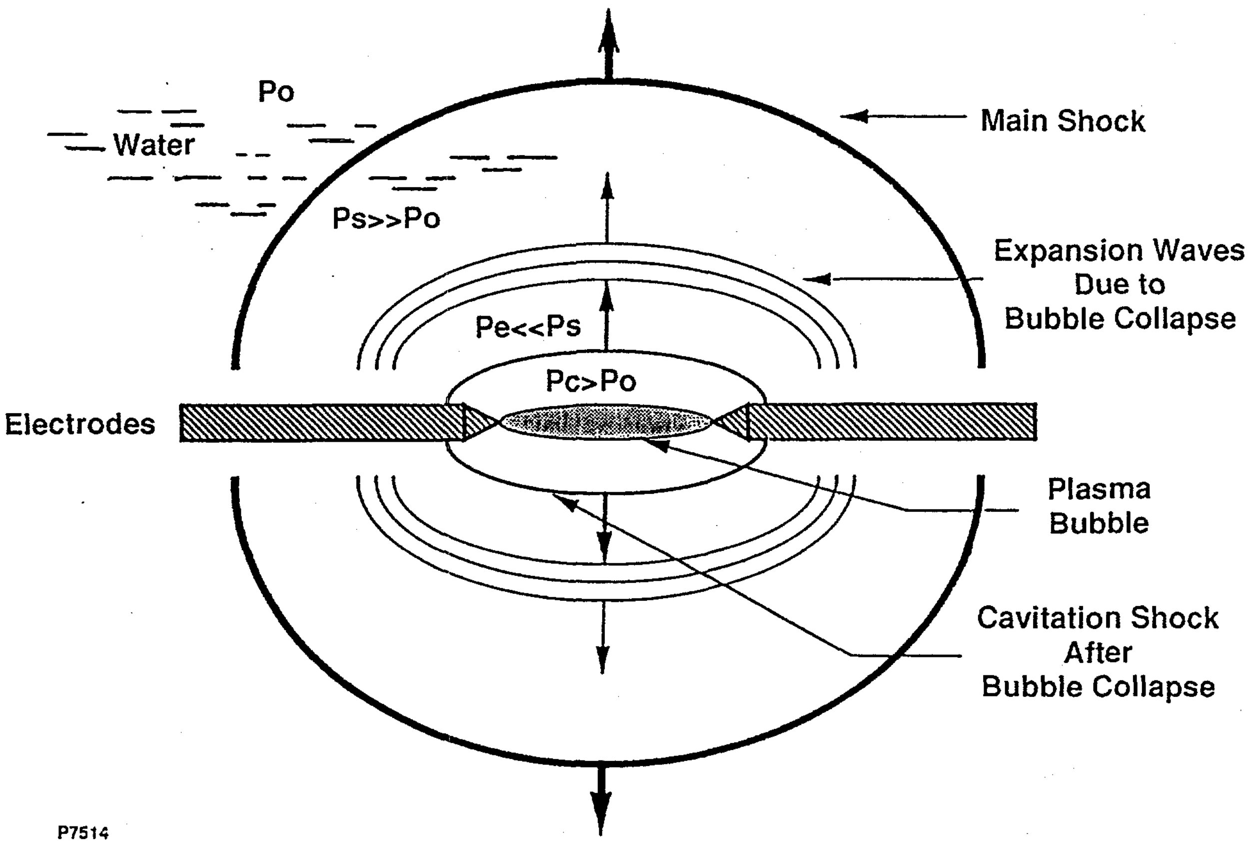


Figure 2.3 EH-Effect: phenomena following electric breakdown through liquid dielectric

High specific power input*
- high single pass scabbling rate

Broad ranges of scabbling depths and widths
- applicable for decontamination of large floor areas
- efficient removal of contaminants from deep cracks and joints

Low energy requirements for scabbler and auxilliaries
- low consumption of electricity and compressed air

Processing tool has no moving parts
- low erosion, long lifteime, less secondary waste

Enclosed space wet process
- no dust formation and cross- contamination
- tolerant to surface condition (wet/dry, dirty/oily, painted)

Small consumption of process media**
- low volume of secondary waste

No personnel's exposure to moving parts, vibrations, dust, media escape
- safe, operator friendly environment

* Energy per time, per unit area
** In water recirculation mode

Figure 2.4 Projected EHS advantages and benefits

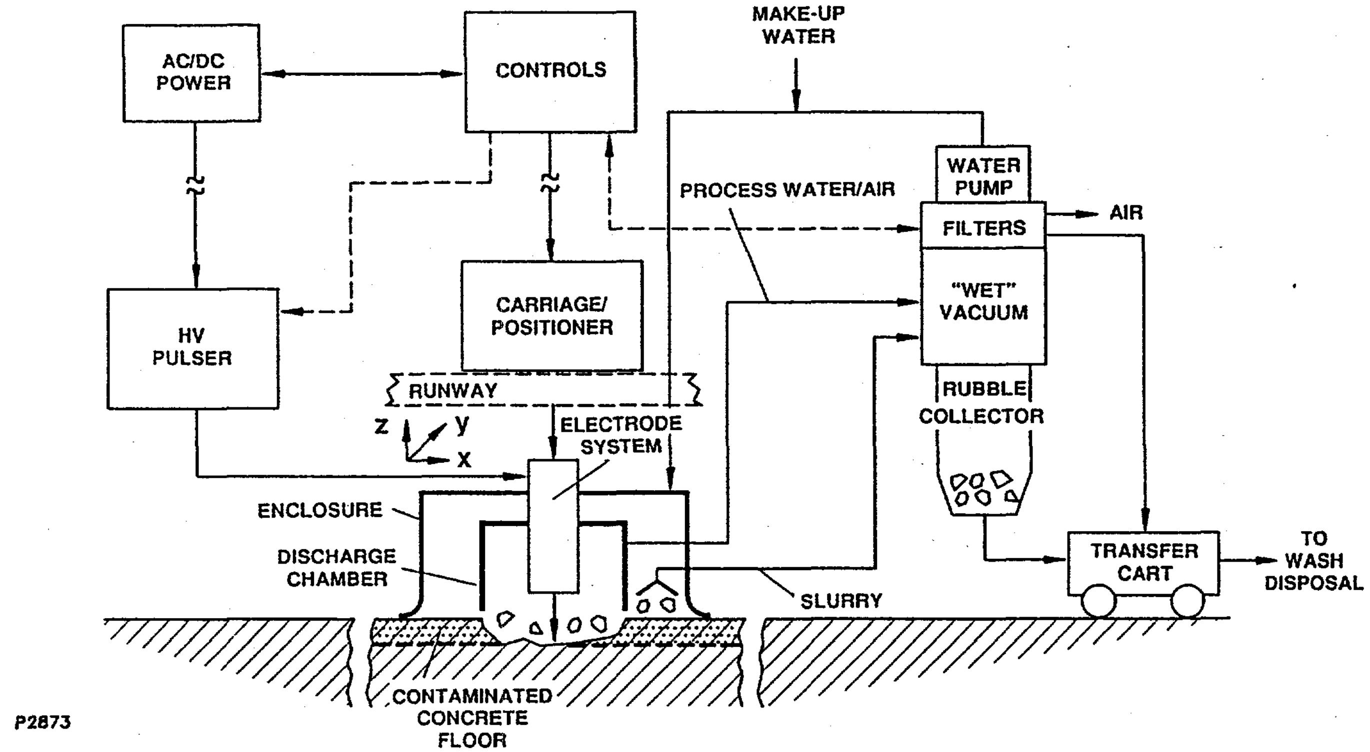


Figure 2.5 Block diagram of the integrated EHS system

3.0 EHS SYSTEM DEVELOPMENT: PHASE I and PHASE II

3.1 OBJECTIVES, TASKS and CHALLENGES

Development of the Concrete EHS System was planned in three phases.

3.1.1 Phase I

The primary objective of the first phase was to prove the technical feasibility of the EH technology for the controlled scabbling of concrete. Feasibility of the concept was demonstrated in the laboratory using the rig shown in **Figure 3.1**. A single pair of rod electrodes was used in this setup to scabble a 3" x 2" x 0.5" concrete slab immersed in a tank of water. Appearance of the EH discharge over the concrete surface before and after water splash formation are shown **in Figure 3.2**. A single continuous pass traverse generated a 2" wide path. Ranges of operating parameters and summary of the scabbling results are provided in **Table 3.1.**

In the next series of trials, concrete floor areas isolated by plastic barriers and covered by a 1" to 1.5" water layer were processed by making several adjoining passes with a module carrying one or two electrode pairs - see **Figure 3.3** and **Figure 3.4.**

In a parallel development, performed by a TSC sub-contractor - St. Petersburg (Russia) Technical University - feasibility of higher (>100kV) voltage scabbling using direct discharge through a surface concrete layer has been confirmed. It was shown that in this scabbling option, less energy is consumed.

Some scabbling experiments were also conducted with concrete impregnated by alkali salts, simulating to some extent contamination of the surface layer by the radioactive Cs 137.

In a summary, it was concluded in Phase I that:

- EHS can be controlled (by varying the pulse energy, pulse frequency, and velocity of the electrode travel) to scabble 1/4" to 1" surface layer in a single pass from bare or painted concrete in the laboratory, at a demonstrated rate of 10 sq. ft. per hour and energy consumption below 0.5 kWh/sq. ft.

- Scabbling non-uniformity is defined mostly by the concrete structure-local defects, density variation, and gravel size.

- The technique is suitable for scabbling/decontamination of (i) large concrete surfaces (open floor areas, individual blocks), and (ii) local defects deeply penetrated by contaminants.

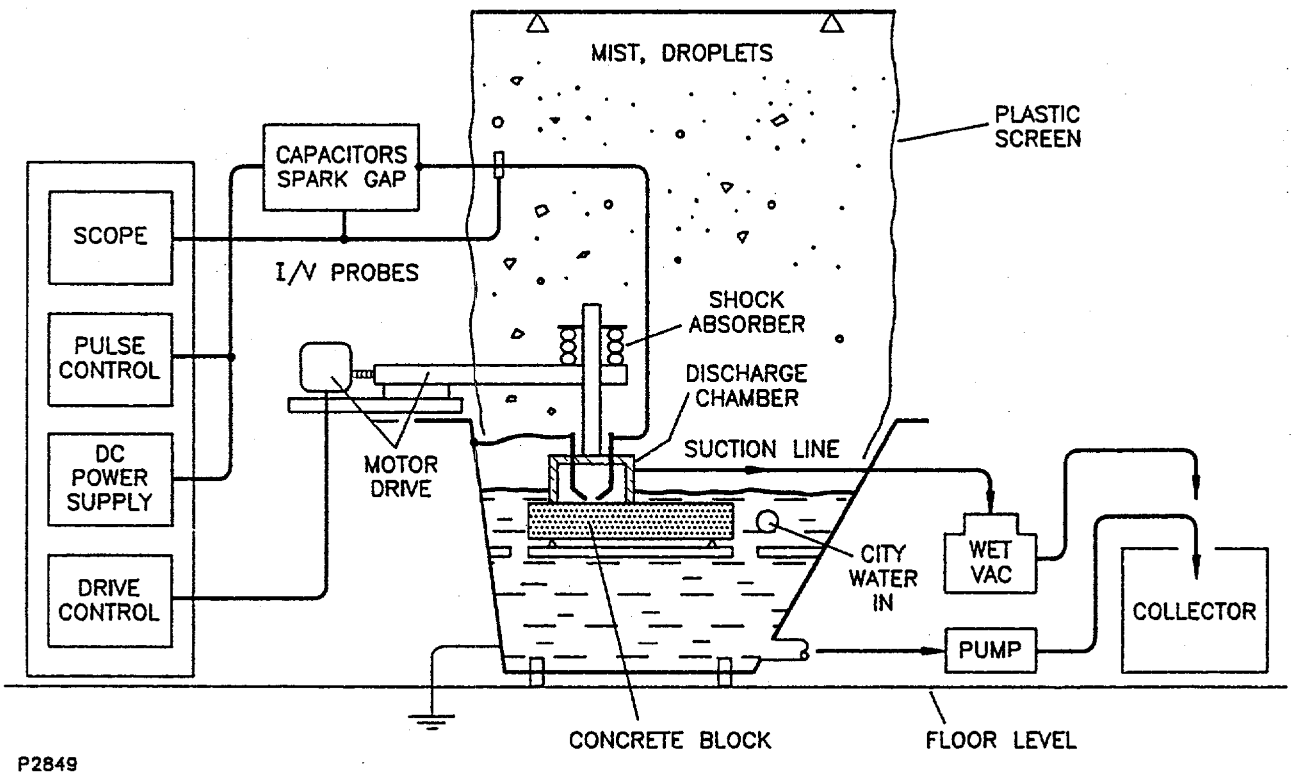
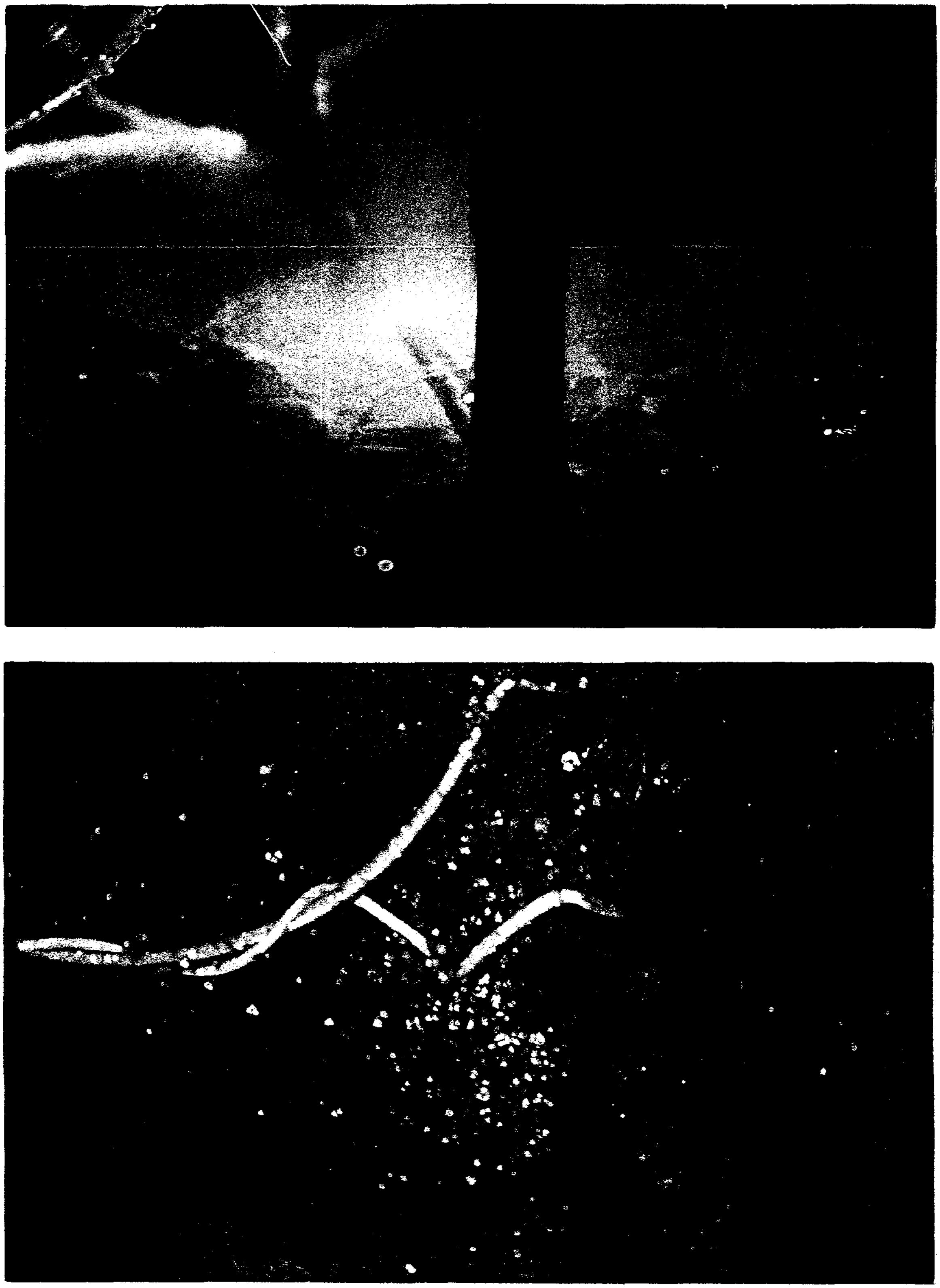


Figure 3.1 Laboratory setup for EHS of concrete slabs



(a)

(b)

Figure 3.2 Instantaneous appearances of the EH discharge over concrete before (a) and after (b) water splash

TABLE 3.1

RANGE OF OPERATING CONDITIONS AND RESULTS FOR LABORATORY UNITS

Operating Voltage	18 - 25 kV
Storage Capacitance	3.7 - 7.4 μF
Pulse Energy 800 -2200 J	800 - 2200 J
Operating Frequency	0.5 - 3.0 Hz
Average DC Power	1.5 - 4 kW
Electrode Velocity Continuous Traverse	1-12 inch/min
Scabbling Depth	0.2" - 1.0"
Scabbling Trace Width	1.5" - 3"
Depth of Water Layer	0.2" - 1.5"
Concrete Removed, Volume/Pulse	0.4 - 1.2 cm^3 (0.05 - 0.25 cu. in.)
Rubble Particle Size	0.1 <d> 0.75 in.
Concrete Area Processes	10-30 sq. in./min
Energy Consumption	400 - 1500 J/g concrete

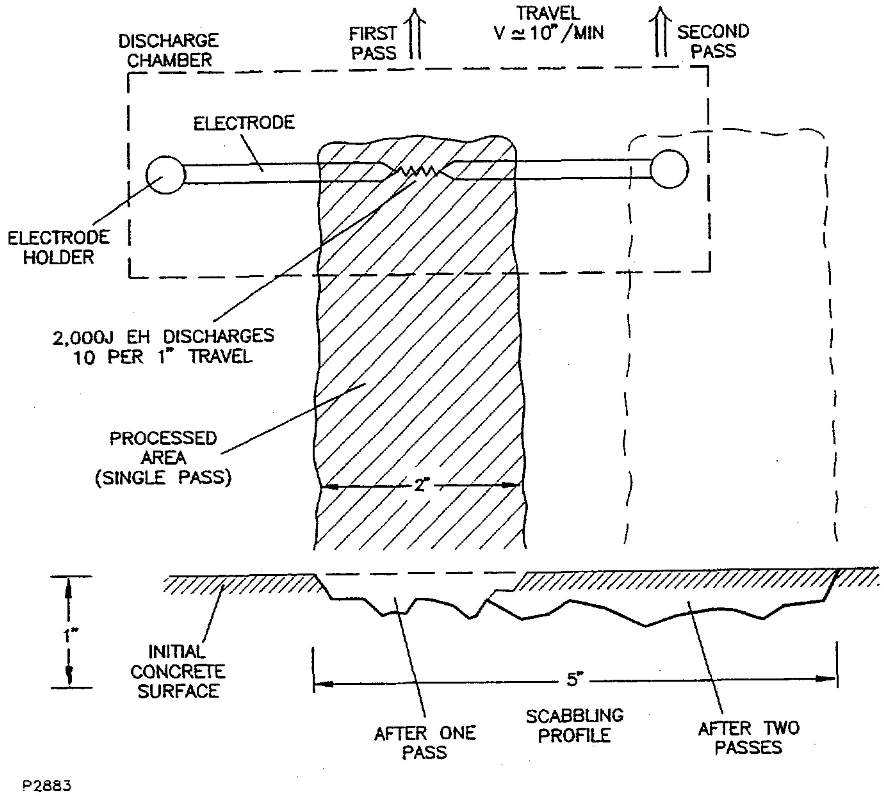


Figure 3.3 Schematic of scabbling groove formation by adjacent passes of the processing head

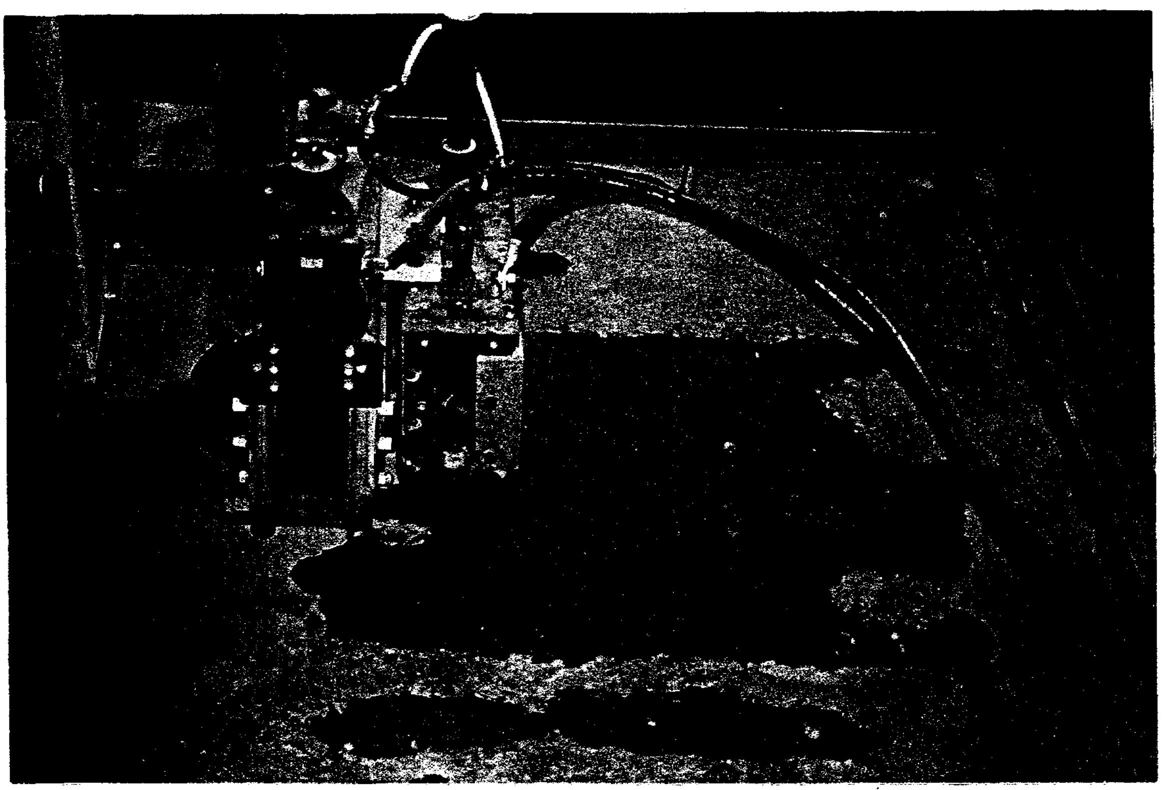


Figure 3.4 Concrete floor processed by two-head/two electrode pairs scabbling module

On the basis of the experimental effort, main performance parameters, capital equipment costs and operating costs were projected for both sub-scale and full-scale industrial units.

3.1.2 Phase II

Although the Phase I effort confirmed conceptual feasibility of EHS, two basic issues remained to be addressed:

a) That practical engineering solutions can be found and implemented for all EHS system elements, and

b) Removal of concrete surface layer by EH scabbling results in substantial decrease in the residual contamination (as measured by radioactivity and/or concentration of uranium).

It should be emphasized here that the EHS system is unique and incorporates components and operations that are rarely faced in a single material processing equipment units. These include:

- High voltage
- High, pulsing current/stray currents, currents and voltages
- High humidity; water droplets, splashes
- Water/air flow with high concentration of (erosive) coarse and fine particulates
- Vibrations/shock waves/acoustic noise

This combination makes the design of a EHS system, which must provide reliable, long term low maintenance operation a serious challenge.

Table 3.2 provides a list of the main specific technical issues/problems that had to be addressed in the course of development of a prototype EHS unit.

In the Phase II efforts (and later, in Phase III), these challenges were addressed, and generally resolved.

TABLE 3.2

DEVELOPMENT OF A PROTOTYPE EHS UNIT

A. Concepts and Configuration	
How to:	
*	Make wide path scabbling without having complicated/vulnerable multi-electrode multi-cable module
*	Isolate water covered floor segments from surrounding floor to keeping sufficiently high water level inside the scabbling chamber without water/debris leaking
*	Avoid/minimize electrode erosion and frequent/continuous discharge gap adjustment
*	Provide controllable, uniform frequency pulsing without using unreliable/sort living triggers
*	Avoid effects of strong pulsed currents/voltages on operation of X-positioner operation of water pumps system of relays/time delays
*	Provide safety grounding
*	Avoid electric breakdown over wet/water splashed components
*	Organize PFN cooling
*	Provide best soundproofing
B. Individual hardware items:	
What components and materials to select and use for:	
*	Enclosure vacuuming/debris removal
*	Enclosure perimeter gasket
*	Commercial sparkgaps
*	Air sparkgap electrodes
*	HV/HC cables
*	Electrode connectors
*	Electrodes
*	Electrode coatings
*	Positioner drives (X and Z)
*	Water filters (and de-ionizers)
*	System platform (e.g. forklift)

Specifically, the following objectives were accomplished in Phase II:

- Designed and assembled first version of a prototype EHS unit
- Conducted scabbling experiments with non-contaminated concrete at the TSC/Everett facility; made changes in hardware and in operating parameters to improve scabbling performance and to increase the lifetime of components
- Designed and tested several versions of a water recirculating/debris removal subsystem
- Assembled SHV (120 kV) scabbling system and tested it in operation with multi-electrode scabbler
- Demonstrated (in August 1995) short-time EHS system operation at the Everett site
- Prepared equipment and documentation for demonstration trials at the DOE Fernald site
- Conducted demonstration trials at Fernald (in September 1995). Collected data on EHS performance and uranium removal
- Evaluated scabbling and decontamination results of Fernald trials
- Made projections of the scabbling/decontamination performance and costs for the industrial EHS units

The resolution of these tasks is described in the next section.

3.2 DESIGNS OF THE PHASE II EHS SYSTEM

After several re-designs and modifications, the EHS unit (see **Figure 3.5**) used in the Everett trials during the summer of 1995 consisted of the following components and features:

A. Electric subsystem

Two similar power supply cabinets (one of which is shown **in Figure 3.6**) were assembled. DC power sources (30 kV max., 4 or 7 kW, by Electric Measurements, Inc. or Maxwell labs.) were assembled together with pulse-forming networks (PFN). These are shown in Figure 3.6b. A trigger-controlled, pressurized sparkgap switch (by EGG) was used in the circuit, **Figure 3.7**. At a typical 25 kV operating voltage and two 6 μF storage capacitors, the unit provided 3 kJ 25 μs pulses (Figure 3.7b) at 1 to 2 Hz frequency.

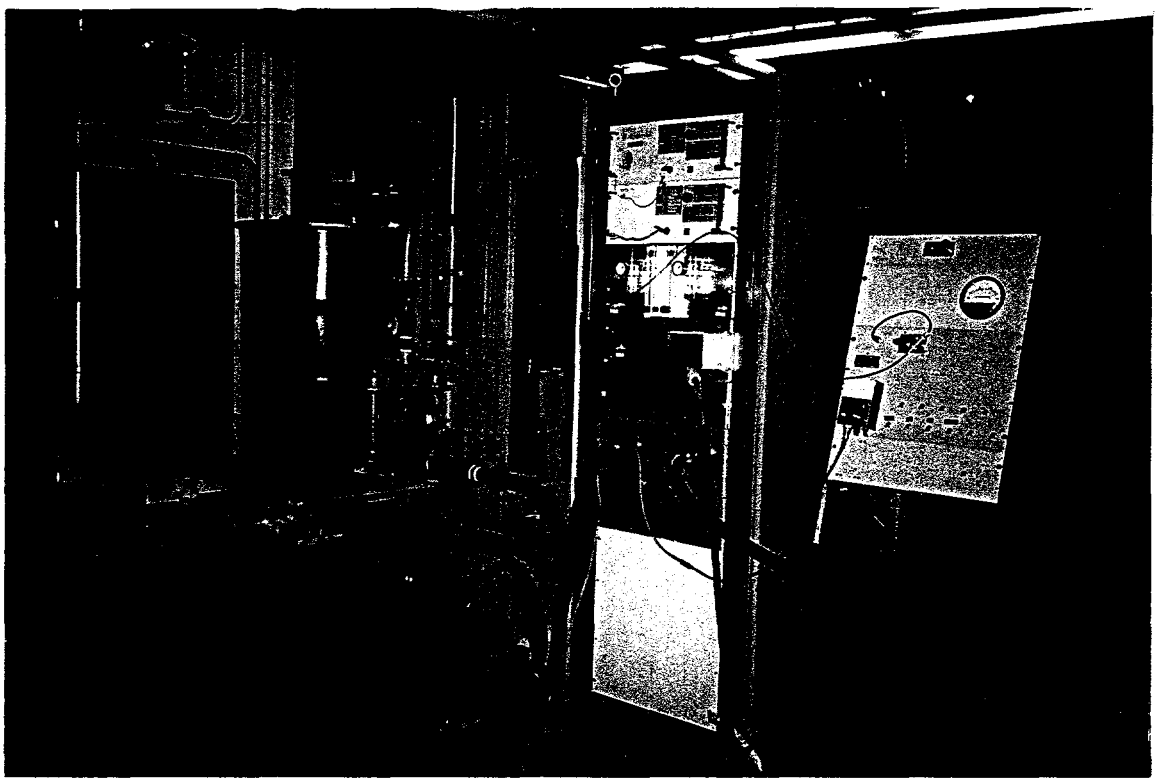
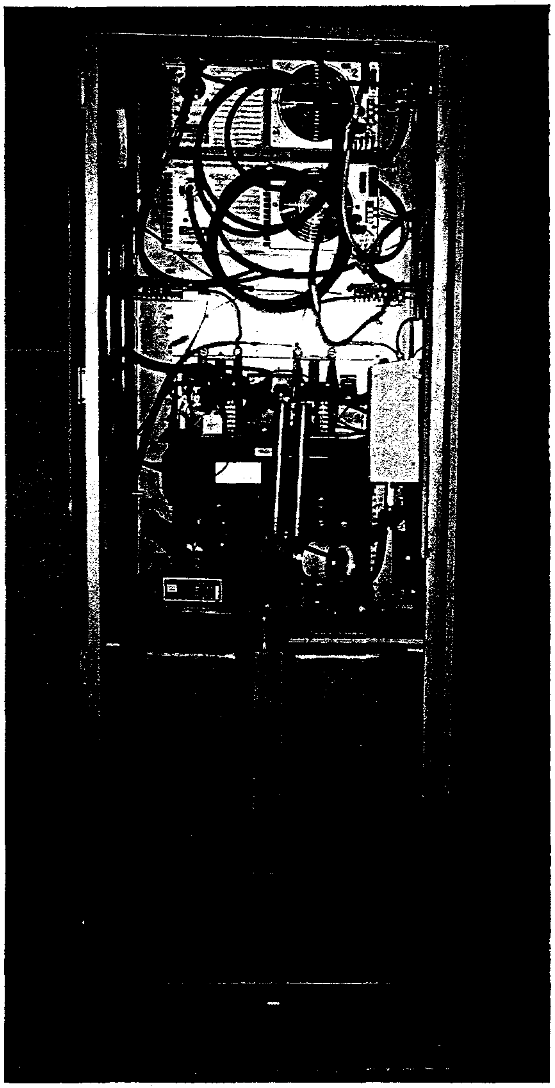
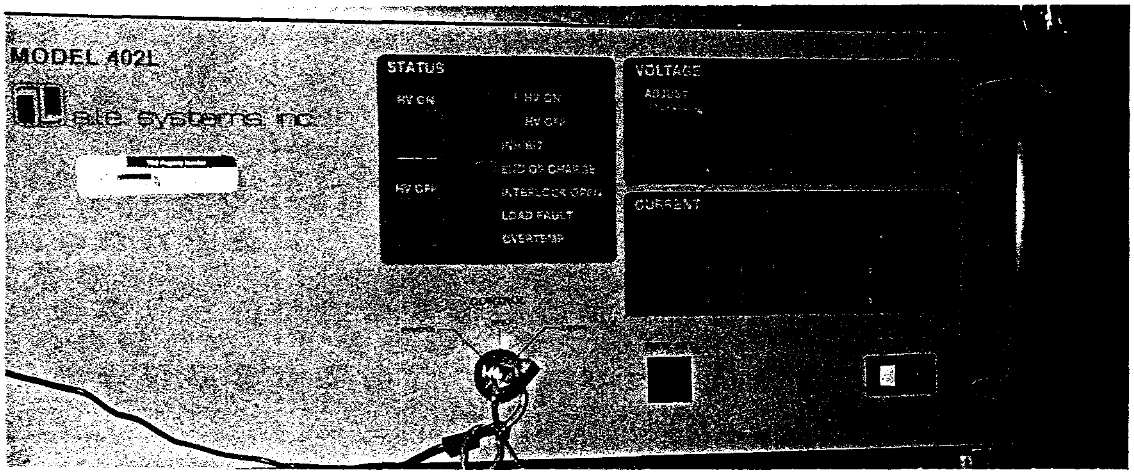


Figure 3.5 General view of phase II EHS unit (as assembled in summer 1995) with control and power supply cabinets in a forefront

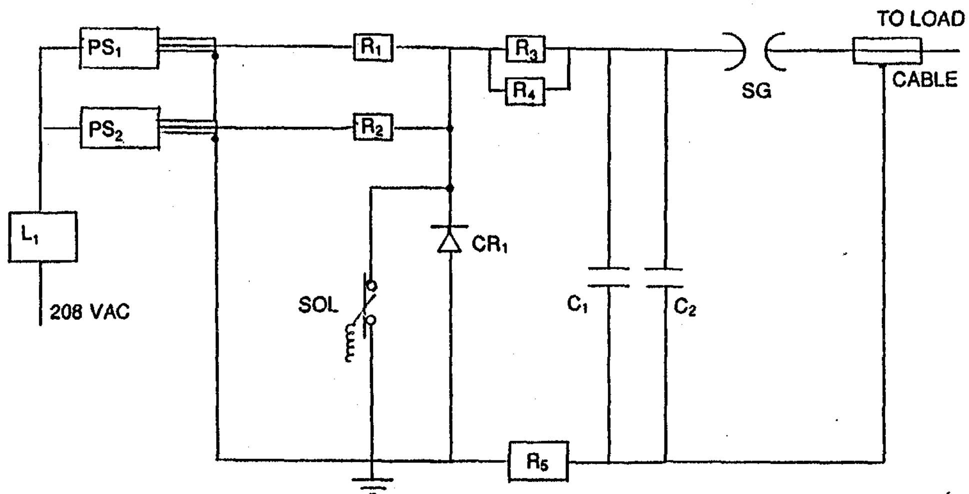


(a)



(b)

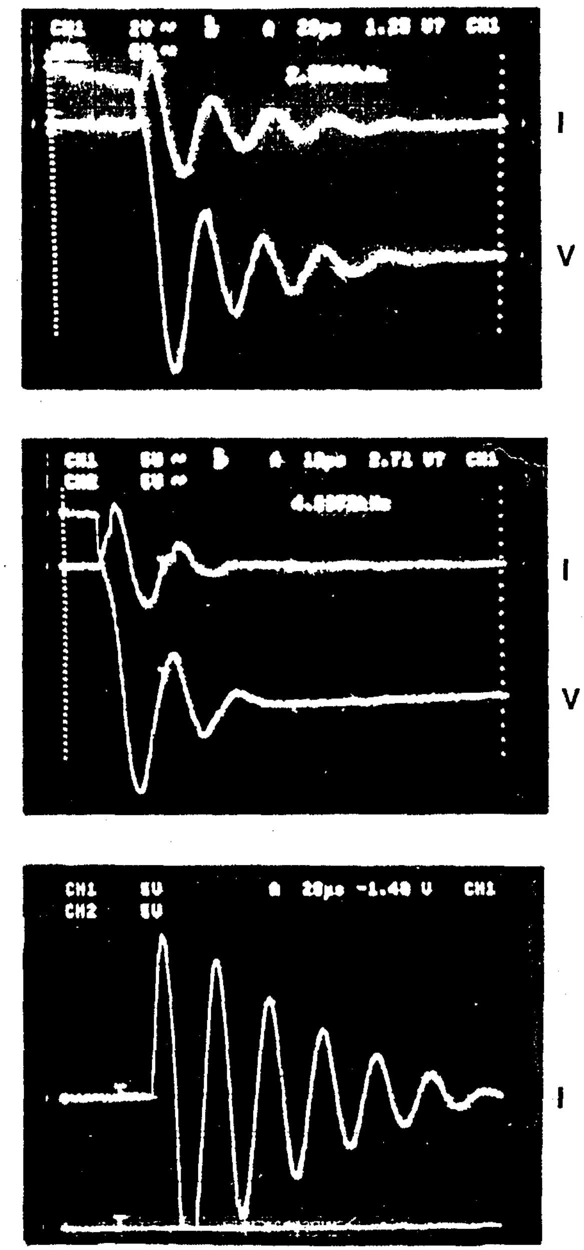
Figure 3.6 DC charger and PFN assembled in a single cabinet.
(a) Rear view
(b) Front panel of 4kW ALE Power Supply



(a)

PS_1, PS_2	Power Supply ALE-402, 25 kV 4 kW
L_1	Line (AC) Filter
R_1, R_2	50 ohm, 25 watt
R_3, R_4	1 K, 225 watt
CR_1	50 kV, Diode
R_5	100 ohm, 100 watt
C_1, C_2	6.3 µF, 50 kV
SOL	Switch
Spark Gap	TSD Open

P7754



(b)

P7717

Figure 3.7 (a) Schematic and specification of 8 kW pulser -
(b) characteristic current and voltage oscillograms

B. Scabbling module design and positioning

The scabbling module is the central component of the EHS unit - the concrete processing tool. It is comprised of electrodes, electrode support frame and HV cables connecting electrodes to the PFN output. To provide area scabbling, i.e. wide path, a sequence of pulses a.k.a. individual electric "explosions" had to cover the area of processing. Single electrode rods moving over the horizontal (X-Y) plane, or multiple, independent electrode pairs had been used initially. Both arrangements are complicated either kinematically or electrically. Fortunately, it discovered in the course of Phase II experiments that a much simpler continuous linear strip-type electrode pair also provides uniform electric pulse distribution, and, consequently, uniform scabbling. This type of electrode is shown in **Figure 3.8**, while **Figure 3.9** explains how due to the preferential breakdown at the electrode-to-concrete contacts, a self-regulated uniform distribution of scabbling pulses takes place.

The linear electrodes are simple to manufacture, to attach to a frame (as in **Figure 3.10**) and to replace; their erosion rate is lower, and the water-exposed surface can be made relatively small. It is important to note that simpler one-dimensional (X)-positioning is required for area scabbling; the width of the scabbling swath is easily modified by changing the electrode length. In the Phase II design, the electrode module was mounted inside a scabbling chamber on the positioner which had two parallel, interconnected motor-driven slides as shown in **Figure 3.11**. The photograph in **Figure 3.12** shows more design details. Two air cylinders provided vertical (Z) module lift which is used when electrodes are moved to the next scabbling position in their periodic cycloidal travel.

C. Scabbling chamber/water enclosure

The scabbling chamber (**Figure 3.13**) keeps a layer of water over the processed floor segment with the help of a rubber foam gasket at the lower chamber perimeter, (Figure 3.14). The foam is compressed partly by the weight of the chamber, module and positioner, and partly by reducing the pressure inside the chamber. It is important that air entering the chamber through the foam provides a counterflow which prevents the process water from seeping outside. At a characteristic -10" H_2O pressure, the air flow rate through the gasket is about 100 cfm (.6 cfm per 1' of gasket length). The air suction was provided by two 1.5 HP blowers or by a wet vacuum unit.

Vertical deformation of the foam up to 1/2" - 1" is permissible. This is sufficient to keep the enclosure "sealed" (despite formation of a scabbling groove) in a static position. To move the enclosure to the next floor segment, it is lifted to avoid damage to the foam.

D. Water/debris flow subsystem

The water layer above the floor fulfills several functions: it transfers breakdown-generated pressure wave to concrete, prevents inter-electrode air breakdown, cools electrodes, prevents dust formation, and assists in concrete debris removal. On the other hand, the contaminated process water, if not recirculated or properly treated, adds to

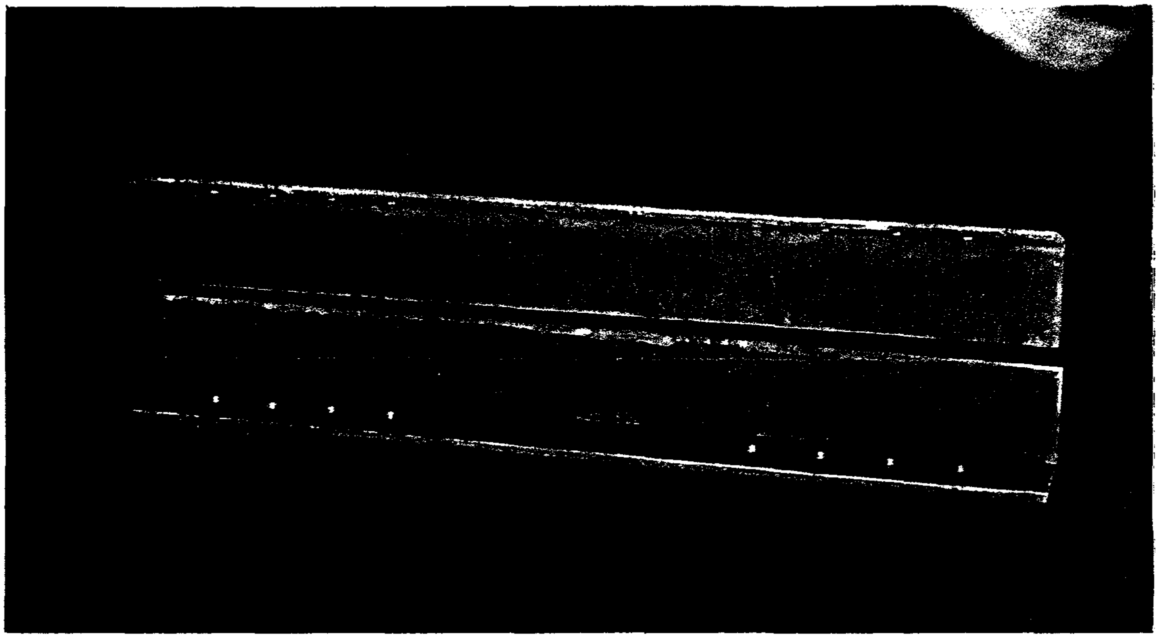


Figure 3.8 Angled strip-type electrodes

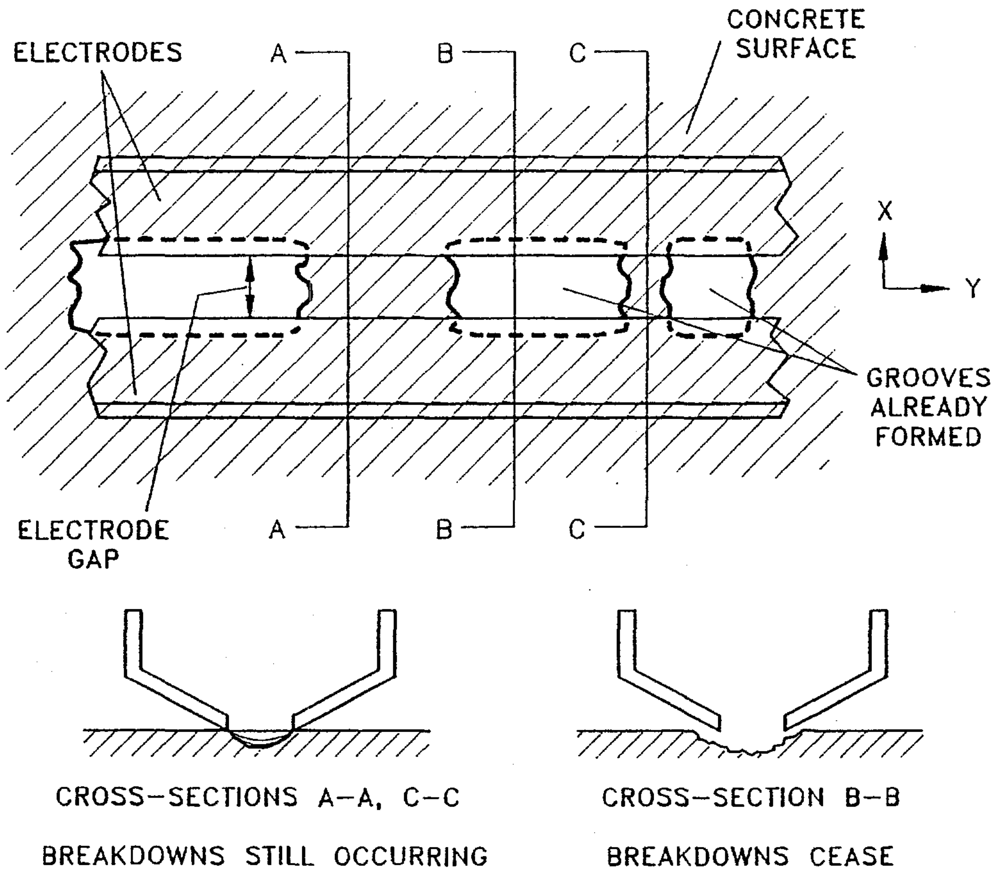


Figure 3.9 Schematics of self-regulation of breakdown distribution along the electrode gap

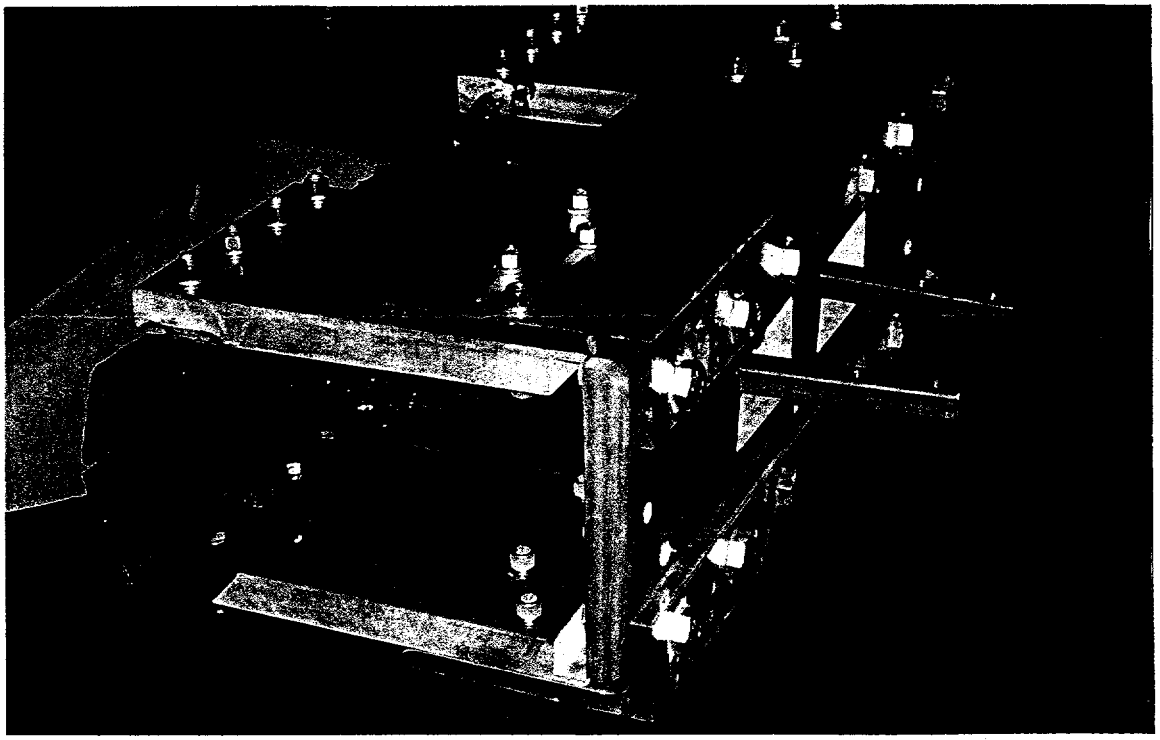


Figure 3.10 26" strip-type electrodes coated by red TRV silicon resin and mounted on the electrode module; solid copper bars are used as cable connectors

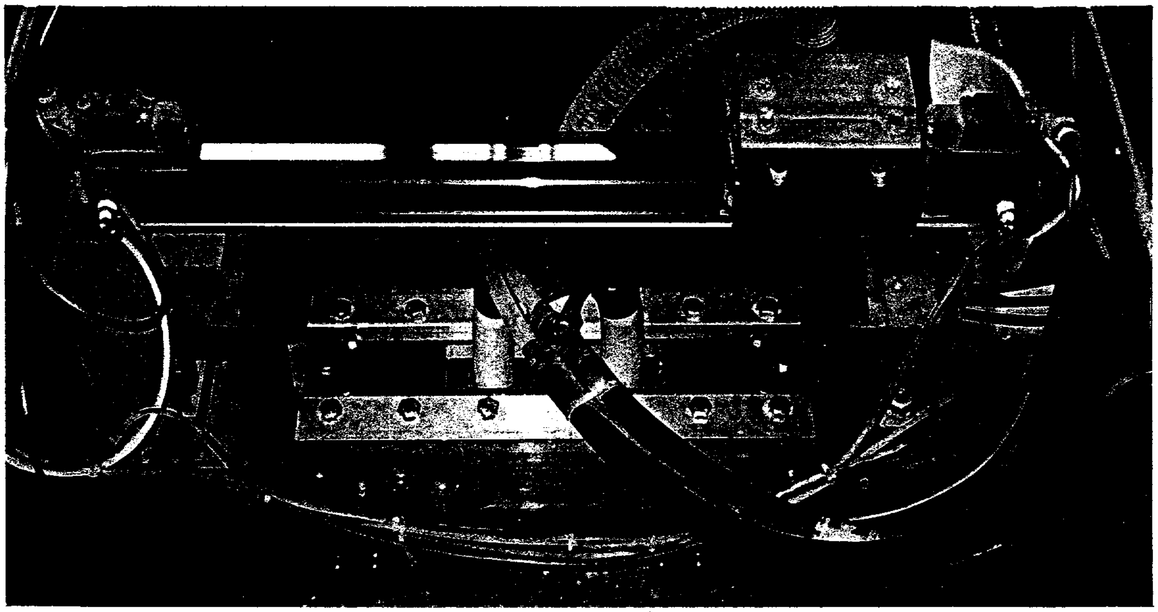


Figure 3.11 Arrangement of a scabbling module and XZ positioner inside the enclosure

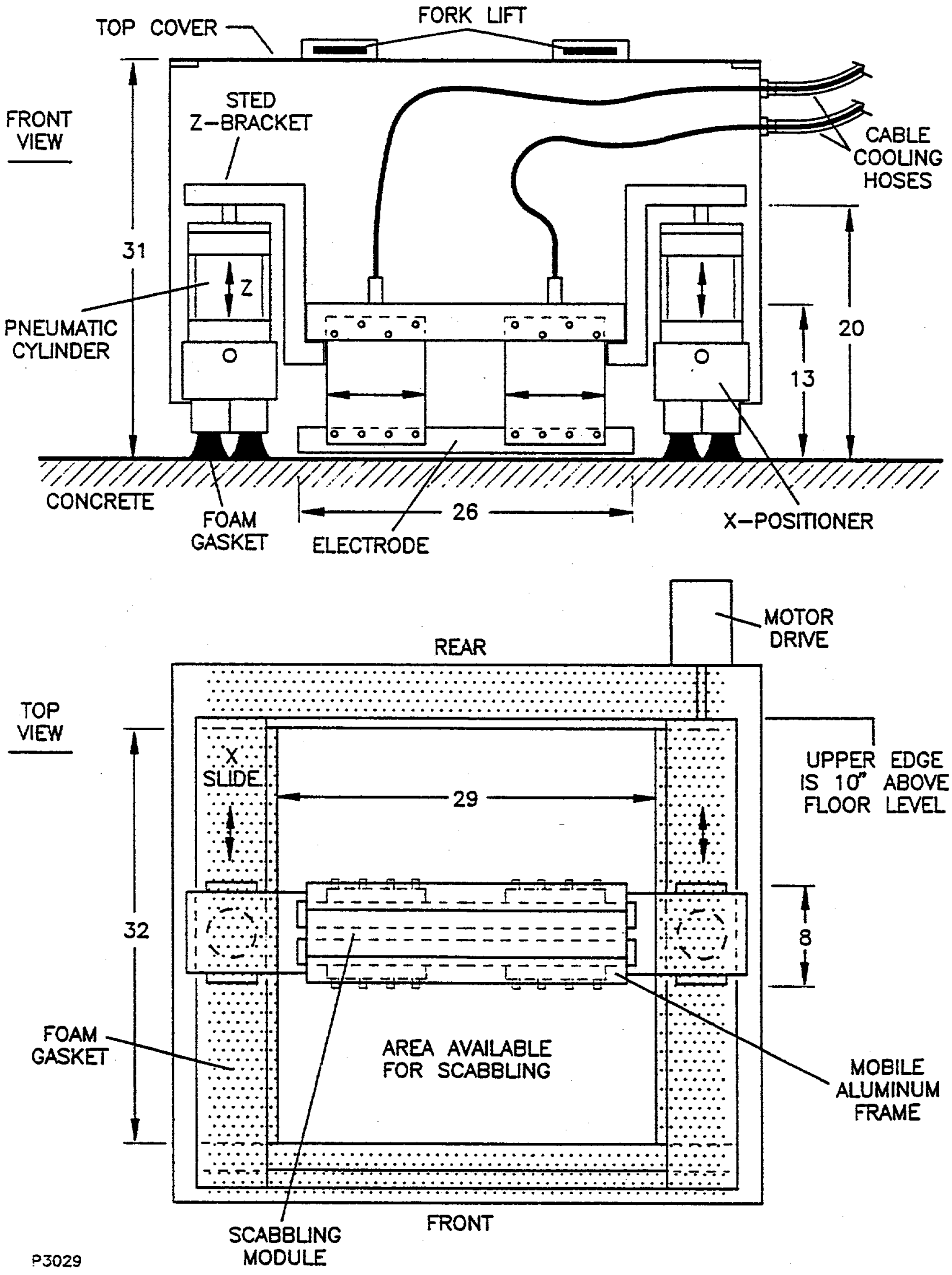


Figure 3.12 Scabbling module supported on two air cylinders (Z-positioner)

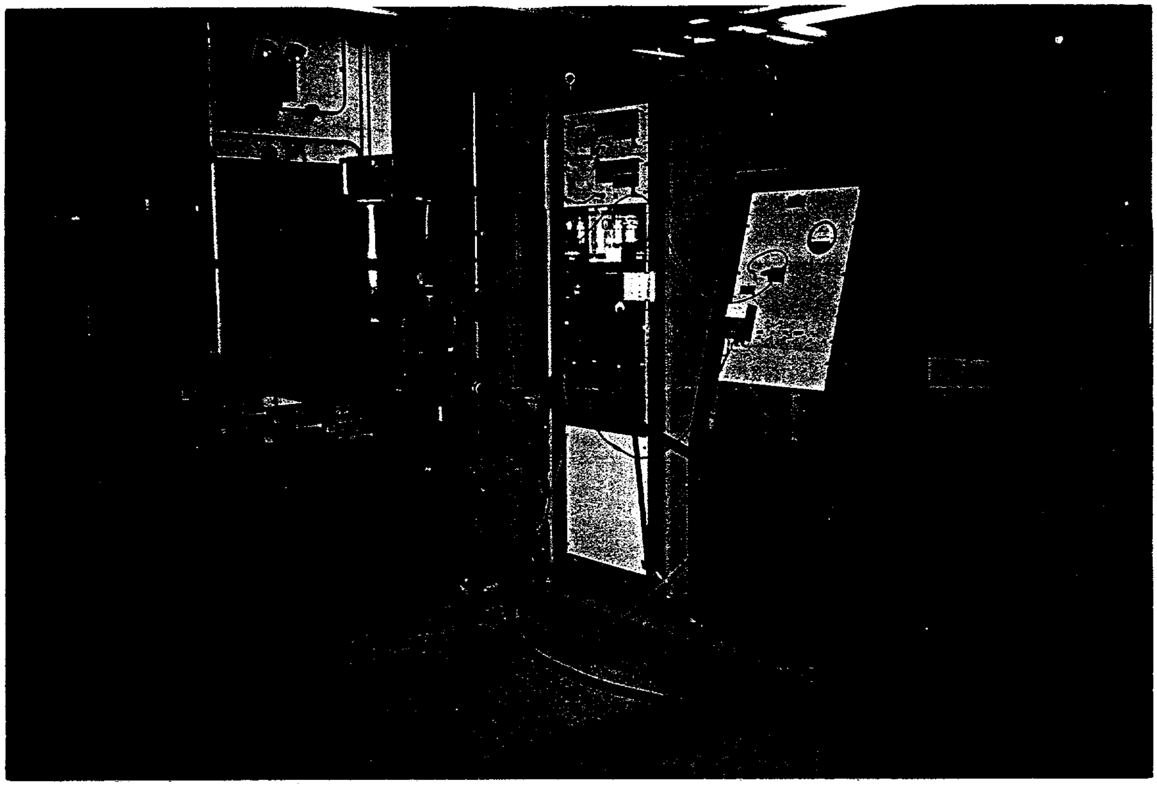


Figure 3.13 Scabbling chamber supported by a forklift, and vacuum blower and diaphragm pump installed above

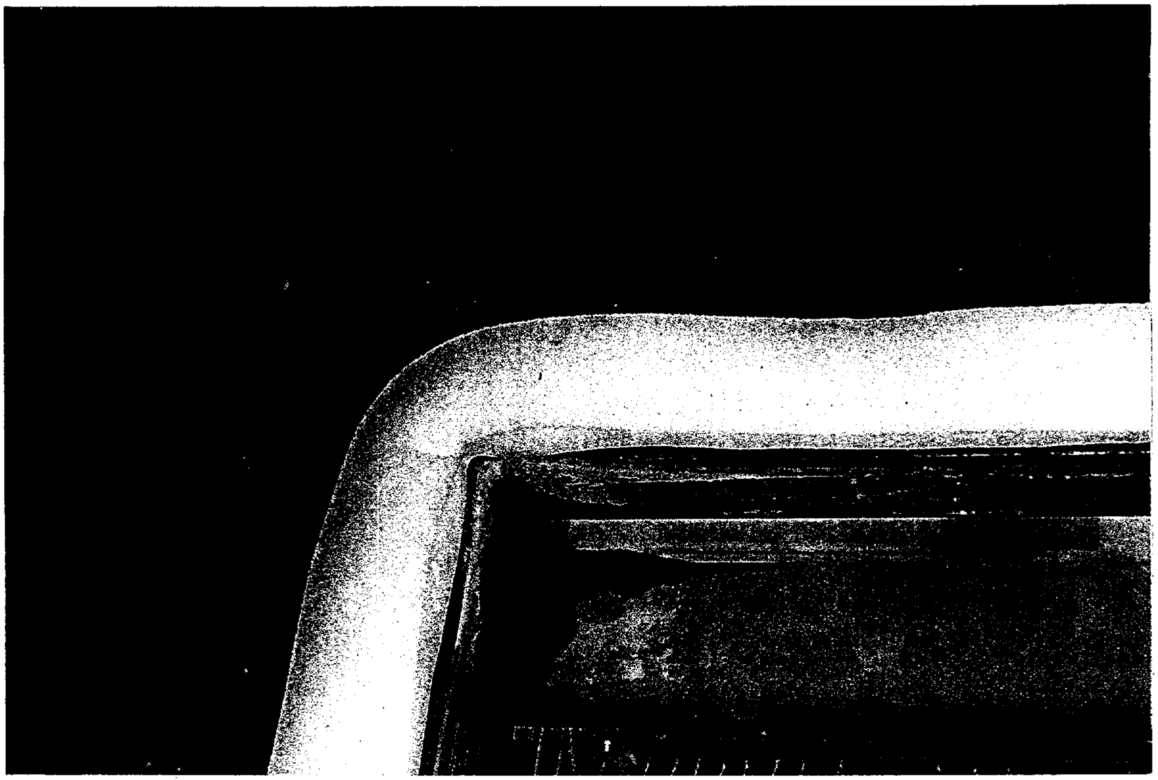


Figure 3.14 Polyurethane foam gaskets (black and white, of different density) installed at the chamber bottom perimeter

D. Water/debris flow subsystem

The water layer above the floor fulfills several functions: it transfers breakdown-generated pressure wave to concrete, prevents inter-electrode air breakdown, cools electrodes, prevents dust formation, and assists in concrete debris removal. On the other hand, the contaminated process water, if not recirculated or properly treated, adds to the total amount of waste. The necessary or allowable degree of water recirculation, minimum makeup, and amount of liquid waste generated by EHS all depend on the nature (especially water solubility) and concentration of the concrete contaminants.

Several modifications of the flow systems were tried. In the final modification, shown in Figure 3.13 and, schematically, in **Figure 3.15**, a standard 55 gallon drum supplies fresh or recycled process water into the scabbling chamber. This was the configuration used during field tests at Fernald. An air-driven diaphragm pump provides a pressure drop across a filter in the drum. After redirecting water flow with a combination of manually-operated valves, the same pump collects water and fine concrete debris from the processed floor and sends it into the drum. Coarse debris either remains on the floor, or is collected and settled in a strainer.

Removal of the coarse concrete rubble is a specific EHS problem. Removal can be achieved either by "pushing" rubble toward a stationary high suction collection nozzle, or by using a suction nozzle to scan the surface in close proximity to the dense and sticky debris layer. For 1/2" deep scabbling, the debris layer is about 1" deep. Both approaches were tried but with only limited success. Some debris remained to be picked up with a wet vacuum unit after the scabbling chamber was moved to the next location.

E. System Integration and Operation Controls

Most of the EHS system components were integrated in a single unit mounted on a self-propelled carriage. A standard forklift track was used to open/close and to move the scabbling chamber over the floor surface. As illustrated by Figure 3.5, the scabbling chamber and main components of a flow subsystem are mounted on the track, while the electric power supply (including DC charger and PFN) cabinet and cabinet containing process controls (AC supply, pulsing controls, controls of X and Z positioners, and air and water flow controls) are located on a separate wheeled platform.

High voltage, high current (up to 40 kA) cables connecting the PFN output to the electrodes deserve special attention. The cables are relatively long, therefore coaxial cable had to be used to decrease the discharge loop inductance and to shorten the pulse. Air cooling (see **Figure 3.16**) was provided to prevent cable overheat.

No.	U_o kV	E_o kJ	L mm	X cm	n	NE_o/S kWh/ft^2	NE_{ef}/S kWh/ft^2	NE_o/m kJ/kg	NE_{ef}/m
1	21	2.8	5	2.5	100	0.47	0.32	1300	880
2	21	2.8	5	2.5	150	0.70	0.47	1280	860
3	24	3.7	8	3.3	100	0.51	0.32	1120	710
4	24	3.7	8	3.3	150	0.78	0.49	1270	810
5	21	2.8	8	3.3	180	0.70	0.47	1280	910
6	24	3.7	8	3.3	150	0.75	0.38	1520	780
7	24	3.7	8	3.8	180	0.74	0.52	1350	850
8	25	3.1	5	3.3	130	0.54	0.39	1270	900
9	25	3.1	5	2.5	130	0.67	0.40	1230	720
10	25	3.1	8	2.5	100	0.52	0.34	1200	770
11	25	3.1	8	2.5	180	0.95	0.67	1350	960
12	27	3.6	8	3.3	150	0.73	0.46	1250	750

U_o Nominal charging
E_o Nominal stored ene
U_{ef} Effective discharge
E_{ef} Effective stored en
L Interelectrode gap
X Distance (step) bet
n Number of pulses nit mass, respectively
n/x Number of pulses
f Pulse frequency
E_o/x, E_{ef}/x Energy input per s
t_p Net pulsing time p2 with Maxwell power supply - 10 μF
M Number of scabbltime is included in the processing time T.
N Total number of p
NE_o, NE_{ef} Total energy input
T Total processing t

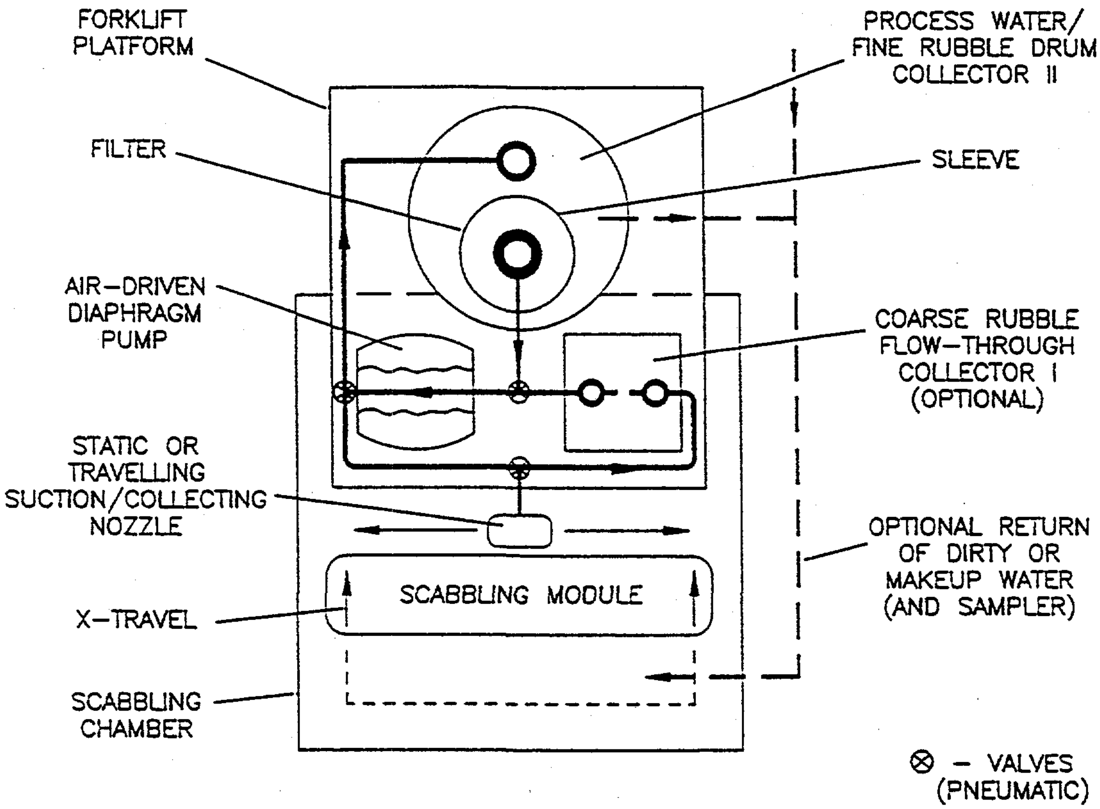


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Figure 3.15 Schematic of a single container water/debris flow system

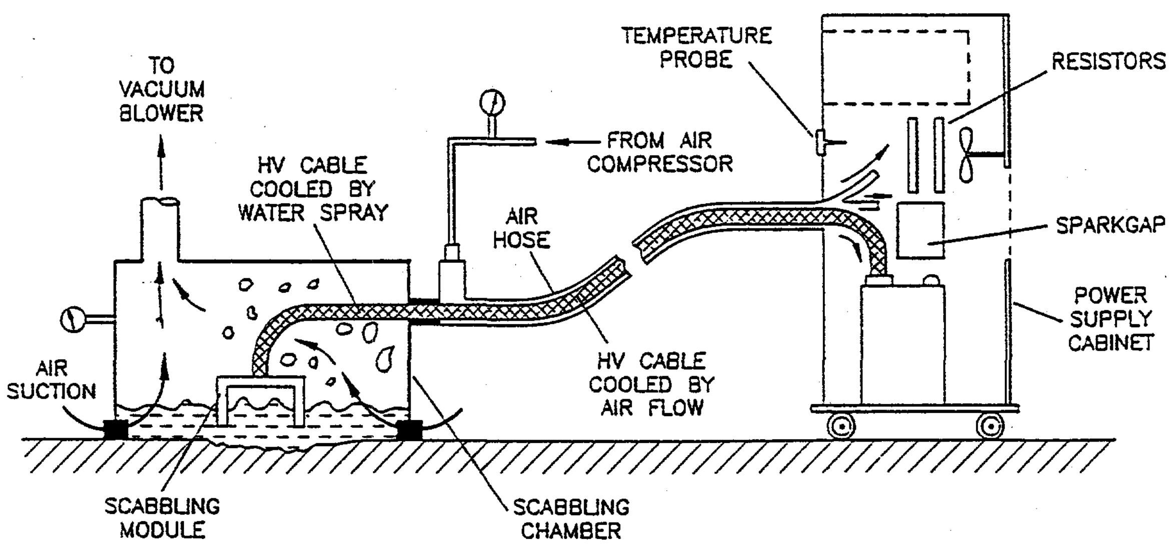

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Figure 3.16 Power supply to scabbling codule HV cable connection and cooling schematic

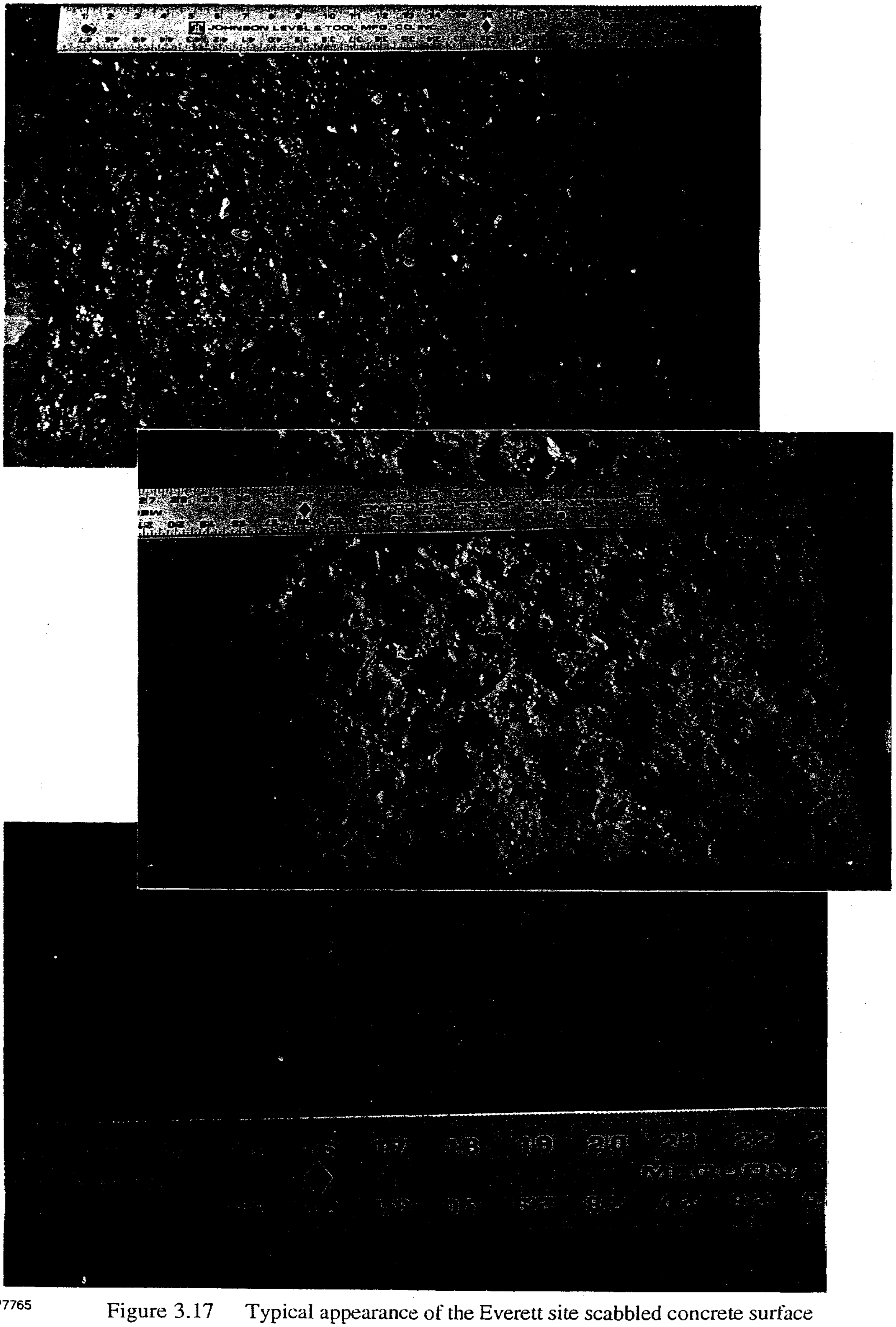

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Figure 3.17 Typical appearance of the Everett site scabbled concrete surface

3.3 PHASE II EHS TRIALS

3.3.1 Everett site trials

Initial trials were conducted at the TSC Everett Building 2 site in Everett, MA. The concrete floor there has 3/4" aggregate, 2" deep bar reinforcement and is 8" thick. A variety of preliminary scabbling experiments were conducted. Observations and measurements were made to study the various effects important to scabbling. These include breakdown localization, current leakage (through clean and process water) electrode erosion; also mechanical effects such as vibrations, electrode-to-concrete surface alignment, water and components heating etc. Changes were made to increase scabbling efficiency and, especially, to improve the lifetime/reliability of the main components.

Quantitative performance characterization and demonstration trials were conducted at the Everett site in May and August 1995, respectively. About 70 sq. ft. (20 segments, 3 to 3.7 sq. ft. each) of floor area was scabbled, 1/4" to 1/2" deep. Typical appearance of the scabbled surface is shown in **Figure 3.17**. Roughness (local non-uniformity) of the scabbled surface is defined by inhomogenous structure of concrete: aggregate components are much harder to remove than inter-gravel mortar. On the other hand, systematic (over the floor segment area) depth variation usually result from the electrode misalignment or discharge localization over limited length of the electrode gap.

Ranges of conditions and operating parameters and performance data obtained in these trials are provided in **Tables 3.3** and **3.4**. The main performance data can be summarized as follows:

1. Consumption of electric energy per unit processed area is 0.47-0.95 kWh/sq. ft. and 0.32-0.67 kWh/sq. ft. if calculated on the basis of "nominal" (i.e., taken from power supply rating) and "actual" (either measured either directly by AC meter or obtained from DC voltage and capacitance) stored energy, respectively. The difference between the nominal and actual values of stored energy is due to incomplete capacitor charging for short time intervals between the sequential pulses.

2. Consumption of electric energy per unit concrete mass removed is 1100-1500 kJ/kg and 700-950 kJ/kg for nominal and actual stored energy values, respectively.

3. For a given scabbling depth, the difference between energy consumption under a different set of operating parameters is not significant. The average value is about 100 kJ (28 W-hours) of the actual storage energy per 1 mm depth, per 1 sq. ft. area.

TABLE 3.3

RANGE OF CONDITIONS AND OPERATING PARAMETERS FOR SCABBLING TRIALS AT TSD EVERETT SITE

DC Power Supply	a) ALE-402, or
	b) Maxwell Lab
Maximum (nominal) Available Power	4 kW
PFN Main Components	a) 13 μF Capacitor, EGG GP-41B Switch
	b) 10 μF Capacitor, EGG GP-15B Switch
Operating Mode	XZ Positioning with Automated Cycle Control
Ranges:	
Charging Voltage	$20 < U_0 < 26$ kV
Stored Energy	$2.5 < E < 3.7$ kJ
Electrode Gap	3/16" < L < 3/8"
Electrode Width	18" < W < 24"
Pulse Frequency	$13 < f < 2.2$ Hz
X-positioner Step	1" < x < 2"
No. Pulses per Position	$50 < n < 150$
Scabbled Area - Width	18" < w < 24"
Length	20" < e < 24"

4. If concrete contamination is limited to a thin concrete layer, the EHS operating parameters can be selected to provide about 4mm scabbling depth (due to scabbling non-uniformity, shallower processing may leave local unscabbled areas). Under these conditions the energy consumption is expected to be about 0.1 kWh/sq. ft.

5. The scabbling rate varies between 6 and 15 sq. ft./hour, and depends only weakly on the specific energy input.

6. When the number of pulses per scabbling position (or per unit length) increases, the scabbling rate decreases somewhat (while the scabbling depth increases).

7. For shallow (under 1/4" deep) scabbling sufficient for removing surface contaminant, a scabbling rate of about 15 sq. ft./hr can be expected. For deeper (~1/2") scabbling, a rate of about 10 sq. ft./hr. can be achieved, but at about two times higher energy input (i.e., at higher installed power).

Assembly and testing of SHV scabbling system

According to short SHV system trials, 3/8" scabbling depth can be achieved at relatively low -100 to 200 J/g - energy consumption. Due to the relatively low pulse current, a moderate mechanical strength of the module was sufficient, and the electrode erosion low. It was discovered, though, that performance may deteriorate after concrete debris accumulates raising the electric conductivity of the process water.

After Phase I experiments showed prospects for increasing scabbling rate and reduction of energy consumption by using higher pulse voltages, an effort was undertaken in he Phase II to develop Super-HV unit for area scabbling. Power supplies/PFN were designed to provide operating voltage up to 130 kV and 1 kJ, 4 μs pulses by using two-cascade or four-cascade PFN/voltage multipliers, shown in **Figure 3.18**.

Both pulse power sources were tried first in the St. Petersburg Technical University laboratory and later at the Everett site in combination with multi-electrode scabbling module **Figure 3.19**.

On the basis of scabbling results and equipment performance at Everett, a decision was made to take the subscale prototype EHS unit for field testing at the Fernald DOE site.

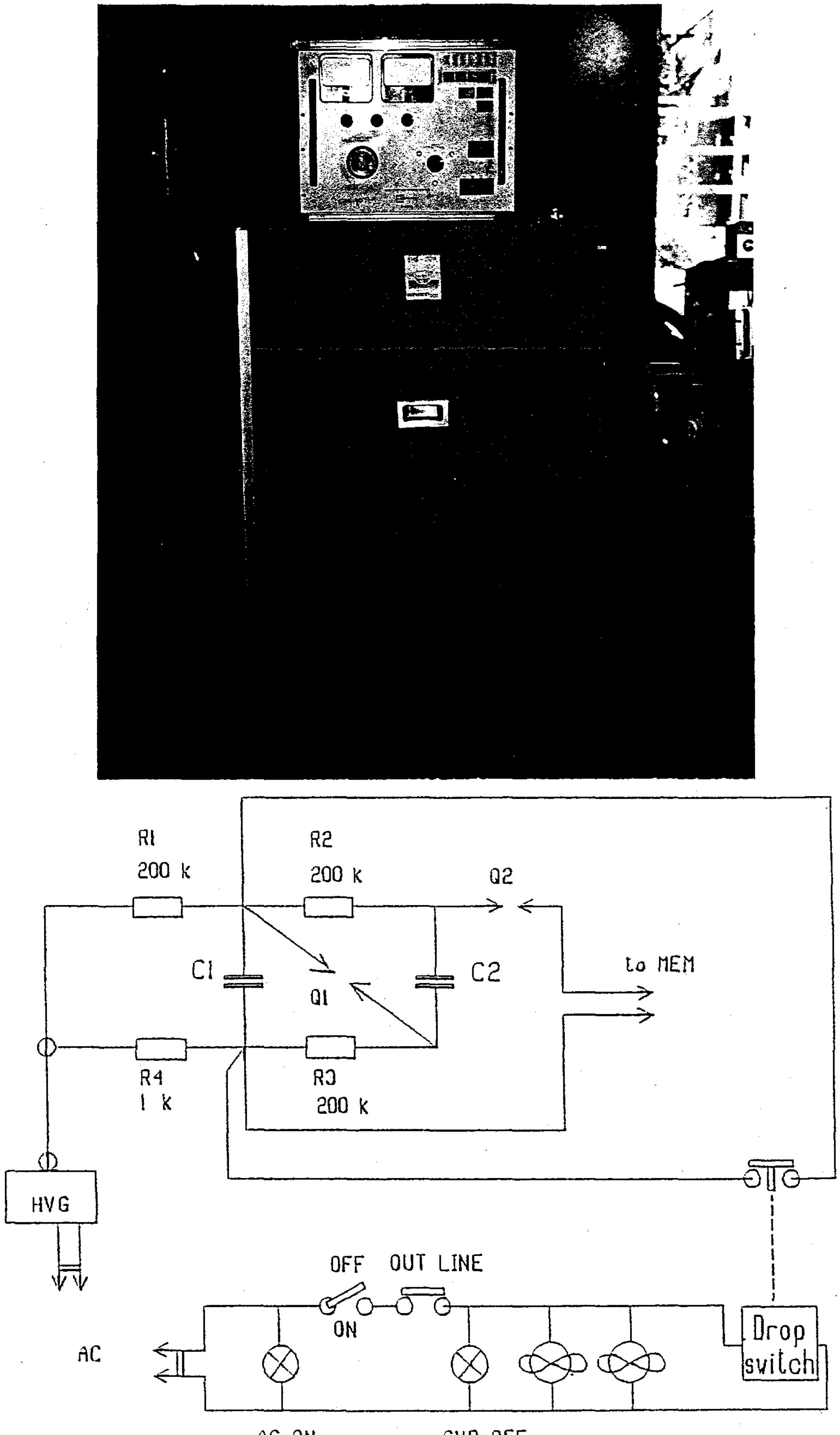
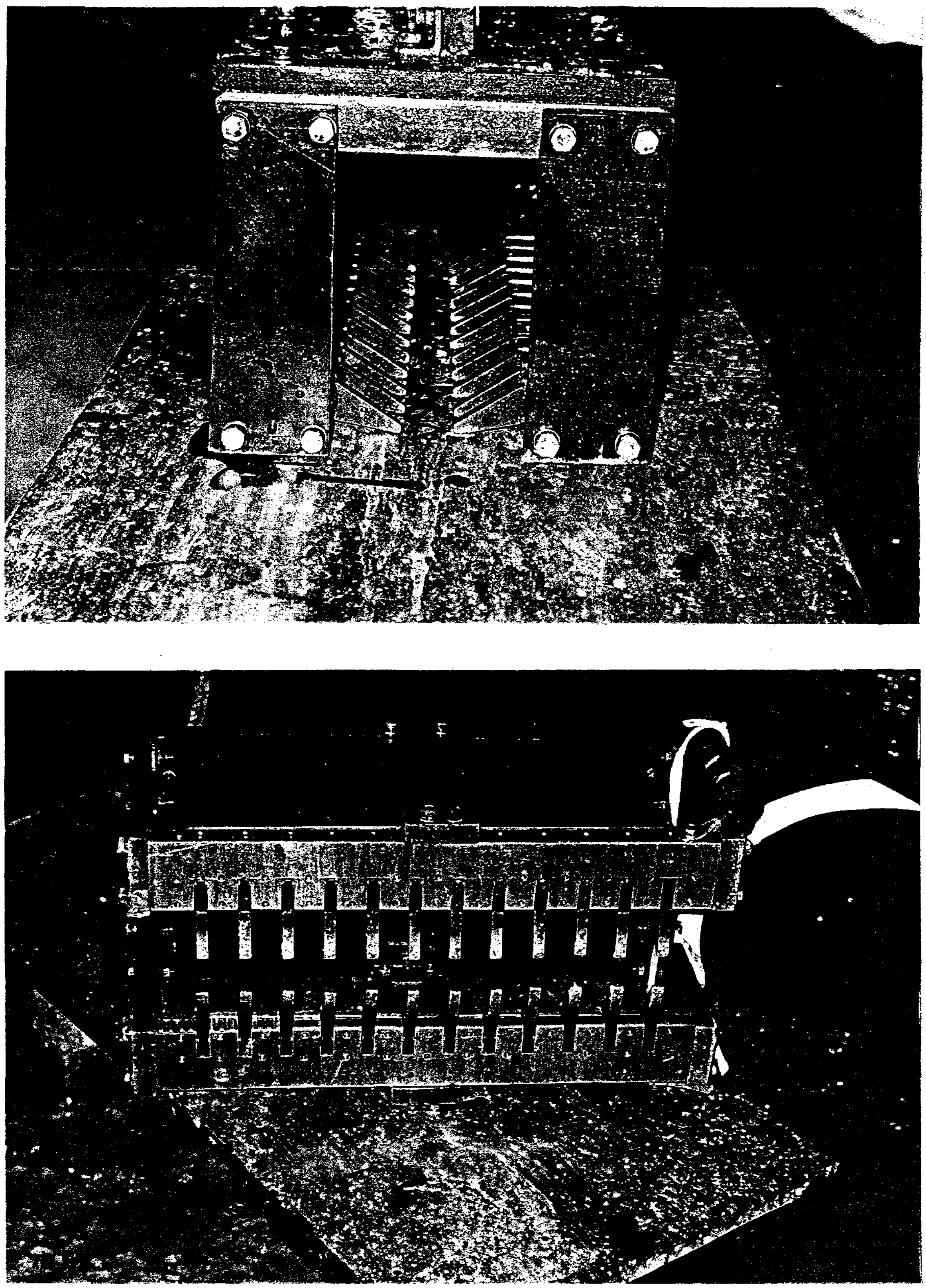


Figure 3.18 Photo and electric schematic of a two-cascade 130 kV pulser



(a)

(b)

P7742

Figure 3.19 Multi-electrode SHV scabbling module:
(a) Side view
(b) Bottom view

3.3.2 Fernald site trials

3.3.2.1 Objectives of Fernald demonstration trials

The field tests at Fernald had a general objective to demonstrate EHS technical feasibility for decontamination of concrete with a given uranium contamination. Specific objectives were as follows:

- Evaluate level/quality of decontamination by EHS under "real-life" conditions
- Demonstrate reliable and safe operation of the EHS unit and its individual subsystems
- Evaluate main scabbling characteristics: rate, depth, uniformity, energy consumption, water consumption
- Determine amount of waste - concrete rubble, dust, water, and other consumables
- Project performance, operating and capital costs of a full-size EHS system

3.3.2.2 Site characterization and test area preparation

The demonstration trials were conducted in Plant 6A of the FEMP federal facility which from 1952 to 1989, produced high-purity uranium metal products by scrap briquetting, rolling, heat treating and machining. The demo trials preparation, implementation, logistics and regulations included preparation (in cooperation between TSC and FERMCO) of a Project-Specific Plan, Health and Safety Plan, and Sampling and Analysis Plan, plus, site visits, training and medical examination of TSC personnel, transportation, unloading/loading/assembling/disassembling, and checkup and release of the EHS equipment.

Of 15 working days at the Fernald site, 8 days were spent by the TSC team on activities directly related to the trials. Scabbling, sampling and various measurements (by TSC personnel) occupied 15 hours; the scabbling itself took about 7 hours. **Figure 3.20** shows the positions of scabbled floor segments of 3.7 sq. ft. each, about 30 sq. ft. total.

3.3.2.3 Scabbling operation

The EHS unit operated flawlessly throughout the trial period. There were no malfunctions of either electric pulse power supply, or controls, positioner, and scabbling module.

The EHS unit operated (see **Figures 3.21** a, b) with either one or two 4 kW, 25 kV DC chargers and a single, open spark gap switch. At the actual charging voltage in the 15 to

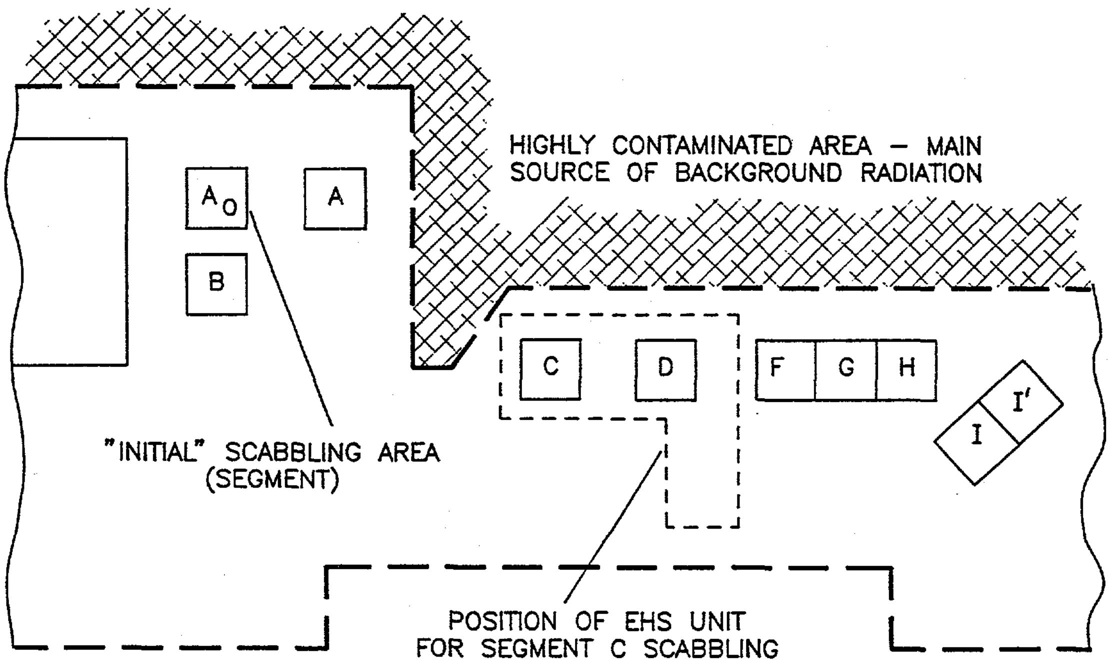
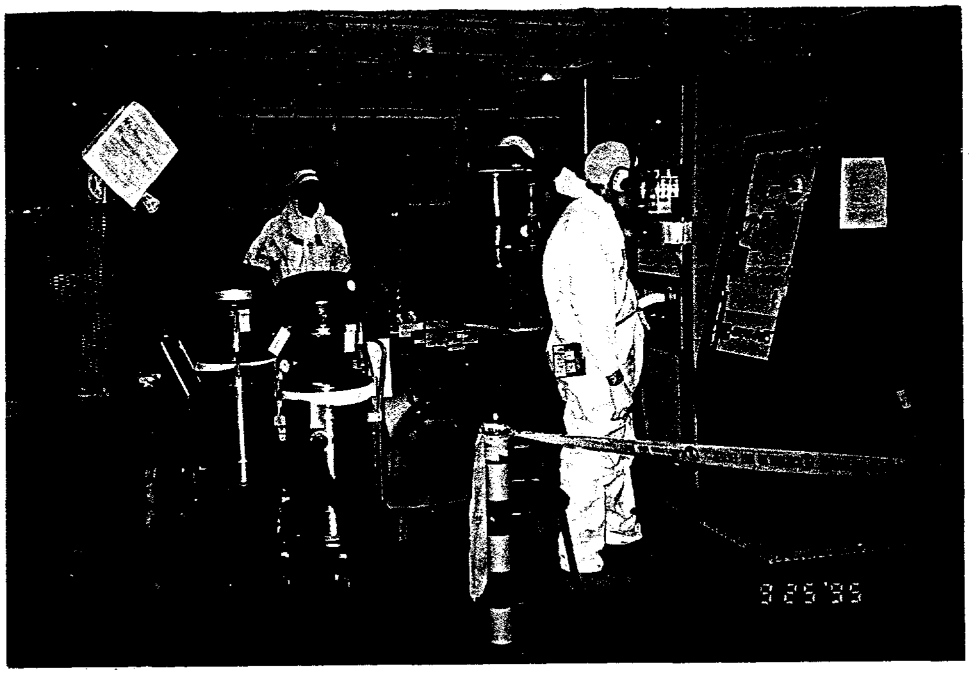
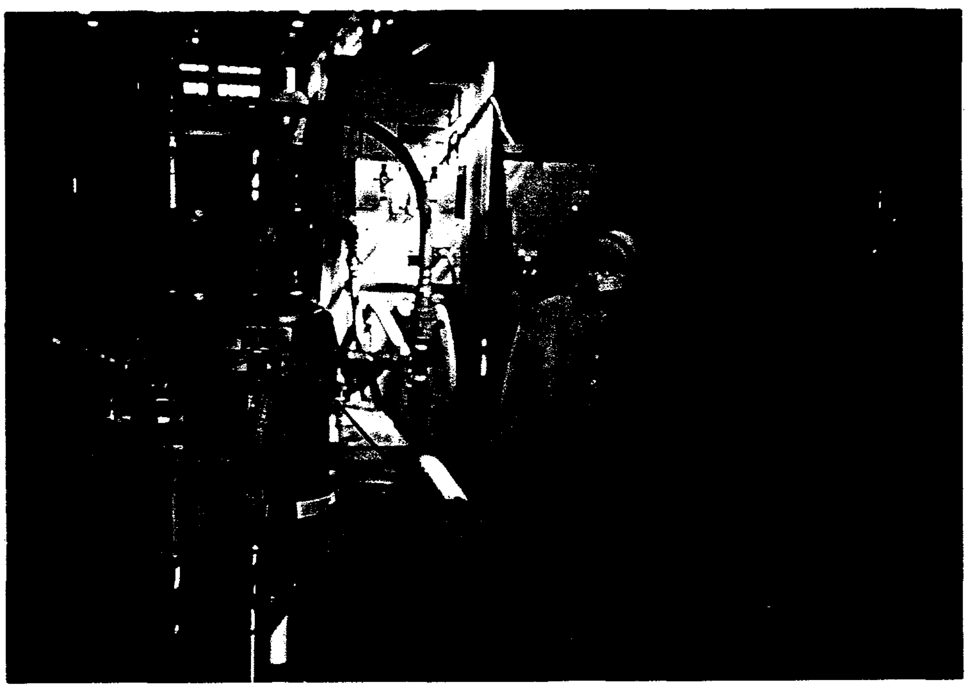


Figure 3.20 Arrangement of Floor Segments in Building 6 Scabbling Work Area



(a)



(b)

Figure 3.21 EHS Unit during Scabbling Operation at Fernald.
(a) Floor Segment C Processing; Contaminated Uranium Rolling Mill is in the Background
(b) Processing Floor Segment F Using 8kW Power; Operator Already More Relaxed

19 kV range, charging current was about 0.2 A, the pulse operating rate was 1.4 Hz (one power supply) and 2.3 Hz (two power supplies), pulse energy was about 2 kJ, and the average effective (i.e. actually used) AC power about 2 kW or 50% of the installed AC power.

The scabbling module used 26" long strip electrodes, operated with 1.4" water gap and were moved by the X-positioner in 1.2" steps.

A water flow system described in section 3.2 (see also Figures 3.13 and 3.15) was used to fill/remove water in/out of the enclosure. Two HEPA filter-equipped wet vacuums were used to evacuate the enclosure as well as for collecting wet debris not removed with the process water.

Module repositioning was controlled by the operator. It took 18 positioner's Δx steps to process the area available for each chamber location. At each location, pulsing + positioning time was about 1 hour with one power supply and about 1/2 hours with two parallel power supplies. **Table 3.5** characterizes test conditions and features, and **Table 3.6** provides other operating and performance data.

Except when two power supplies were used, the operating conditions were not much different from those at the Everett site. The scabbling rate at comparable condition (e.g. with same pulse frequency) and depth was 20 to 40% lower than in Everett. At 2.3 Hz frequency net (pulsing only) rate was about 10 sq.. ft. per hour. The average energy consumption (based on the actual AC power level) was about 0.5 kWh per sq. ft. which was, again, somewhat higher than at the Everett site.

The difference in both rate and energy numbers can be interpreted as evidence for higher strength of Fernald concrete, but there could be other factors involved. The data are insufficient to make a statistically-valid conclusion.

3.3.2.4 Scabbling quality

The appearance of the scabbled concrete and depth distribution obtained by a mechanical depth gauge along one cross-section is shown in **Figure 3.22**. Compared to Everett concrete, where large "stones" were withdrawn from the mortar, scabbling of Fernald concrete left most of the stones intact indicating better stone/mortar bonding.

Detailed scabbling depth measurements were made at Fernald by a laser-based instrument (Geodimeter). Examples of scabbling depression reliefs obtained by this techniques are presented in **Figure 3.23**. We estimate that precision of these measurements is about 15%. Because of 2" distance between measurement points, Geodimeter does not reveal a fine surface structure and smoothes the depth profile. Gauge measurements are cumbersome but better characterize strong spatial depth distribution. Figure 3.22 presents distribution of depth values over two cross-section of one floor segment.

TABLE 3.5

DESCRIPTION OF FERNALD SCABBLING TRIALS

Date	Test #	Floor Segment	Power Supply Operation				Scabbling Duration/min.	Remarks
			No. of Chargers	Frequency Hz	No. of Pulses*	U_O**, kV		
10/22	1	A	1	1.33	200	22	64	Preliminary Test; 16 steps†; fresh water
10/25	2	B	1	1.35	180/360	23	70	18 steps†; steps 14-18 360 pulses; fresh water
10/25	3	C	1	1.36	190	23	50	Fresh water
10/26	4	D	1	1.5	250	24	65	Recirculated water
10/26	5	F#	1	1.5	225	24	60	Second pass through steps 1-6
10/27	6	G	1	2.5	200	24	28	Recirculated water
10/27	7	H	2	2.5	250	24	36	Second pass over cracks (steps 12-14)
10/28	8	I'	2	2.5	250	24	-	Only 2 steps; water leak through floor joint
10/28	9	I	2	2.5	200	24	30	Fresh water

*Per each electrode position (step)
**Initial charging voltage
†18 steps all other tests
#Segment E was not scabbled

TABLE 3.6

OPERATING AND PERFORMANCE DATA FOR FERNALD SCABBLING TRIALS

Test No.	N	T_p min	T_r^+ min	Input Energy, kJ		<d> cm	V cm^3	M kg	S/T_p ft^2/hr	Specific Energy Consumption		V/T ft^3/hr
				E_{ef}	NE_{ef}					NE_{ef}/S kWh/ft^2	NE_{ef}/M kJ/kg	
1	3200	41	23	2.3	7400	0.79	2500	6.0	4.8	0.63	1240	0.13
2	3080*	40	24	2.4	7800	0.38	1420	3.4	5.6	0.58	2160	0.07
3	3420	42	8	2.5	8250	0.68	2350	5.65	5.3	0.62	1450	0.12
4	4500	30	35	2.4	10800	0.63	2170	5.2	7.4	0.81	2070	0.15
5	4500	30	30	2.4	10800	0.51**	1760	4.2	7.4	0.81	2520	0.12
6	3600	15	13	2.05	7400	0.51**	1760	4.2	14.8	0.56	1730	0.24
7	4500	18	18	2.05	9200	0.51**	1760	4.2	12.3	0.70	2150	0.20
9	3600	15	15	2.15	7800	0.81	2800	6.7	14.8	0.59	1160	0.38

N — Total number of pulses
T_p — Total pulsing time
T_r^+ — Total repositioning plus auxiliary time
V — Volume of concrete removed
M — Mass of concrete removed
S/T_p — Scabbling rate
<d> — Average scabbling depth
* — Local crack scabbling not counted
** — Average for F, G and H segments

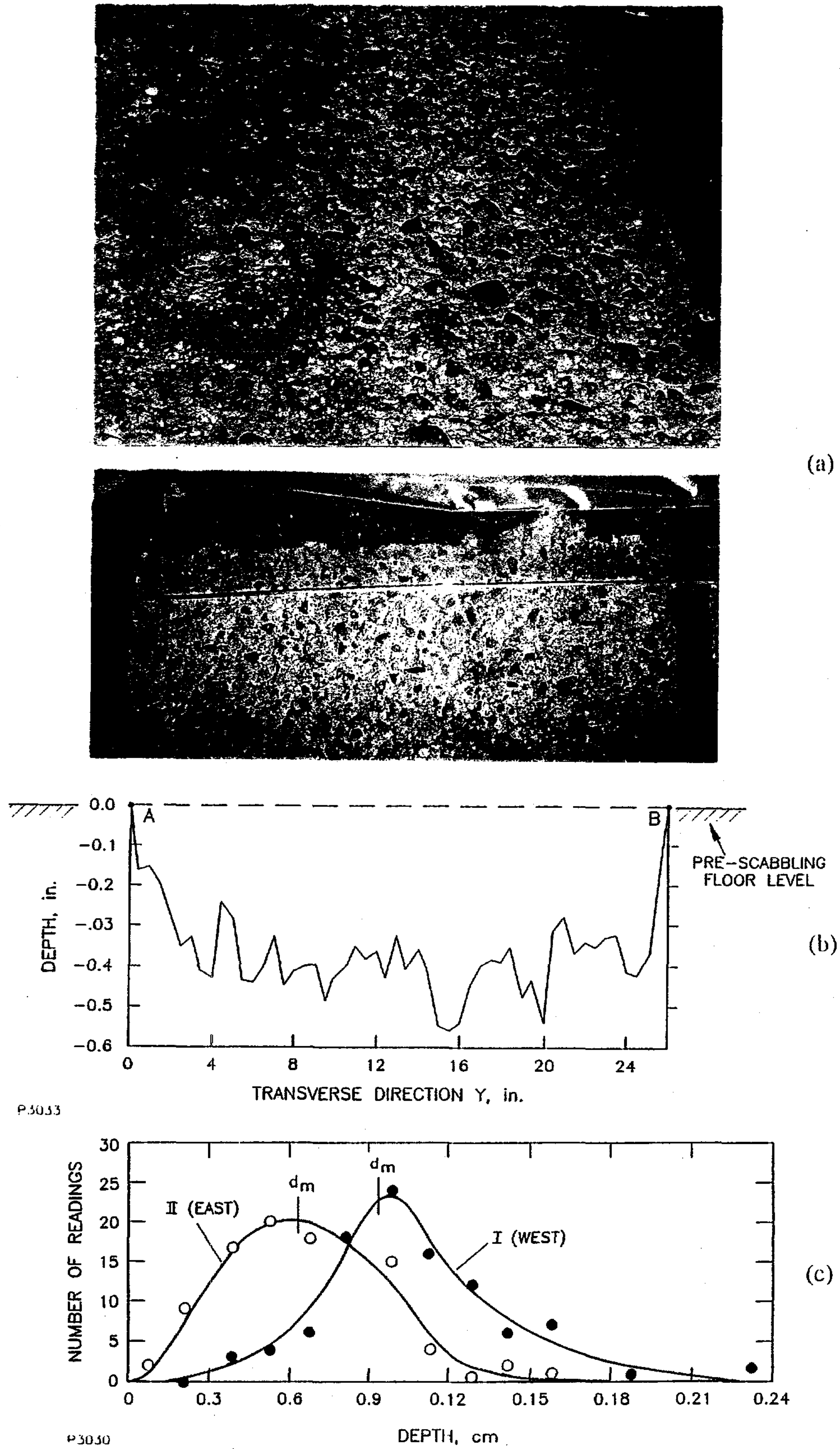
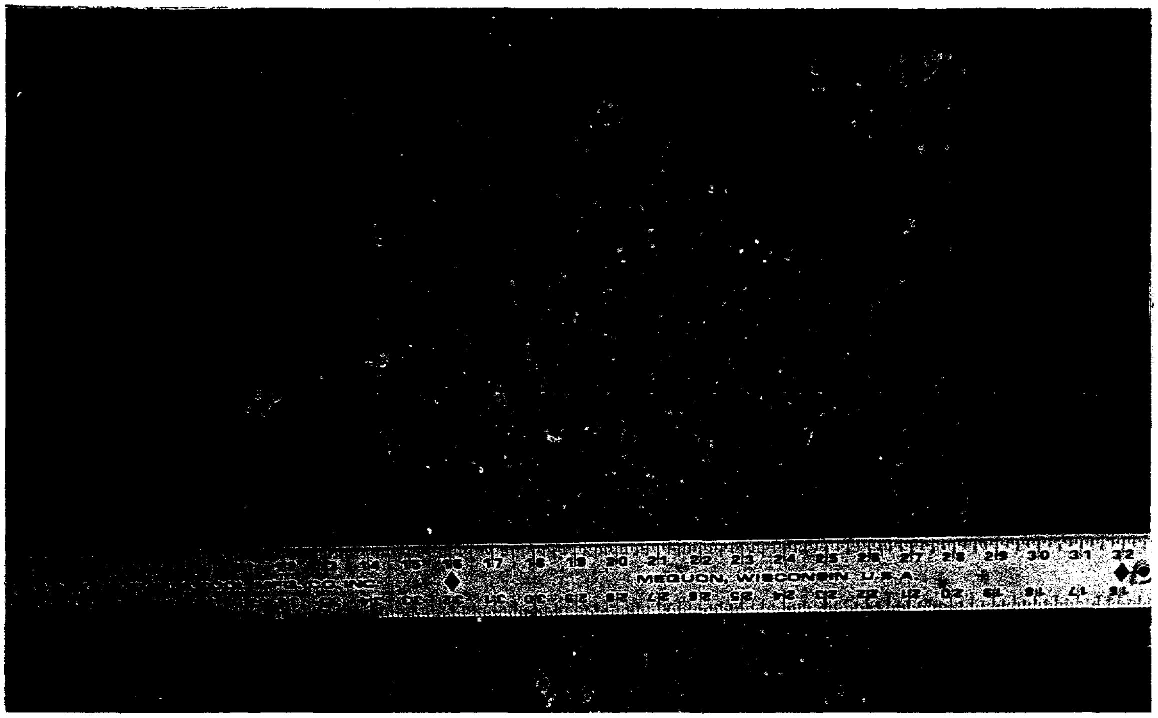


Figure 3.22 Features of Scabbled Surface
(a) Appearance
(b) Scabbling depth distribution obtained by point-to-point gauge measurement
(c) Depth Distribution Function for Cross-Section of the Floor Segment



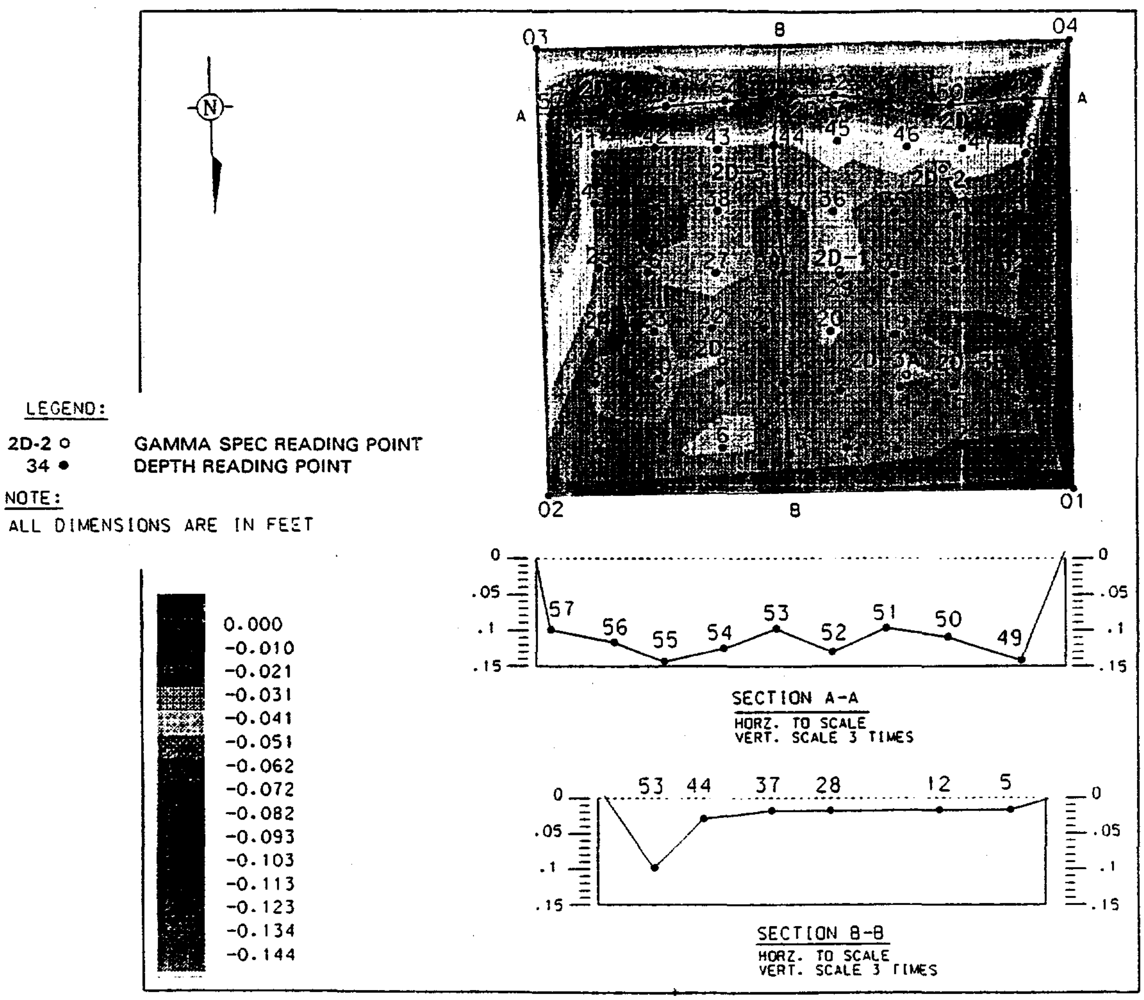


Figure 3.23 Topographic map and scabbling depth profiles for decontaminated floor segment at fernald (FEMP Geodimeter Data)

As an independent check of scabbling depth data, we recommend simple independent average depth evaluation by a) total debris weight measurements, and b) "sand backfill" measurements.

In addition to concrete inhomogenuity, irregularities in breakdown discharge localization may also result in local depth variations. Randomness of discharge distribution along the electrode gap can be disturbed by such factors as variances in

- electrode-to-floor clearance
- electrode gap width
- electrode edge condition
- vertical pressure on the floor surface
- debris content/water quality

These factors may result in systematic (large scale) changes of scabbling depth in both Y (lateral) and X directions. They can explain, for instance, some systematic reduction of scabbling depth in the X direction observed at Fernald.

3.3.2.5 Concrete floor decontamination data

Removal of concrete surface layer is a precondition for decontamination, but still does not assure high decontamination quality.

Among the factors affecting EHS success, the most important are:

- Correct selection of a scabbling depth
- Negligible penetration of a surface layer-bound uranium into the bulk concrete due to EHS - related phenomena (i.e. shock propagation, crack formation, water penetration)
- Absence of recontamination of a newly-formed surface by uranium solution or particulates recirculated with the process water
- Complete removal of wet concrete debris, including fines
- Insignificant contamination of surroundings during the EHS operation

Two main techniques were used to monitor EHS decontamination at Fernald:

a) Concrete surface radioactivity survey; counts-per-minute (CPM) measurements were made using b and g radiation sensors by both FERMCO and TSC teams

b) An X-ray Fluorescence (XRF) spectrometer was used by FERMCO team to determine total uranium concentration in the concrete layer.

For each floor segment, at least five pre- and post-scabbling measurements were made; **Figure 3.24** provides an example. Additional readings were taken at the locations of surface defects.

The floor was pre-washed to remove "semi-loose" contamination; resulting CPM was of the order of 1,000 units with an exception of local defects where the initial CPM reached 2500 (cracks, dents) or even 20,000 (joints). Post-scabbling washing was also practiced but did not result in significant changes in the surface radioactivity.

More detailed description of these techniques and some other approaches, and discussion of the data obtained is given in TSC Phase II and FERMCO reports.

Typical results are presented below.

Pre- and Post scabbling radioactivity and total uranium readings averaged over floor segments are given in **Table 3.7** and **Table 3.8**, respectively.

It appears that EH scabbling to 1/4" average depth achieves a factor of ten, or more, reduction of the uranium content, from the initial level of several thousands rpm/100 sq. cm (or equivalent amount of several thousand ppm of uranium). Under these conditions, the input from small local processing defects ("unscabbled islands") into the total radiation from floor areas larger than few square feet would be insignificant.
Also, it should be taken into account that when the residual contamination is caused by the surface-sticking fine debris, deeper scabbling might not improve the quality of decontamination at all.

Of practical interest (e.g., for comparison with "free release" limits usually determined per 100 sq.cm area) are also contamination levels averaged over specific floor \areas. In our opinion, larger areas are more characteristic when a "full body" irradiation is the main health concern. We conclude from the experimenytal data that when CPM and XRF signals are averaged over scabbled 2-4 sq. ft. floor segments, then more 90% uranium removal is achieved at about 70% of the treated floor area.

Useful information about the uranium contaminant and its partition between process water and coarse/fine concrete debris was obtained also from measuring radioactivity and uranium content of the collected debris and process water. This allows a check of scabbling material balances, and of partition of uranium between the concrete rubble and the process water. This is important for designing flow recirculation and debris separation, and to determine tolerable degree of water recirculation and makeup water volume.

Locations for water and debris sampling and characteristic uranium contents of the samples are shown in **Figure 3.25**. It follows from the measurements that EHS generates.

a) Liquid waste: unfiltered process water containing several hundred ppm of uranium, mostly in the form of (or attached to) particulates of larger than 0.5 mm diameter. Removal of this debris reduces radioactivity practically to a "fresh" water

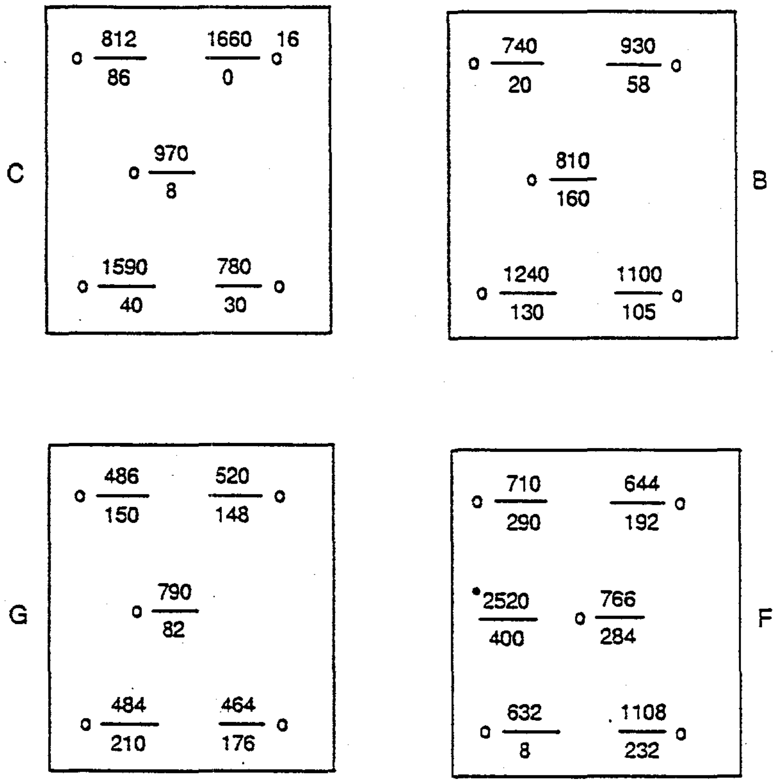


Figure 3.24 Pre (numerator)- and post (denominator)- scabbling radioactivity data over four floor segments

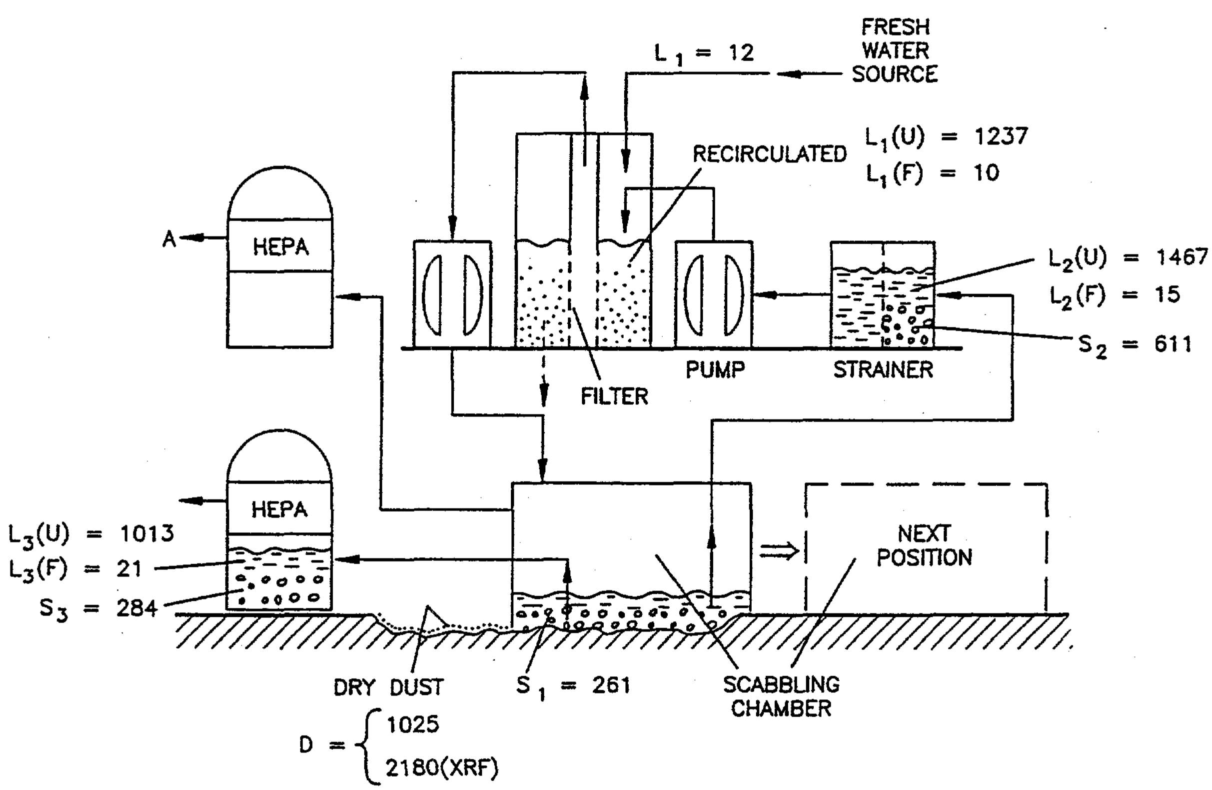


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Figure 3.25 Schematic of the process water and solid waste sampling. total uranium content (in ppm) is for B segment

TABLE 3-7

PRE- AND POST-SCABBLING RADIOACTIVITY READINGS AVERAGED OVER FLOOR SEGMENTS, TAKEN BY TSD

Floor Segment Designation	Average Radioactivity, CPM		CPM Ratio
	Pre-Scabbling	Post-Scabbling	
B	370	26	14.2
C	1130	19	59.0
D	3060	210	15.5
F	1280	280	4.6
G	450	122	3.7
H	860	78	11.0
I	1240	25	49.0
Average	1200	109	22

TABLE 3-8

PRE- AND POST-SCABBLING XRF DATA AVERAGED OVER FLOOR SEGMENTS

Floor Segment Designation	Average Uranium Content, PPM		PPM Ratio
	Pre-Scabbling	Post-Scabbling	
A	846	133	6.4
B	2570	652	3.9
C	1210	158	7.6
D	2090	61	34.0
F	2280	310	7.4
G	5770	191	30.0
H	5090	407	12.4
Average	2840	273	14

level. As a result, recirculated process water does not re-contaminate the concrete floor surface. Also, when - as at Fernald - uranium contaminant is practically insoluble, an open-loop operation becomes possible: the exhausting water can be made non -radioactive by filtration.

b) Solid waste: coarse concrete rubble with uranium content also of several hundred ppm (corresponding to 1000-2000 decays per minute radioactivity). The amount of rubble collected from 3.7 sq. ft. segments is in the 2.5 to 5 kg range; amount estimated for 0.2" deep scabbling is 1 kg per sq. ft.; at average 500 ppm initial uranium content, 0.5 g of uranium is removed from each square foot of floor.

c) Solid waste: cement dust remaining as isolated particulates over the rough scabbled concrete after wet sludge is removed by wet vacuuming.

According to FERMCO measurements, about 15 g /sq. ft or 1.5% of the total amount of concrete removed by EHS, remains on the dried floor. According to XRF measurements, the uranium content of this (collected and compacted) dust reaches 2000 ppm which is 2-4 times higher than that of a coarse rubble. Under these conditions, the dust may provide 3 to 5% of the initial 500 -1000 CPM radioactivity. This estimate is not inconsistent with the fact that typical measured post/pre scabbling uranium content ratios were in 10 to 50 range; smaller decontamination ratios indicate "abnormal" local quantity of the residual fines.

As could be expected, EHS did not generated airborne radioactive dust. Radioactivity of the air samples collected for a few hours near the operating unit was under 10-11 mCi/cc, which is five times lower than the level allowed for operation without a respirator.

3.4 PHASE II EHS SYSTEM DEVELOPMENT SUMMARY

Tasks performed in Phase II led to the following conclusions:

- EHS system provides a single pass removal of a concrete layer by a batch mode sequential processing of floor segments.
- The scabbling depth can be controlled from 1/4" to 1" by varying the pulse energy, pulse frequency, and travel velocity of the scabbling module. The scabbling path width can be pre-selected from 1.5" to 26" range by changing the width of the scabbling electrodes.
- A pulsed electric power source of relatively simple design, assembled from commercially available components, satisfies the EHS requirements.
- A scabbling module with a single pair of linear ("strip") electrodes is a rugged and reliable processing tool with a long lifetime. With wide electrodes, uniform scabbling can be achieved without the need for lateral positioning.

- A reduced pressure scabbling chamber/enclosure isolates the processed floor area, preventing leakage of the process water and concrete debris to surrounding space.

- Scabbling rate depends on electric power available, required scabbling depth and type of concrete. At average 1/4" - 3/8" depth and 4 kW effective AC power, the net rate of scabbling (i.e. not counting time for unit transfer and debris removal) is 10 to 15 sq. ft. per hour. The effective processing rate, which takes into account the ancillary operations, could be 30 - 50% lower.

- The electric energy consumption required for scabbling is about 0.5 kWh/ft^2 or about 20 kWh/ft^3 of concrete. With auxiliaries (motors, blowers, compressors) taken into account, the consumption would be about 1.5 times higher.

- Water consumption in a closed loop operating mode and manual removal of coarse concrete rubble is 1-2 gal/sq. ft. which is equivalent to about 0.25 gpm water makeup/loss.

- Four or five pre- and post-scabbling radioactivity and uranium concentration readings were taken per every treated floor segment, i.e. for about 1 sq. ft. area.With this area averaging, EH scabbling results in about 10 times reduction of an average radioactivity and total uranium content. For more heavily contaminated locations with surface defects, contamination level is reduced more -several tens of times.

- Post-scabbling removal of residual fine debris (i.e. by a strong dry vacuum suction or by cold/hot pressure washing) may be required to achieve further improvement of decontamination quality.

- To optimize EHS operating parameters, especially average and minimum scabbling depth, requirements for decontamination ratio (pre/post scabbling contamination readings), absolute level of residual contamination and the size of floor area used for signal averaging should be well defined in advance of operation.

TSC considered the results of the demonstration trials as positive and recommended further development/improvement of the EHS system/operation, accompanied by larger scale demonstration trials through the implementation of the third phase of the project.

4.0 PHASE III OBJECTIVES AND TASKS

4.1 OBJECTIVES

The objectives of Phase III were the re-design, assembly, and testing of a EHS prototype system to prepare it for reliable operation and improved performance adequate for longer duration demonstration and testing at DOE selected site(s).

Specific tasks were assigned to upgrade three main system components: electrical-pulse power supply, mechanical-scabbling chamber and electrode module, and flow-water circulation and debris collection/removal. The system configuration had to be modified to make the unit more compact, and easier to operate.

The EHS unit performance had to be tested/demonstrated by field trials conducted on a scale sufficient to evaluate the capabilities of the EHS technology in general, and of the prototype unit specifically. At least a 1000 sq. ft. floor area, preferably of uranium-contaminated concrete, had to be scabbled to provide reliable evaluation.

Modifications of the Phase II EHS system had to assure significant improvement of design features and performance parameters.

The necessary (or desirable) improvements can be subdivided in the following categories:

A. Increase of concrete scabbling rate
   1. Higher power input
   2. Shorter time of ancillary operation

B. Better scabbling quality
   1. Better control of scabbling depth in a broad range
   2. Real-time depth control
   3. Better scabbling uniformity: elimination of depth changes besides the ones controlled by concrete structure

C. Lower labor requirements
   1. Programmed cycle
   2. Mechanized operation
   3. Convenient controls and communications
   4. Improved operator's conditions and safety
   5. Minimum maintenance
   6. Long-life components and consumables

D. Lower energy consumption
   1. Higher energy transfer efficiency
   2. Lower power requirement for ancillary operations

E. Improved unit configuration
   1. Short and convenient communications/connections
   2. Flexibility with respect to component changes (for specific applications/conditions)
   3. Unit mobility and maneuverability

F. Lower water consumption
   1. Lower sensitivity of scabbling to water quality
   2. Better separation of concrete debris
   3. Tight scabbling chamber with lower vacuum requirements

G. Complete and rapid removal/separation of concrete debris
   1. Improved rubble pickup technique
   2. Improved removal/separation of fines

H. Reliable operation
   1. Selection of long life commercially-available components
   2. Proper selection or design of EHS-specific items and materials
   3. Protection of equipment against EHS-specific electric and mechanical factors

In the next sections of this report, we describe efforts to address these issues. Not all could be resolved - completely or even partially - with the resources available. Remaining problems are identified, and possible future solutions are suggested.

4.2 PROGRAM TASKS

Tasks that constitute the Phase III program are specified and described in a Statement of Work. The program was modified in January 1997, after a DOE decision was made to transfer large scale EHS demonstration trials from Fernald to FIU site. Tasks and subtasks included in the modified program are listed in **Table 4.1**.

Table 4.1
Phase III Program Tasks and Subtasks

3.1	NEPA Documentation	
3.2	Test Plan	
3.3	Upgrade EHS System to a Commercial Prototype	
	3.3.1	Modification of EHS Subsystems
		- Electric
		- Water Flow/Debris Collection
		- Scabbling Chamber
	3.3.2	Integration of Modified Subsystems and Preparation
		for Longer Duration EHS Trials and Demonstrations
	3.3.3	Demonstration of EHS System Operation at the Everett Site
3.4	Comparative EH Scabbling Testing at Florida International University	
	3.4.1	Planning Meeting/Visit to the FIU Demonstration Site
		and Preparation of the Test Plan
	3.4.3	FIU Demonstration of the Commercial Prototype EHS System with Two Electric Subsystems
3.5	Technical and Economic Assessment of the EHS Technology	
	3.5.1	Technical Evaluation
	3.5.2	Economic Assessment
3.6	Project Management and Reporting	
	3.6.1	Management
	3.6.2	Topical Report

5.0 DEVELOPMENT OF UPGRADED EHS UNIT

This section summarizes modifications of major EHS subsystems to meet *objectives listed in Section 4. It should be noted that (as seen in some Figures* below) the modifications were implemented step-by-step; in most instances, only the "final" design or configuration is described here.

5.1 ELECTRICAL COMPONENTS

5.1.1 DC power source

An increase of electric power delivered to a scabbling tool is a most straightforward way to raise the scabbling rate. Three new DC power supplies/capacitors chargers were made available to substitute for (or to be added to) two ALE-402, 4 kW units used for the Phase II unit.

The ALE-802, 8 kW, 30 kV and 50 kV units were installed in a single cabinet **Figure 5.1** which now has four units to select or to combine in a parallel configurations. Another supply -ALE-303- delivers much higher (32 kW) power at maximum 31 kV. This water-cooled unit was installed in a separate cabinet **Figure 5.2.**

Besides the power supplies, the cabinets contain some of the process control switches and indicators (duplicated by controls located on the forklift).

Next step toward the higher power was to modify electric circuitry used in the ALE power supplies to limit capacitor charging times. This limit, regularly used with externally triggered switches, reduced the average power that could be extracted from the power supply in our PFN units operating with "free-running", breakdown-limited switches. This modification immediately results in 30- to 50% increase of available power, permitting increase of the pulse frequency and/or capacitance. In addition, in this mode, pulsers operate at almost constant values of the voltage, charging current and repetition rate.

A third modification allowed more reliable functioning of power supplies when two or three of them work together. Instead of connecting the units in a "master/slave" configuration, their DC outputs have been connected in parallel; this change eliminated system malfunctioning and deliberate shut-offs due to instantaneous output voltage inequalities or surges. By connecting three 30 kV power supplies in parallel, the output power could be raised to 8+4+4=16 kW.

5.1.2 Pulse Forming Networks

It was shown in laboratory experiments that alternative PFN designs - an initial, lower voltage/higher current and energy used in most Phase II trials, and higher voltage/lower current designed by the SPB TU, complement each other: the first one is more efficient for deeper (1/2" to 1"), while the second - for shallow (1/4" to 3/8") scabbling. The two PFNs are compared in Table 5.1.

Table 5.1

Comparison of low voltage/high current and high voltage/low current pulsers/scabblers

Scabbling Feature	HV	SHV
Typical Scabbling depth, in. most convenient maximum achieved	 3/8 - 3/4 3/2	 3/16 - 3/8 3/4
Net Processing Rate*, ft. sq./hr. (achieved in 1996)	25(1)	70(2)
Had advantage in: Scabbling uniformity: local large area	 Yes 	 Yes
Simplicity of design: electric mechanical	 Yes 	 Yes
Electrode erosion		Yes

Without time for chamber traverse/rubble removal
(1) At 30 kW, 1/2" depth (2) At 15 kW, 1/4" depth

Because each of these PFN can be, in principle, used for deep as well as for shallow scabbling, it might be more practical in the future to have a single design. At this stage of development, however, it seems desirable to explore capabilities and specifics of both PFNs.

The configuration of the whole electric system was changed, i.e., compare Phase II and Phase III configurations shown in Figures 3.16 and 5.20. The PFN units were relocated from the power supply cabinets onto a box-covered platform installed on the top of a scabbling chamber.

There are several reasons for the relocation:

a) With shorter HV cables between PFN and electrodes, the circuit inductance is lower, and electric pulses are shorter and "sharper"; this, especially in a high voltage mode, benefits scabbling efficiency.

b) Cabinets with DC power supplies/chargers could be positioned outside the scabbling area, thus permitting remote operation and an independent movement of the scabbling chamber and other forklift-mounted equipment.

c) Electric interference between the chargers and PFNs is reduced.

d) Power supplies and PFNs could be "mixed and matched".

e) Both PFNs, being assembled on identical supporting platforms, could be exchanged with a relative ease.

f) It is easier to soundproof a PFN box.

Design of a "low" voltage PFN-L evolved throughout the Phase III. The initial design is illustrated in **Figure 5.3.** A two-capacitor design with airgap switch operating in a ceramic chamber (**Figure 5.4**) allows protection against overheating of the PFN components and cables PFN heating. In the final design, the PFN-L was changed as follows:

- A the third capacitor has been added to increase pulse energy, if necessary.
- The HV switch was modified to allow better gap blow-through and to provide more accurate and convenient gap adjustment.
- The long, air-cooled coaxial cable was replaced by two shorter, single-wired, and water-cooled cables.

The new PFN-L assembled on the standard fiberglass platform is shown in **Figure 5.5** with soundproofing enclosure removed. During shake-down trials, the 16 kW (8+4+4) charger/PFN-L electric pulser operated reliably; without misfires, breakdowns or overheating. The pulse frequency could be conveniently changed in a 2 to 10 Hz range by adjusting voltage or air gap switch. Energy of a single pulse is changing, with higher energy corresponding to lower frequency, leaving total energy delivered per unit time as well as average consumed power (measured by an AC meter) constant.

The high voltage PFN-H was completely redesigned and rebuilt. It was assembled according to electric schematics (**Figure 5.6**) developed and tested at St. Petersburg Technical University earlier. It represents a Marx generator that quadruples input voltage from 30 kV to 120 kV, instantaneously reconnecting four capacitors from a parallel to a serial configuration. The assembly uses TSC-provided hardware (capacitors, sparkgaps, resistors etc.). The new design allows integration of the PFN-H within the original EHS system: the same DC power sources and the same scabbling module can now be used for both PFN-L and PFN-H. A final arrangement is illustrated by **Figures 5.7, 5.8** and **Figure 5.9** where the PFN-H unit is shown during the shakedown testing. Operation was stable at 30 kV charging voltage (supplied either by ALE-408 or by ALE-303 charger), about 1 kJ pulse energy and up to 40 Hz pulse frequency. In **Figure 5.10** a single pulse waveform with 5μs period, and 20 Hz pulse sequence are shown.

(a) (b)

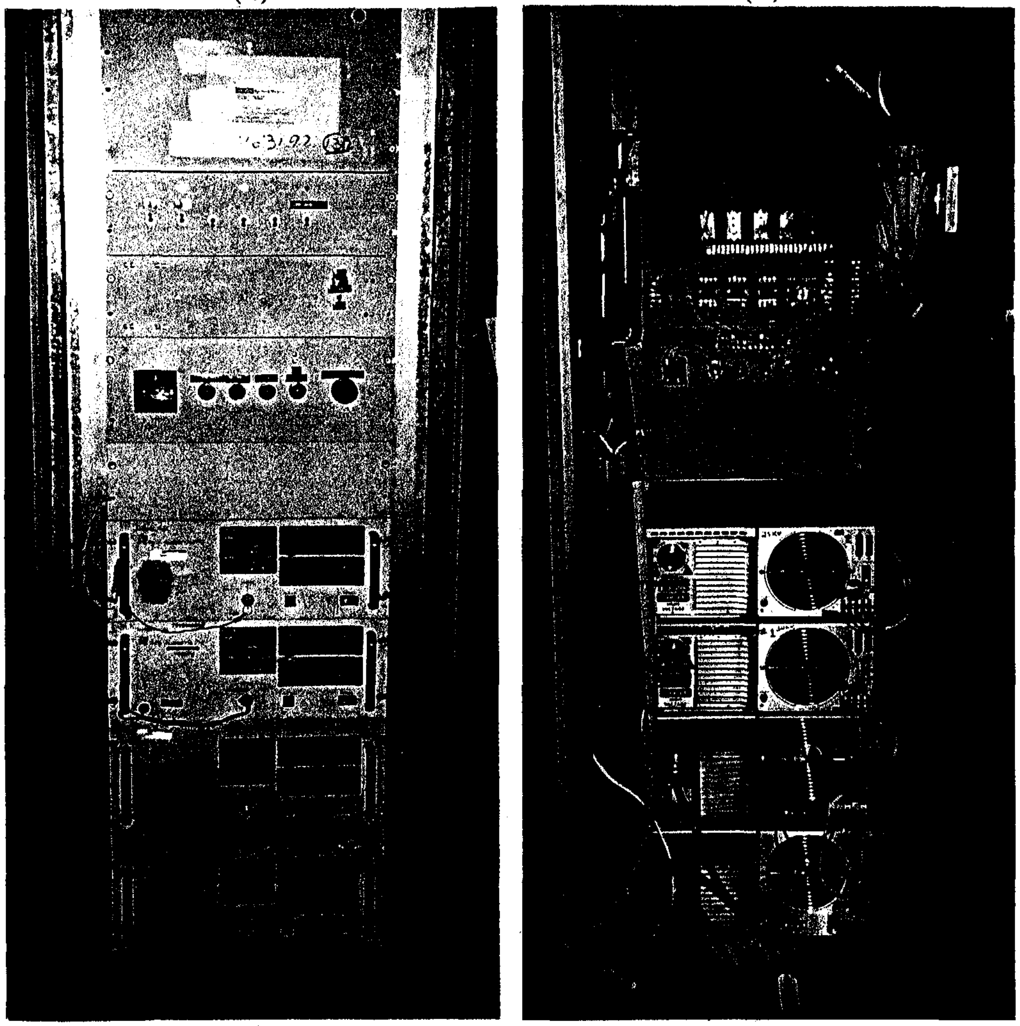
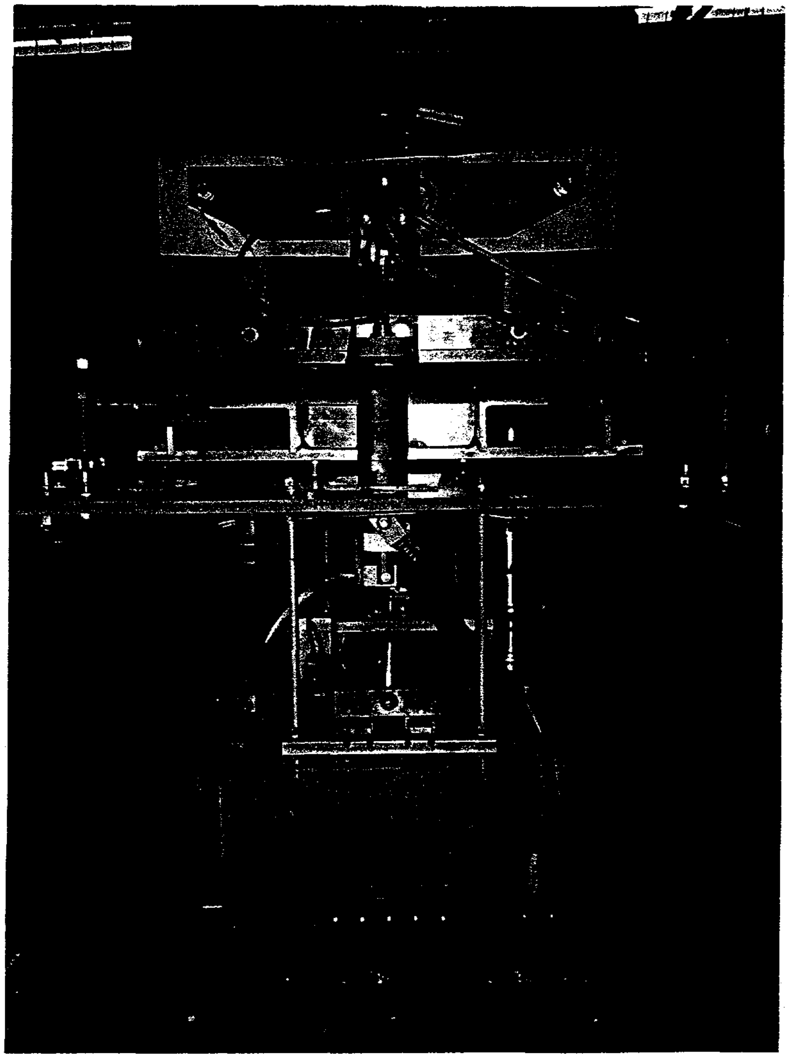
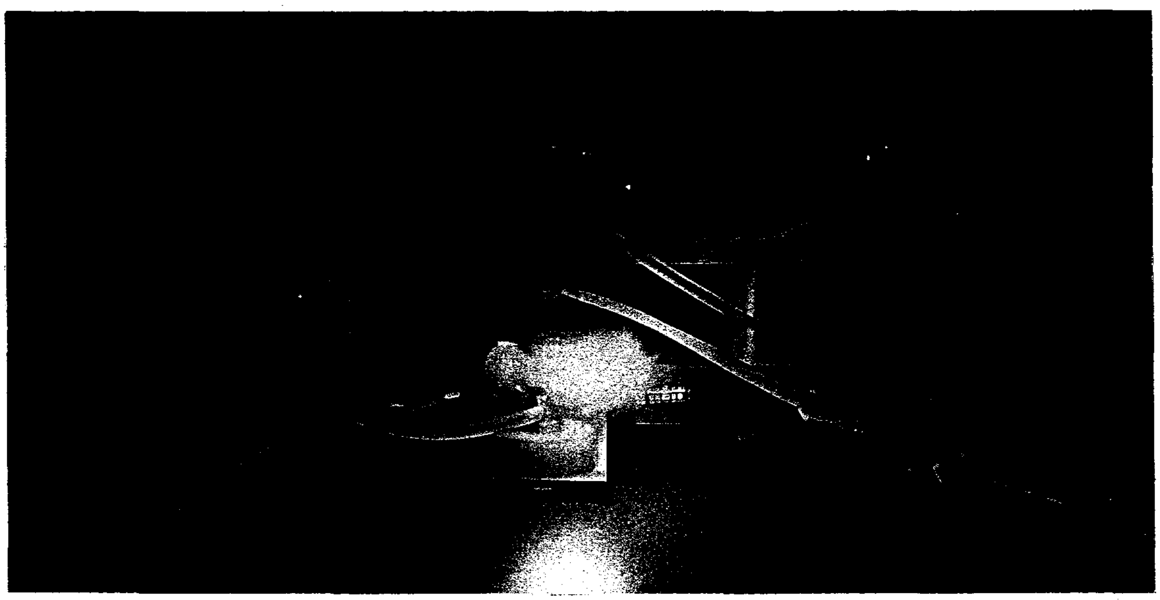


Figure 5.1 Four unit 16 kW DC power source;
(a) front view,
(b) cabinet interior (including cooling, resistors, diodes and some process controls)

Figure 5.2 High power power supply cabinet with 32 kW water-cooled DC power source

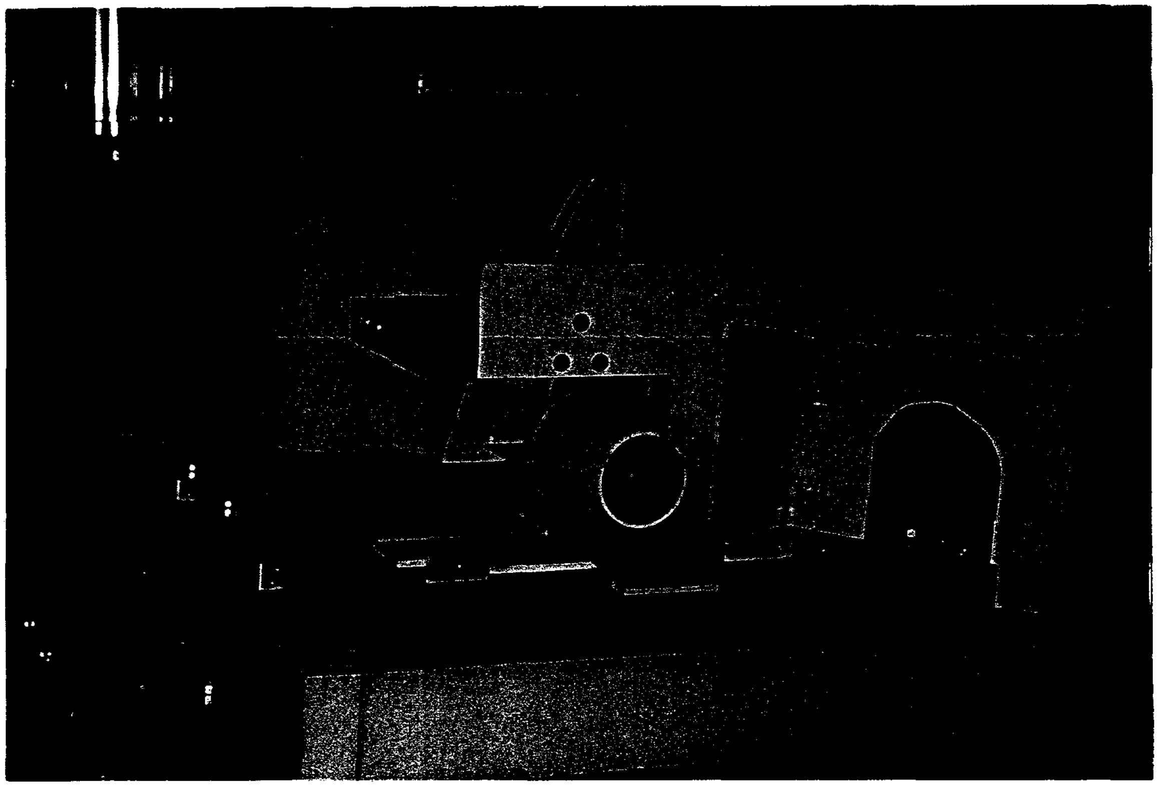


(a)

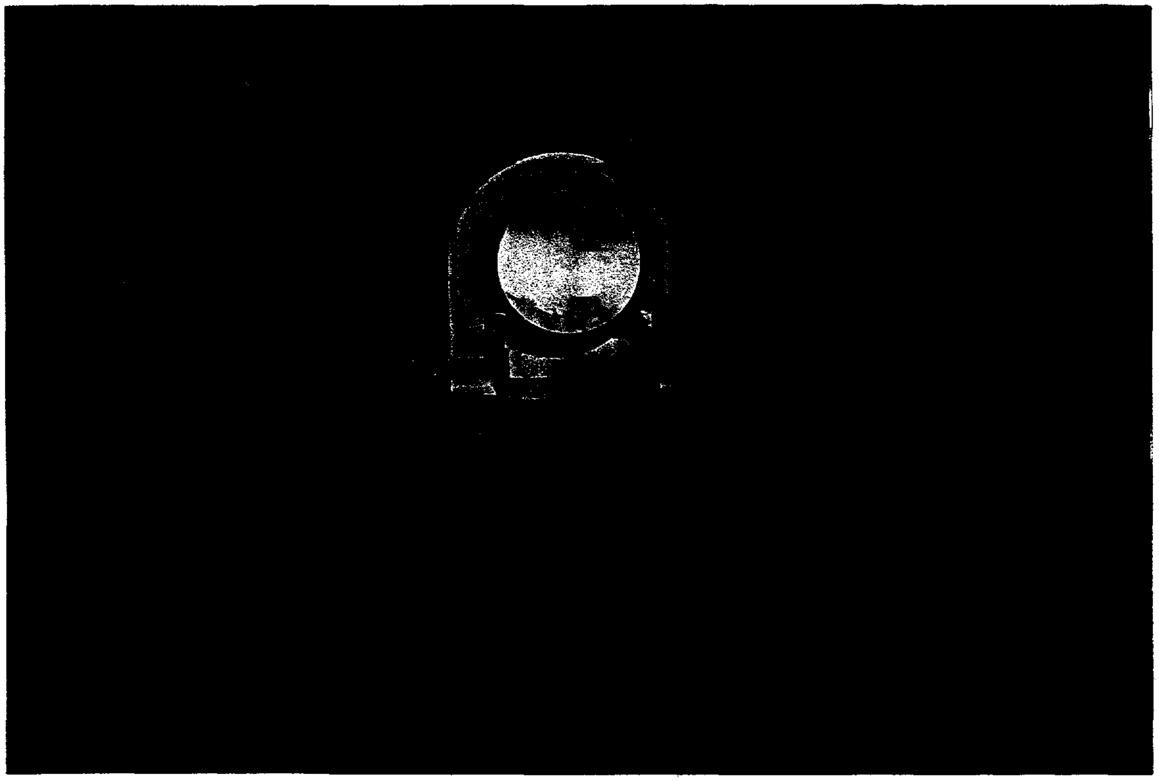


(b)

Figure 5.3. PFN-L unit mounted on the scabbling chamber cover (a) and shown in operation with switch breakdown jetting from the airgap(b)

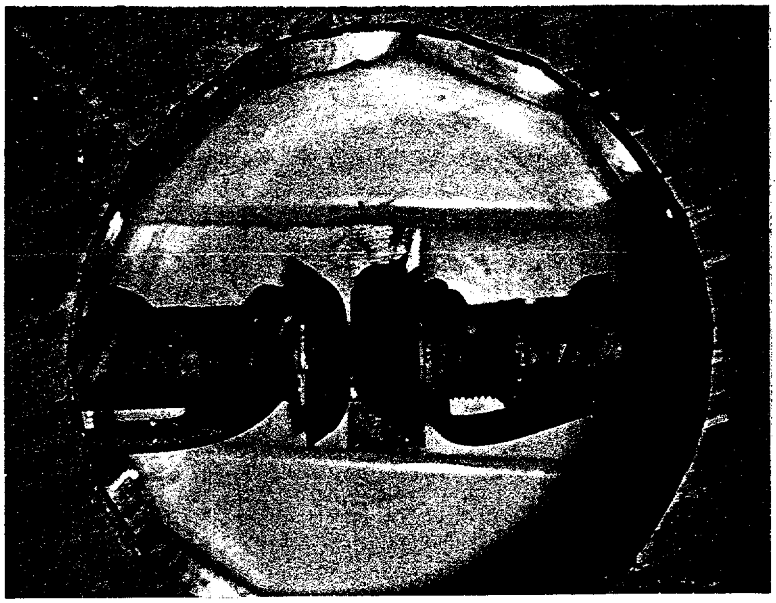


(a)

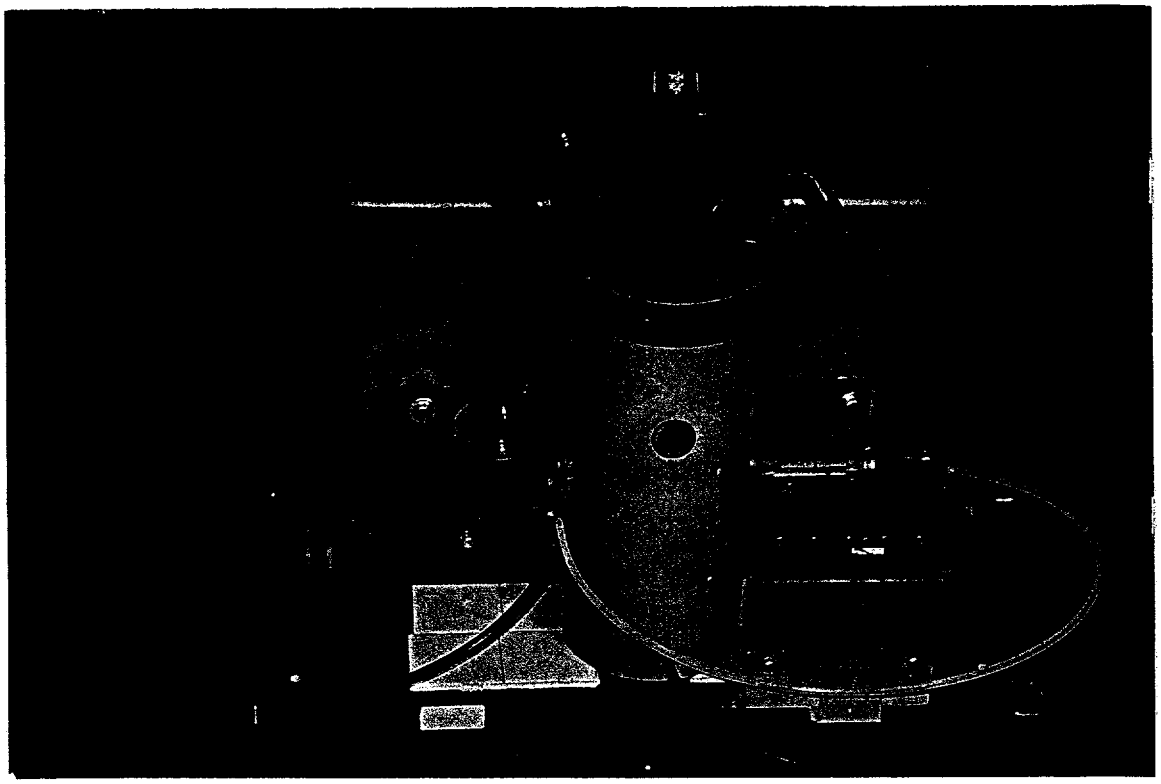


(b)

Figure 5.4 PFN design with airgap ceramic enclosure (a).
Spark gap design can be viewed through a jet exhaust (b)

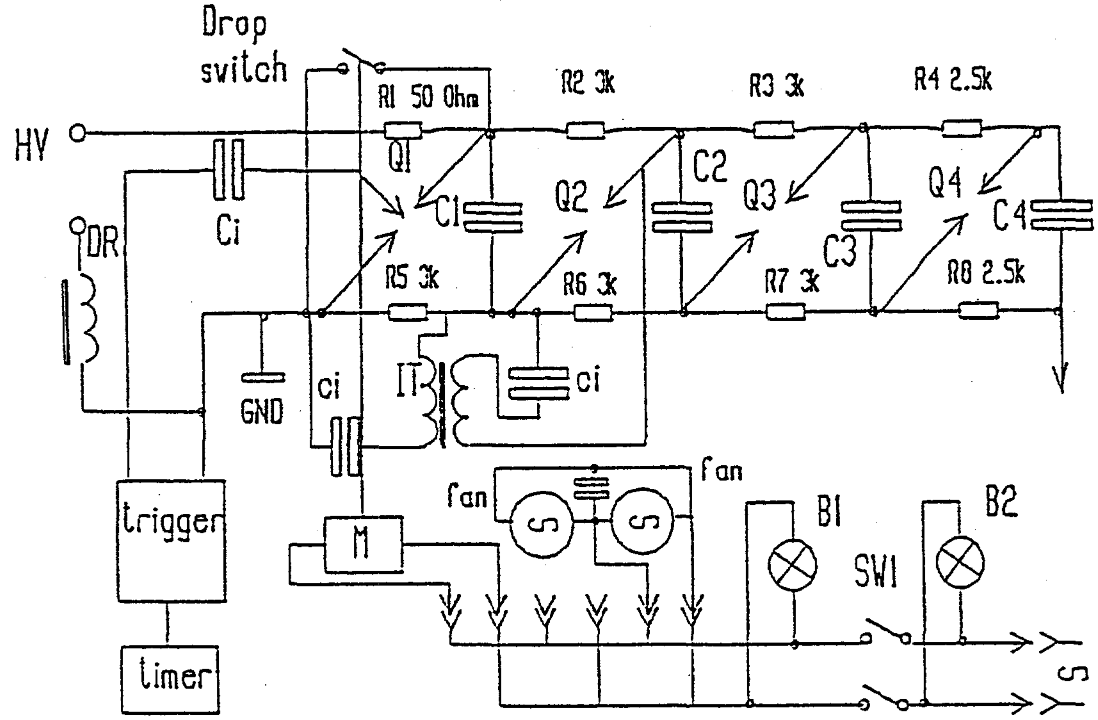


(a)



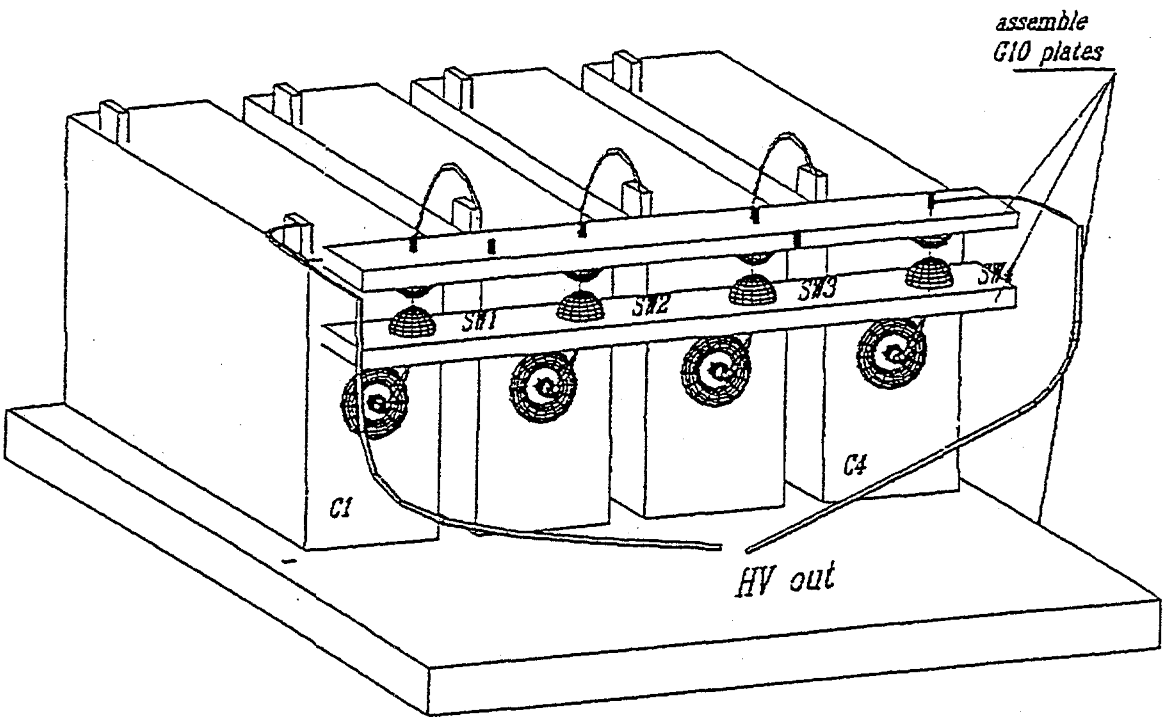
(b)

Figure 5.5 Modified and re-assembled 30 kV PFN-L unit.
(a) Adjustable sparkgap switch located inside the high air flow duct
(b) Water is used to cool the switch electrodes



P774S

Figure 5.6 Electric schematic of 120 kV PFN-H



Charge resistances are not shown.
SW – high voltadge switch

Gap in SW1 is 9.1 mm, SW2 – 9,8 mm,
SW3 – 11.2 mm, SW4 – 21 mm.

Figure 5.7 PFN-H assembly schematic drawing

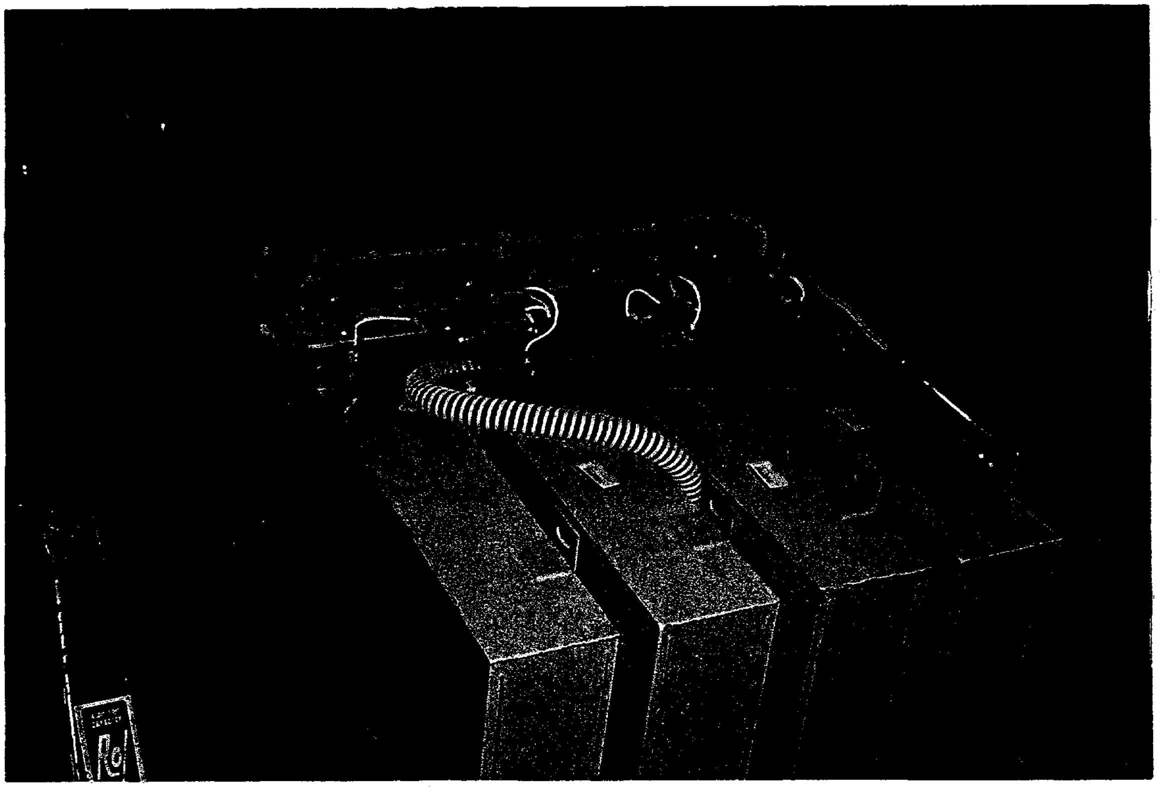


Figure 5.8 Four stage PFN-H: arrangement of capacitors

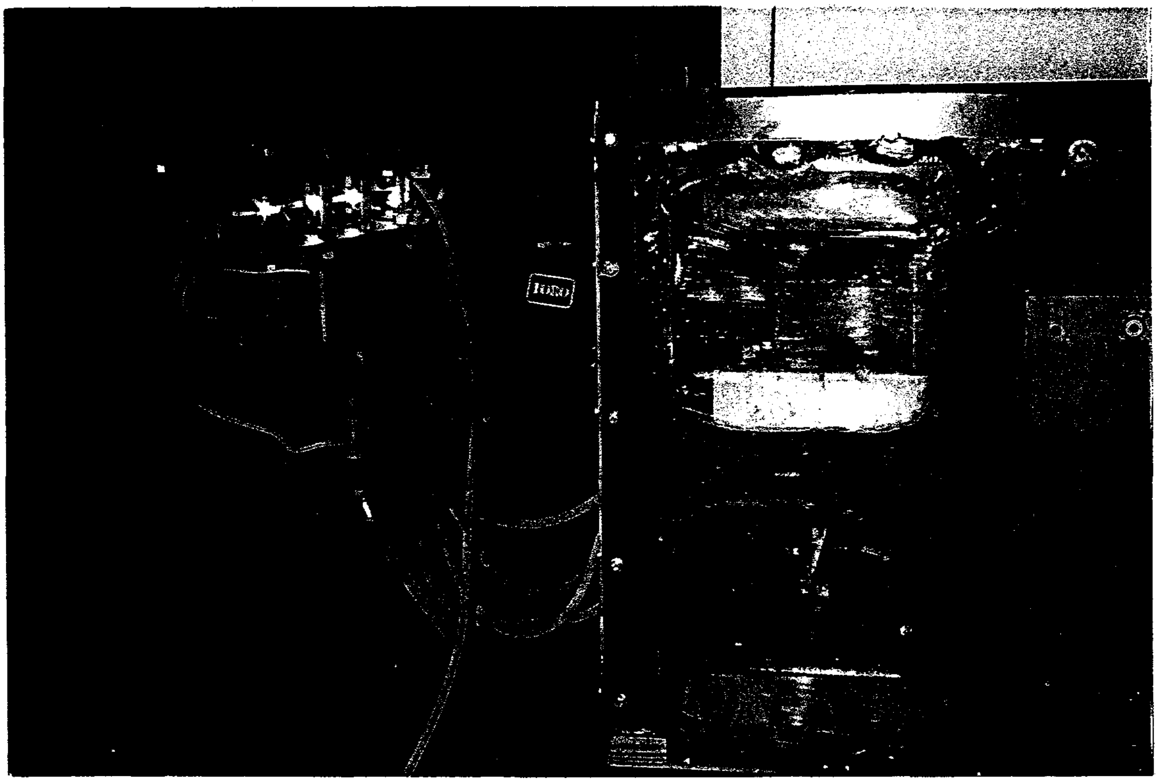
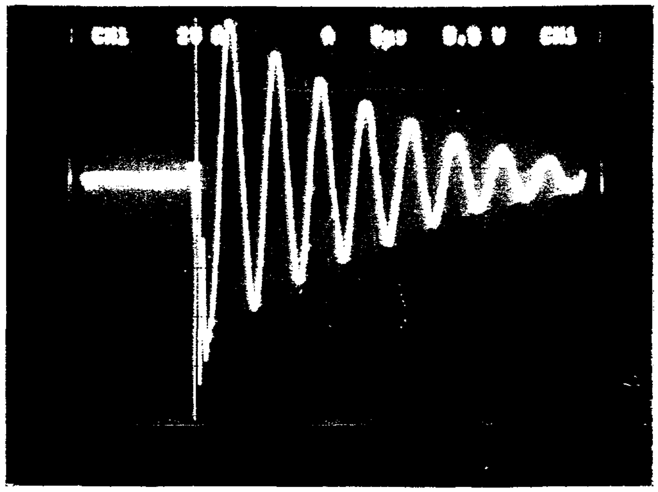
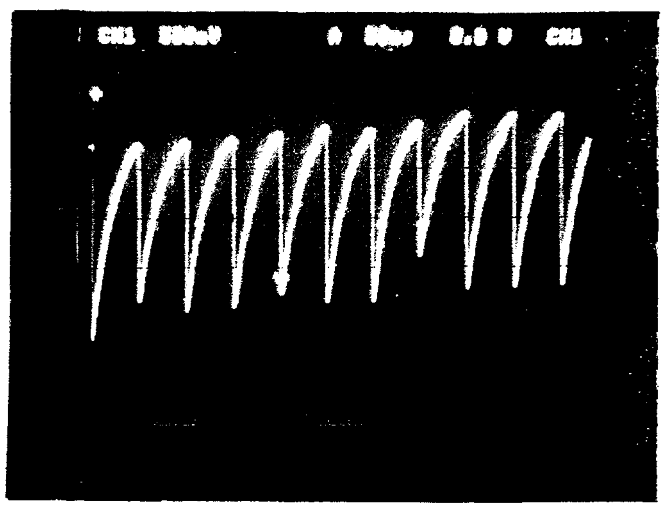


Figure 5.9 EP unit shakedown testing at the Everett site



(a)



(b)

Figure 5.10 Electric pulses generated by PFN-H:
(a) single pulse current waveform,
(b) 20 Hz pulse sequence

5.2 MECHANICAL COMPONENTS

5.2.1 Scabbling chamber and positioner

Upgrade of a scabbling chamber (water enclosure) was directed, in the first place, toward increasing the floor area which could be scabbled at each processing position. For this purpose, the aluminum frame of the chamber was re-welded, extending the chamber in the direction (X) of scabbling. Combined with an increase of the electrode (Y) length from 26" to 32", this increased the scabbled segment area from 3.7 sq. ft. to 6.9 sq. ft.

To make observation/control of positioning and scabbling process easier, initially one, and later two chamber sidewalls were made of a transparent material (plexiglass or lucite) as can be seen in **Figures 5.11a, b.**

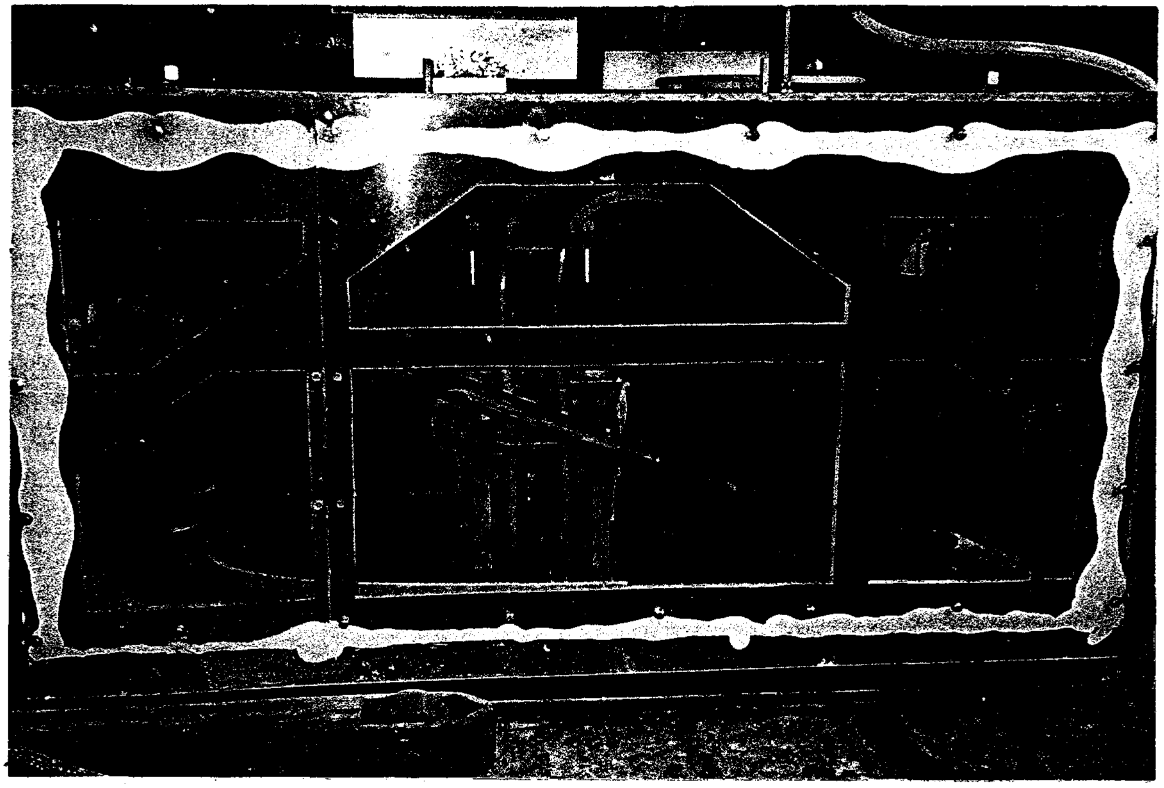
A new positioner used to transfer scabbling module in X (horizontal) and Z (vertical) directions was designed, assembled and installed in this larger scabbling chamber. The unit shown in **Figure 5.12** could be used with either electric or pneumatic drive; it differs from the old (Phase II) one in several important points:

- The design is simpler: instead of two parallel coupled slides Figure 3.12, a single-wider, longer, heavier and more stable-slide is used.
- The slide is attached to, and lifted or lowered together with the chamber's cover. This arrangement provides better access to electrodes, connectors and other parts which may require change or maintenance, and to the floor surface for debris removal or scabbling evaluation.
- Instead of the electric motor, an air turbine **Figure 5.13** is used to move the scabbling module. This approach eliminates problems with the motor caused by high voltage pulses taking place in the chamber.
- A block of four pneumatic cylinders (see **Figure 5.14**) attached to a X-slider and holding electrode-supporting frame is used to lift or lower the electrode module along the Z axis.

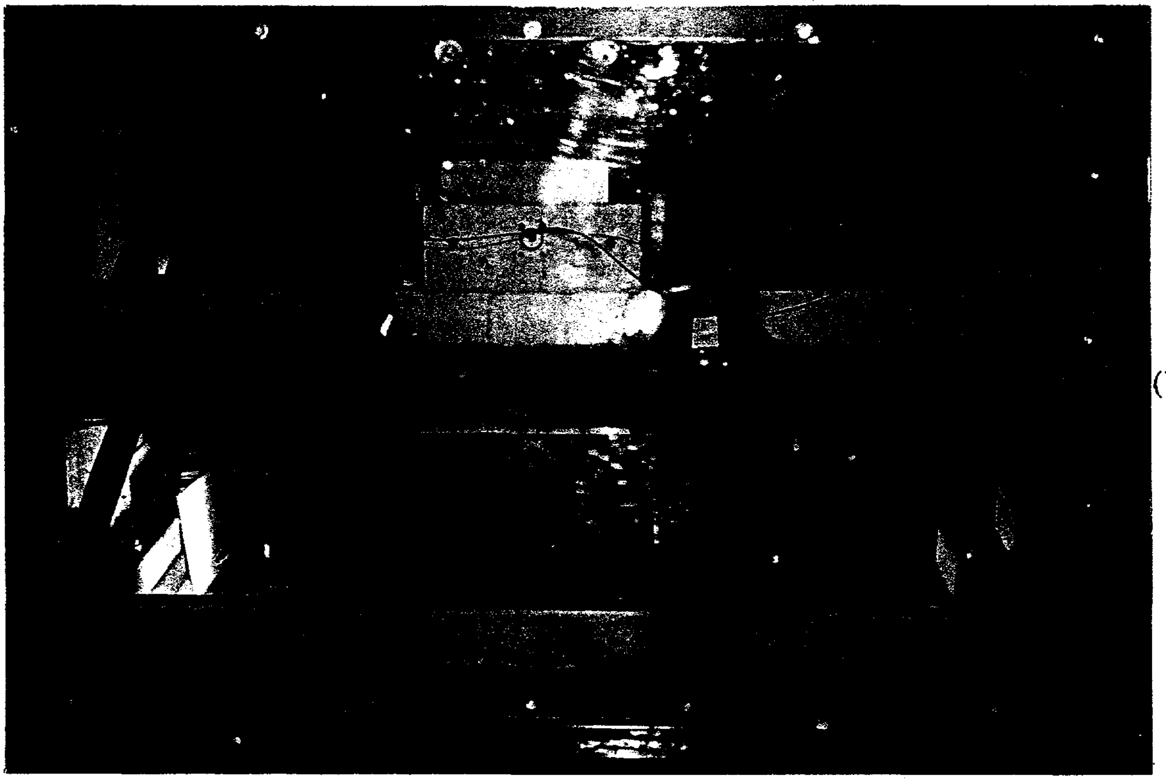
5.2.2 Electrode module, electrodes and cables

An electrode module has a strong frame made of heavy aluminum shapes and thick G-10 fiberglass plates. The module can sustain impulsive loading imposed by the strong, frequent electric "explosions". Electrodes are attached to the frame by multiple bolts.

In a scabbling process, the scabbling module perpetrates cycloidal motion in the X-Z plane by a sequence of alternating horizontal sliding (X) and up-and-down (Z) steps. Positioning - length, duration and speed of each step - is controlled by a system of adjustable delay relays (**Figure 5.15**) controlling



(a)



(b)

Figures 5.11 Modified scabbling chamber with transparent sidewalls for better process monitoring,
(a) side view,
(b) front view; puling light flash is visible

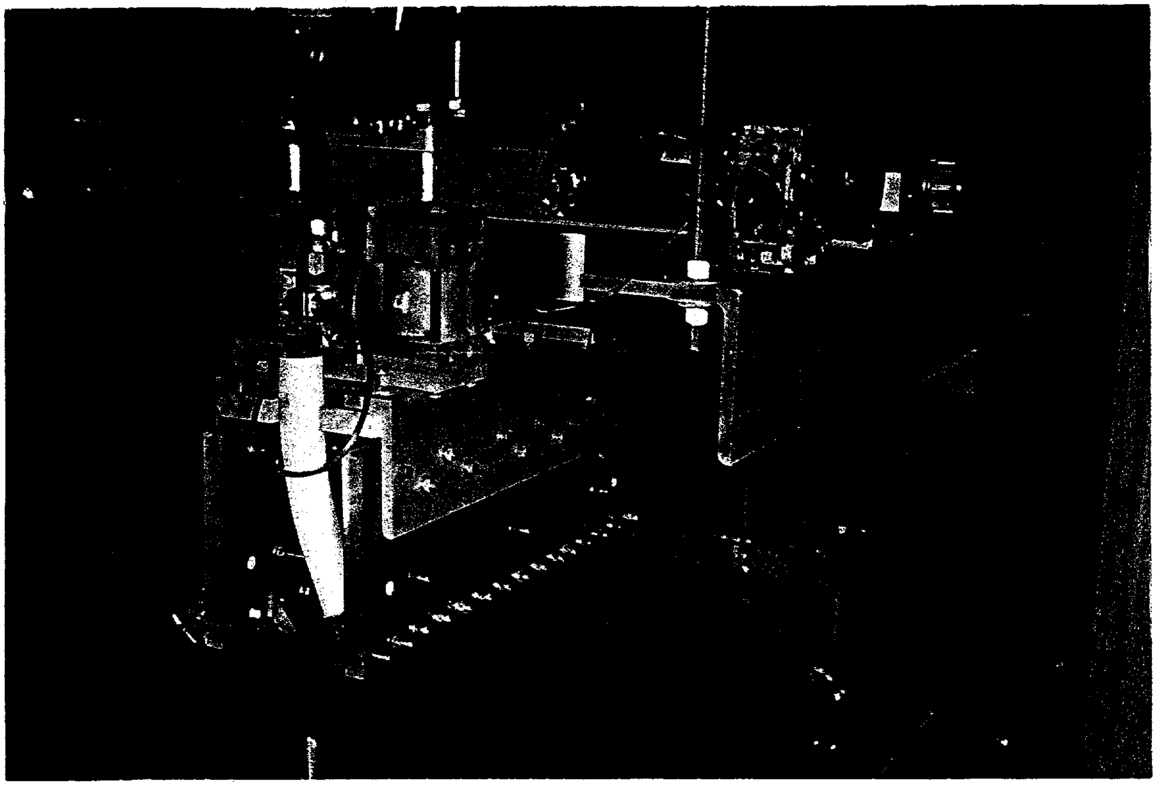


Figure 5.12 XZ positioner with scabbling module mounted below

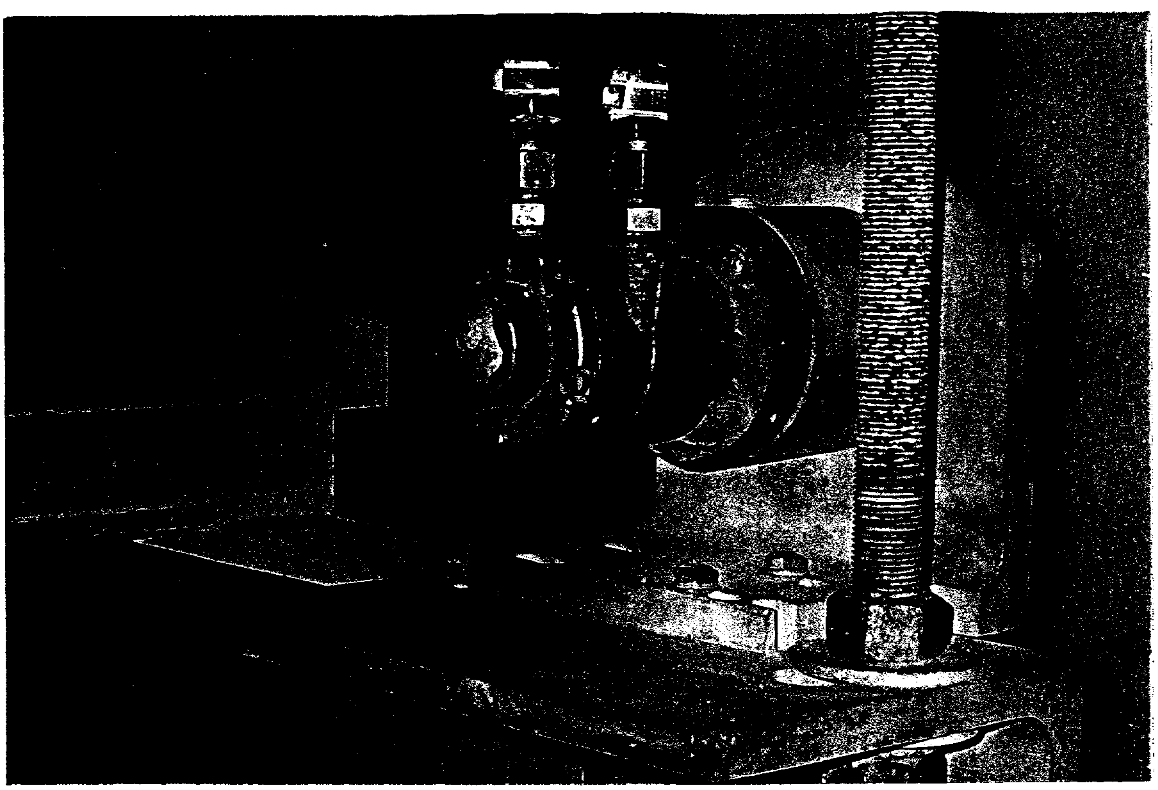


Figure 5.13 Air turbine/belt drive of the X positioner

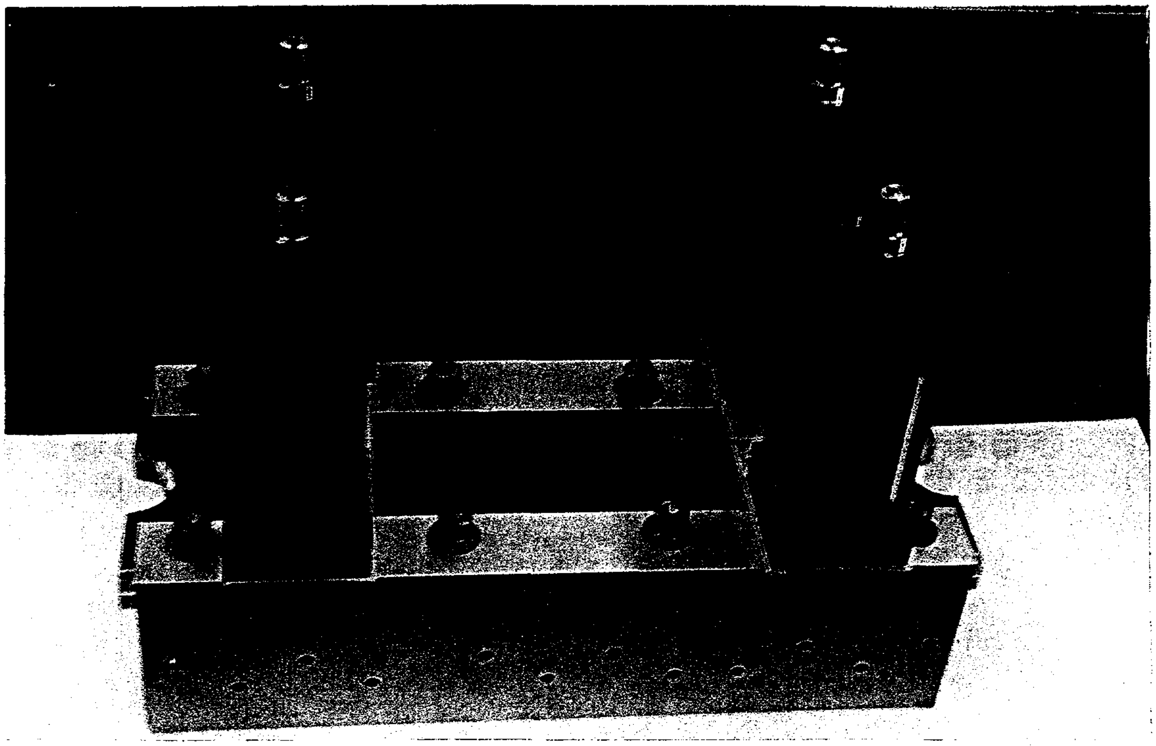


Figure 5.14 Pneumatic cylinders - mount and Z-positioner of a scabbling module

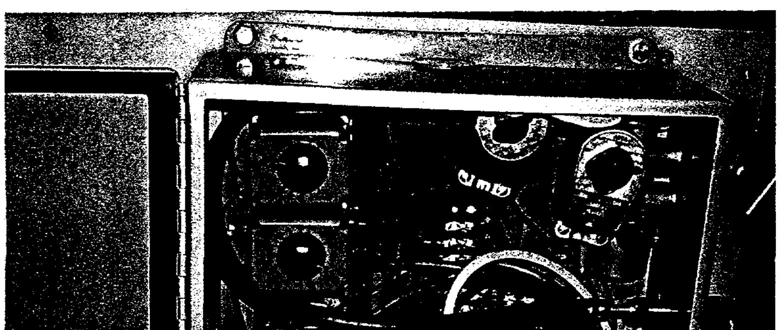


Figure 5.15 Box with positioning and valve controls, and air manifold with regulators and gauges

pneumatic actuators. Force and momentum in the sliding and lifting mechanisms are controlled by the air pressure in supply manifolds. The control box and air manifold are located on the forklift frame.

The electrodes are the key components of the scabbler. Several designs and materials were tried for electrodes used in both the low- and high-voltage electric systems to satisfy the following requirements:

- Mechanical strength of electrode material with respect to permanent and impulsive loading. No brittle materials, however strong under permanent load, are acceptable.

- Rigidity of a pre-formed structure/shape

- Machinability (easy to manufacture by bending, drilling, grinding etc.)

- Commercial availability/low cost of the basic shapes (long strips, angles, etc.)

- Low erosion rate with respect to:

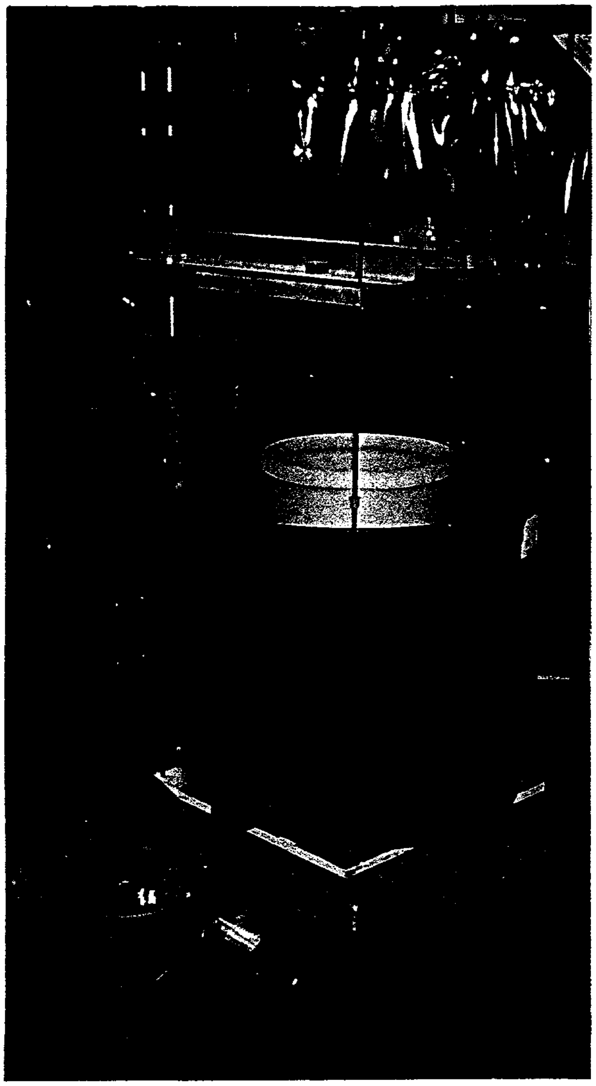
  - thermal effects of local high current arcs,
  - electrochemical effects,
  - electrode-to-concrete erosive friction

- Lowest possible surface area in a direct contact with water.

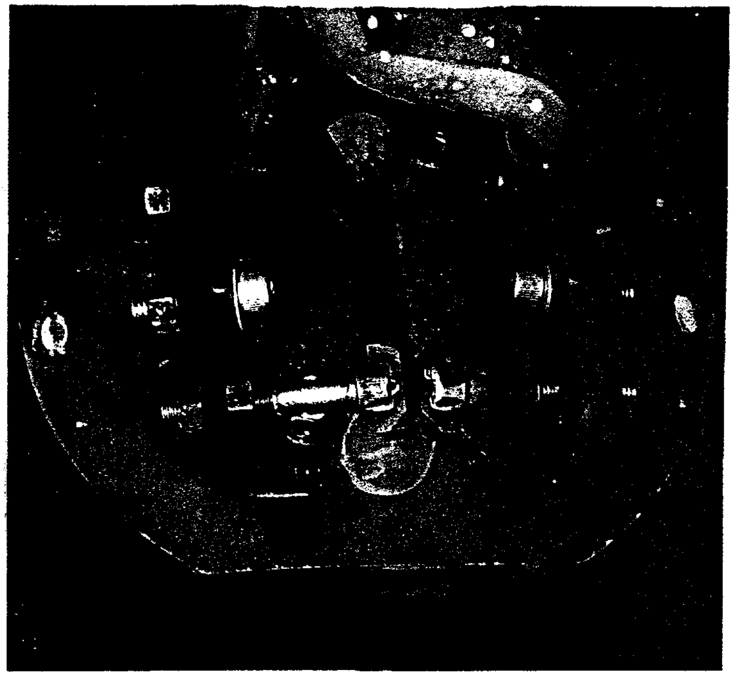
The pulsed discharge erosion behavior of several alloys and coatings was tested on a separate rig (**Figure 5.16.**) Samples used as electrodes were attached to a holder, submerged in water containing suspended concrete debris, and "pulsed". The erosion was evaluated by the weight change after a few thousand pulses. For low energy (~1 kJ) pulses, erosion of steel electrodes was low, corresponding to less than 1 mm/hour electrode gap change at the "real" scabbling conditions. For stronger, 3-5 kJ pulses, (characteristic of low voltage operation) the erosion rate increases to about 2 mm/hour equivalent. Even this higher erosion/gap widening can be tolerated and corrected by relatively infrequent gap adjustments.

Strength/rigidity requirements are also more stringent for a low voltage/high current unit where local arc heating and mechanical stresses produced by shock waves are much higher.

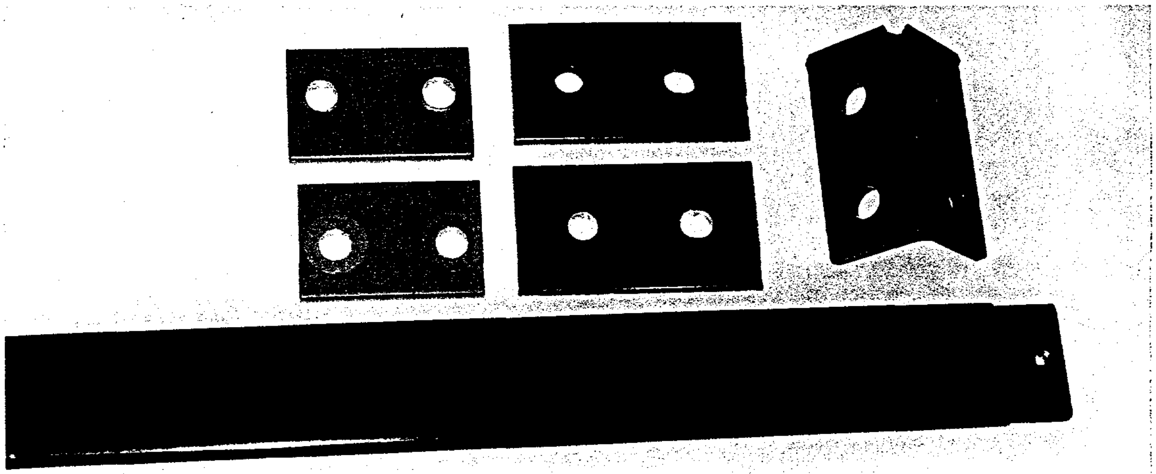
It was found that ordinary low carbon steel meets the combination of erosion/strength requirements better than more "exotic" and expensive metals and alloys. Its ductility is an asset, while rigidity can be increased by using enforcements (gussets etc.). A combination of a high melting point, acceptable



(a)



(b)



(c)

Figure 5.16 Laboratory rig for testing electrode erosion and durability of insulating coatings by a pulsed electric discharge (a), electrode holder with cables attached (b), and samples and electrodes (c) thermal conductivity and intense water cooling, provided by turbulent water, limits arc erosion. Low corrosion resistance (i.e., compared to that of stainless steels) is not of importance for the relatively short - hundreds of hours - periods of usage.

Several electrode configurations used in Phase III experiments and trials are shown in **Figure 5.17.** Photos of "new", uncoated and coated, as well as used electrodes with coatings partially removed by discharges are presented.

The lowest possible area of electrode-to-water contact is important - and even crucially important for a high voltage operation - because premature discharge of the capacitor via leakage current takes place through this interface.

The following measures were taken to resolve the problem:

1) Reduce electrode area,
2) Insulate electrode surfaces (besides pulse-current electrode edge) by a solid dielectric,
3) Insulate electrode surfaces by nonconducting coatings.

It was discovered that:

- Reduction of electrode surface is not effective because there is a limit set by the electrode strength and frame attachment considerations.

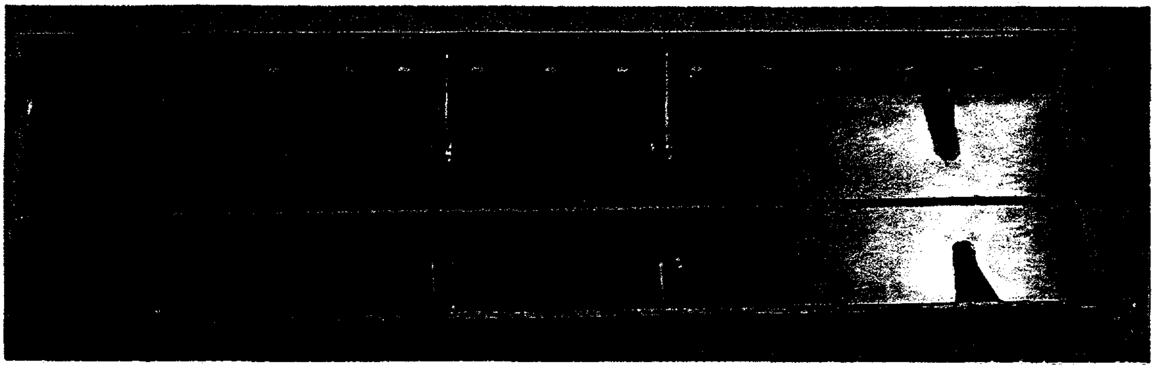
- Most solid dielectrics are brittle and crack very soon; the best of them, fiberglass-based, fail by splitting at distances less than one inch from the arcing edge.

- The best of the ductile paint, polymers and epoxy coatings tried as insulators, survive tens of minutes of operation in a high current mode or a few hours of operation in a low current mode. For longer times, scabbling performance deteriorates*.

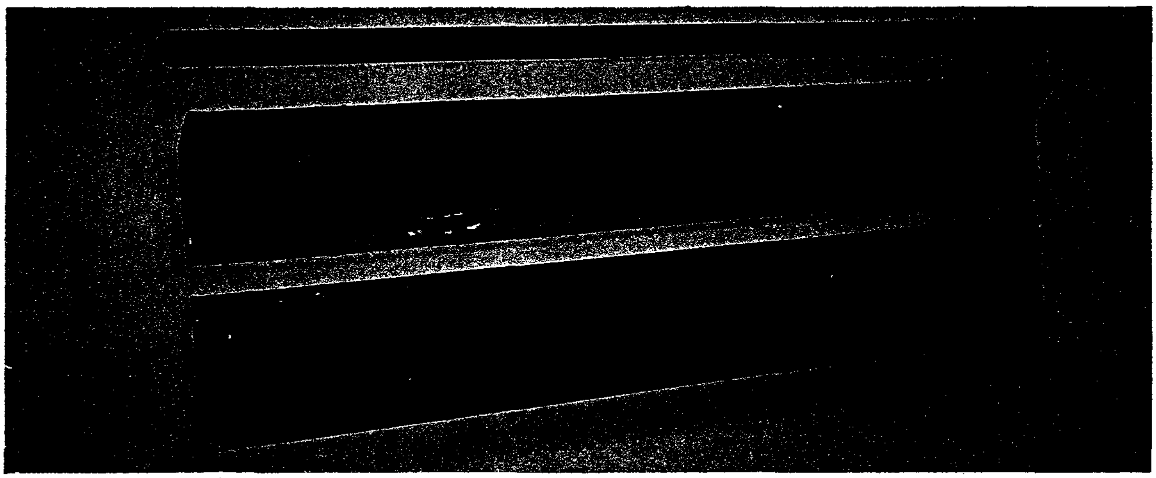
For most practical purposes, the effective operating lifetime of an insulating coating at the acceptable (about 1/2") distance from the edge should be at least one eight hour shift; it should also be possible to renew the coating or change the electrode (for the subsequent restoration) in a short time - e.g., one hour.

Coatings we have tried barely meet these requirements even in a low current mode. Better electrode-protection results were obtained by combining thin fiberglass sheets (or fiberglass mesh) with silicon rubber (high performance RTV) coats (see **Figure 5.17a**). In a low current mode these coats survived without repair two days of operation (i.e. about 5 net pulsing hours).

**Footnote:* The current leakage effects are discussed in Section 8.2



(a)



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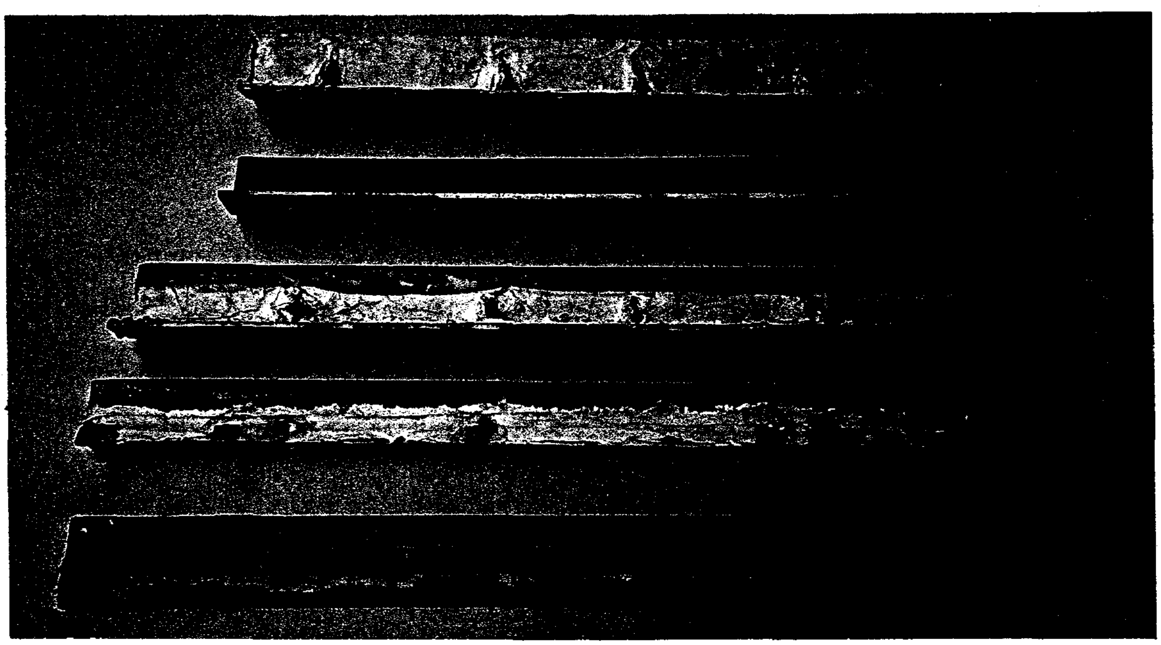


(c)

Figure 5.17 EP/EH electrode shapes/configurations
(a) Reinforced 32" electrodes for deep EH scabbling
(b) EP electyrodes with fiberglas+RTV coat after sveral hours of operation
(c) Angular and flat, 28" and 32" electrodes with white RTV and fiberglas coats partially eroded

Cables and cable-to-electrode connectors are other vulnerable components. Cable cooling requirements for the pulsed current are much higher than those calculated on the basis of the average power. In a low voltage/high current mode, air cooling initially used for coaxial cables was barely sufficient. Lately adopted single-wire, water-cooled cables are more reliable, but have higher inductance.

Experience with cable connectors shows that they should be located above the water level in the scabbling chamber; this was done previously for low voltage operation using heavy copper extension bars. Use of lighter underwater connectors operating in a high voltage mode is not acceptable: cables consisting of multiple small diameter wires are subject, especially in high hardness water, to high electrochemical erosion.

5.3 FLOWS AND WASTE COLLECTION

Removal of the concrete surface layer results in formation of debris (concrete rubble). This consists of a coarse aggregate with individual grains not substantially different from their initial size, and mortar which includes finer "sand" with particle dimension in a broad range, from one mm to several mm. This wet debris has a density about two times lower than original concrete and, therefore, not only fills depressions produced by scabbling but also forms a bulging bed over the floor surface. For 1/4" deep scabbling, the volume of debris covering a 7 sq. ft. floor segment is about 1/3 cu. ft. This debris, which contains water-insoluble contaminants, should be removed, separated from the exhausting or returning process water, and collected in a proper container.

To improve performance, i.e., water flow and vacuuming rates, convenience, reliability, and to add debris collection/separation functions, the system used in the Phase II tests had to be almost completely replaced by a new one. Schematic of the new flow system is shown in **Figure 5.18**; its flow loops and components are described below.

5.3.1 Air flow

Three power heads used for reducing air pressure in the scabbling chamber (vacuuming) are mounted on a platform built over the rear of the forklift truck (see **Figure 5.19**). Air entering the scabbling chamber through the foam gasket flows via a main collecting manifold and two auxiliary hoses first into the head space of a collecting drum, and from there, via hard tubing, into the power heads. The flow rate is controlled by manual valves; pressure in the chamber (typically -10" H_2O) and in the drum (about -40" H_2O) is measured by gauges.

5.3.2 Water and debris flow

An 85 gal. drum (or 55 gal. drum used initially) is used both as a water reservoir and a debris collector. Water - fresh or stored in the drum - is transferred into the scabbling chamber by two pumps - a first stage sump pump which also serves as a primer, and a second (seen in Figure 5.19), larger main

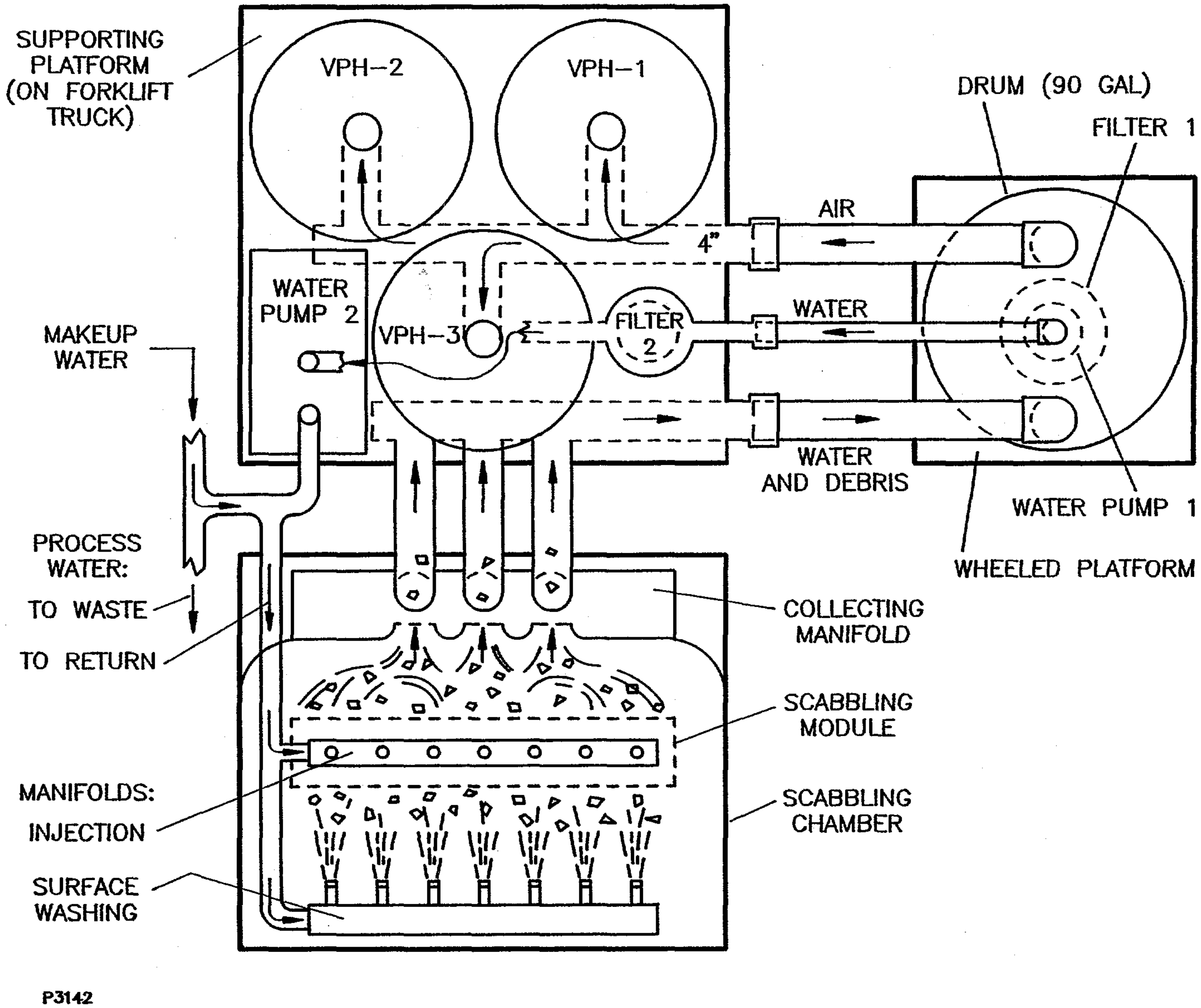
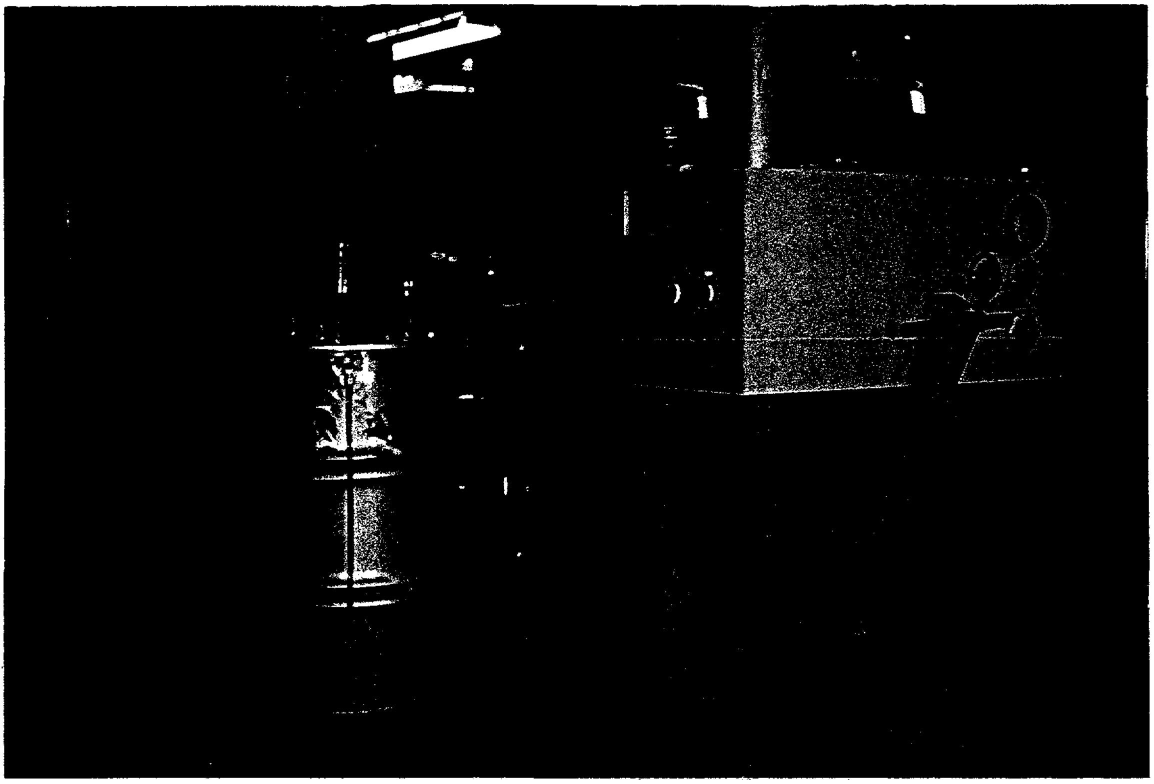
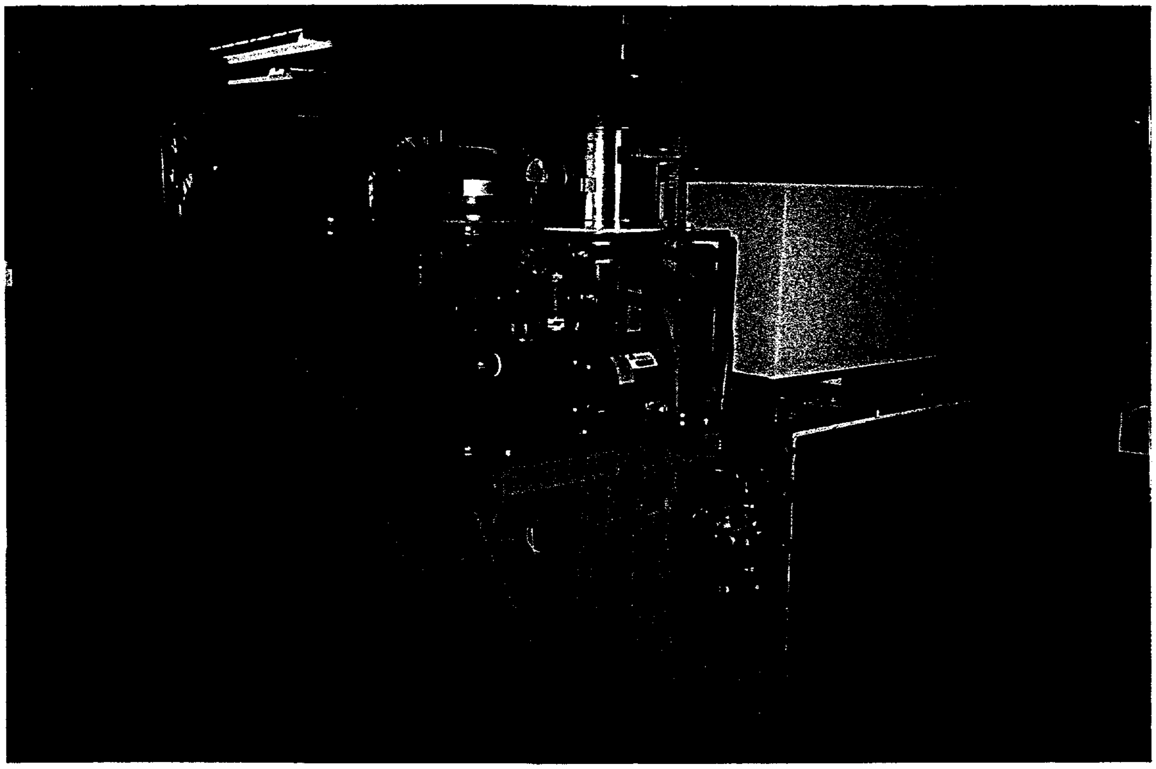


Figure 5.18 A diagram of the Phase III air/water/debris flow system -the main option



(a)



(b)

Figure 5.19 Flow system with most components mounted on a truck.

(a) Rear view, 55 gal. debris collecting drum in the forefront,
(b) Side view with plastic enclosure removed
Air power heads are orange and black.

pump. Filters are installed to protect the pumps and to reduce the amount of solids returning into the chamber. The first (coarse) filter has 0.5 or 1.0 mm openings, the second (fine) filter-100mm openings; the second filter can be bypassed.

To remove process water and part of the debris from the scabbling chamber, and to transfer them into the drum, 30" to 50" H_2O chamber-to-drum pressure difference is used as a driving force. The water/debris suspension is collected by the main manifold nozzles (see **Figure 5.20**) located close to the chamber bottom. The suction can be continuous, (throughout the process cycle), intermittent, or follow pulsing/scabbling proper.

Balancing of inter-dependent air and water/debris flows requires operator's attention and valve manipulation. Higher pressure difference, reduced air penetration into the chamber, and substitution of solenoid valves for the manual ones, would make operation faster and easier.

5.3.3 Removal of residual debris/concrete rubble

Even with continuous water circulation, only 50 to 70% of concrete debris - suspended fine fractions and coarse particles settled not far from the collection nozzles - are transferred into the drum without additional actions taken. After trying other approaches, including use of X-Y traveling collecting nozzle, after-scabbling surface washing by multiple stationary water jets, simple manual procedure was accepted as at least a temporary solution, suitable for removing even thick and dense beds of concrete debris.

This procedure involves:

- opening the scabbling chamber by lifting a top cover,
- pressure-washing the scabbled floor by a hand-held slot-shaped nozzle forming fan-shaped jet,
- continuous removal of debris "pushed" by the jet toward collecting manifold that transfers rubble into the drum with air and water stream,
- closing the chamber, and moving it to the next scabbling position.

With low power equipment (see **Figure 5.21**) the full procedure takes 3-5 minutes, depending on the amount of debris. Efforts were made to perform the washing without opening the chamber, but it was difficult to go around scabbling module and to reach areas at the chamber corners. This longer procedure was even longer, and left leaving up to 10% of the debris in these areas.

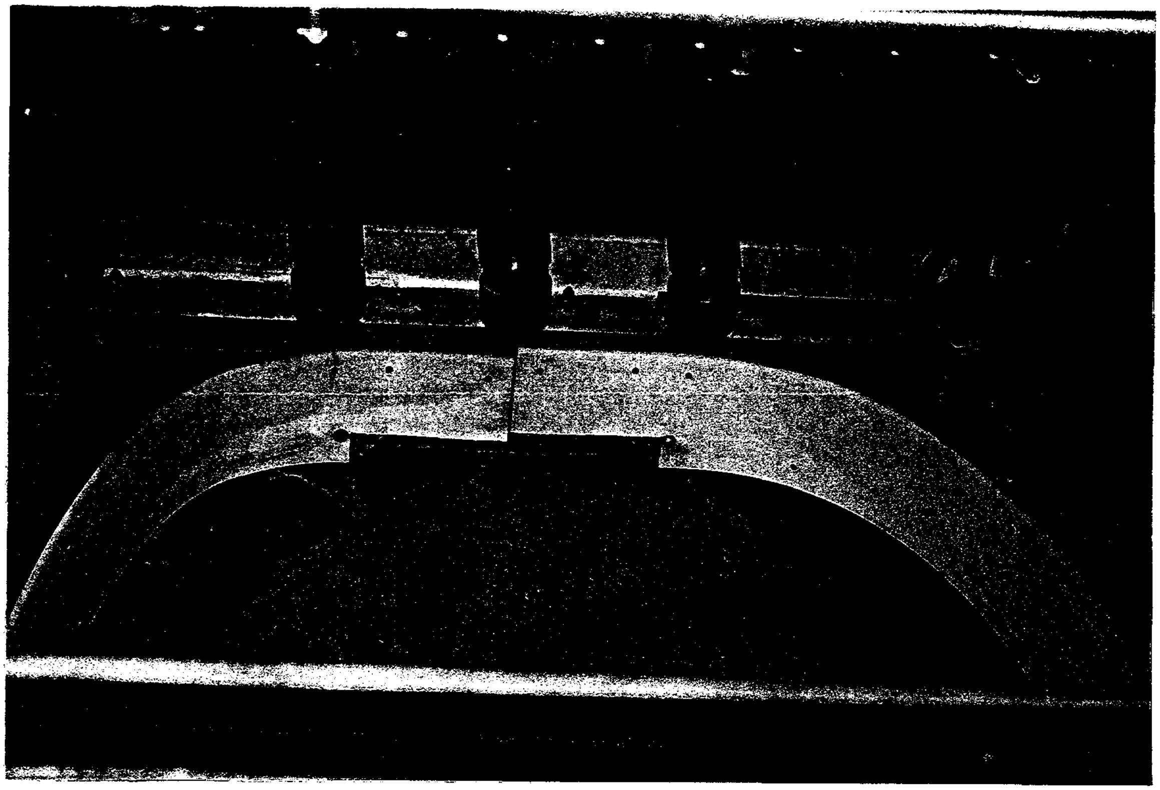


Figure 5.20 Scabbling chamber interior: debris collecting manifold with three suction nozzles, optional sump pump (optional) and several water jet nozzles attached to (lifted) module are seen

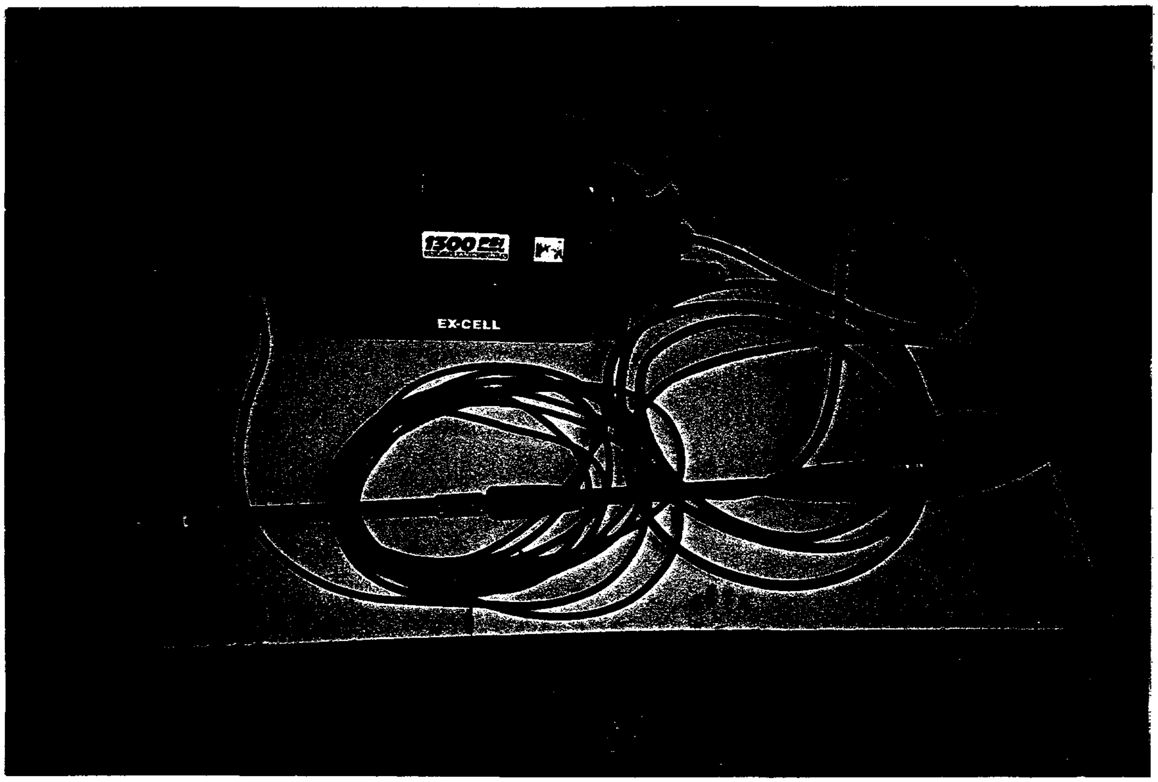


Figure 5.21 Electric power washer (nominal 1.9 gpm, 1300psi)

To achieve better result within the closed chamber, more complicated high pressure, multi-nozzle configuration is needed. Portable pressure washers with electric motors or gasoline/gas engines are available for purchase or rent. Their pressure ranges from 2,000 to 4,000 psi and water flow rate from 2 to 8 gpm.

Efficiency of the rubble collection in the drum is rather high. Coarse and mid-size (<1mm) particulates which constitutes more than 95% of the total amount generated by EHS are gravity-settled and/or screened by a filter installed in the drum around the sump pump. The drum itself is a standard item positioned on a separate wheeled platform. After becoming half-filled, with about 40 gal of debris, it is exchanged with a "clean" (emptied or spare) unit. In an improved, more convenient design, the drum cover with attached flow manifolds, hoses, pump and filter would remain attached to the forklift truck.

A relatively small proportion (2 - 6%) of debris leaving the drum with the exhaust or return water may be captured by a secondary wire mesh, bag, cartridge or cyclone filters. Because the absolute amount of fines is still large - roughly, 100 g per sq. ft. of the floor area, the capacity of the secondary filter should be substantial, as the water has 0.1%-1% solid content.

Requirements/methods for the secondary filtration and other possible return water treatment methods depend on the amount and nature of the concrete contaminant, and whether the EHS unit operates in a water flow-through (possibly followed by water post-treatment) or in a water recirculating mode.

5.4 GENERAL SYSTEM CONFIGURATION AND EHS UNIT CARRIER

As already mentioned, all components of the EHS system are mounted on a standard forklift truck - the same as used in Phase II of the project. Other commercially available trucks with 2,000-2,500 lb. capacity can be used with minor modifications. From the Phase II configuration, the current unit differs by the following:

- The PFN is located over the scabbling chamber and, accordingly, can be lifted and lowered by the fork. The DC power supply/charger remains in the separate cabinet. The distance between this cabinet and the main unit can be arbitrarily long.

- To reduce the noise produced by the airgap switch discharges, the PFN is covered by an internally or externally soundproofed box - see **Figures 5.22, 5.23** and **5.24.** The noise levels, with and without the box, are 120 95dB and 125 dB, respectively.

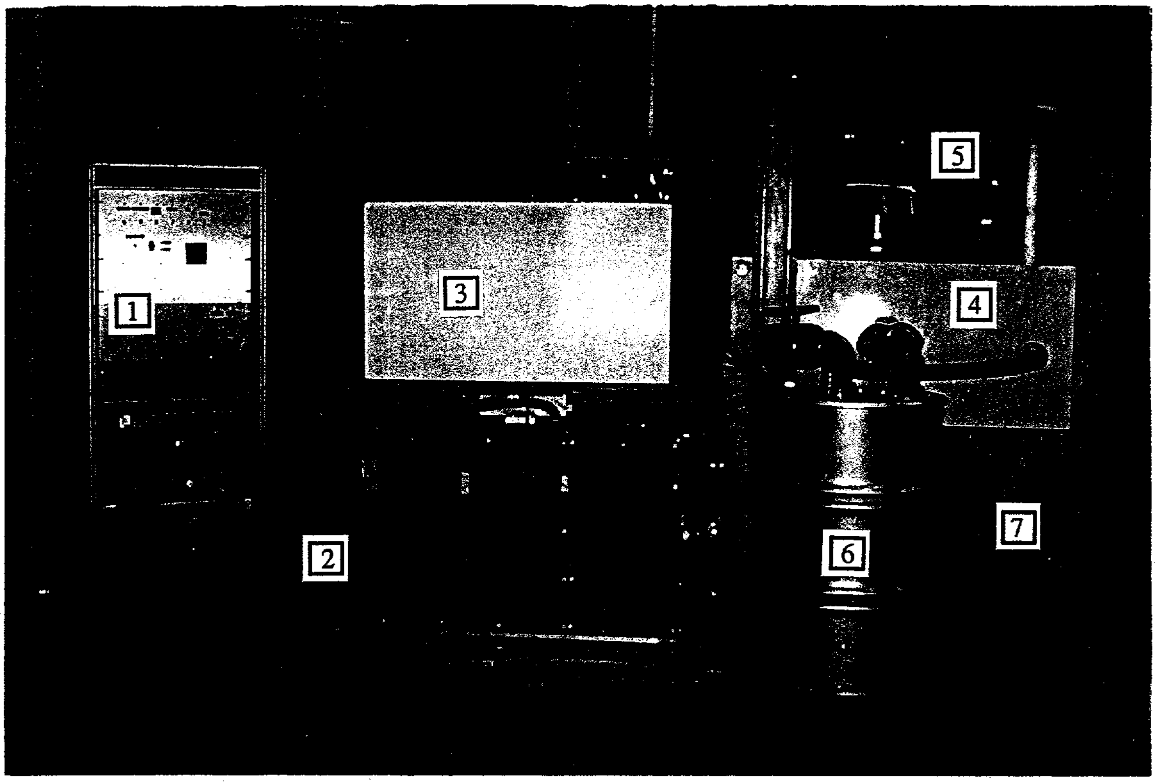
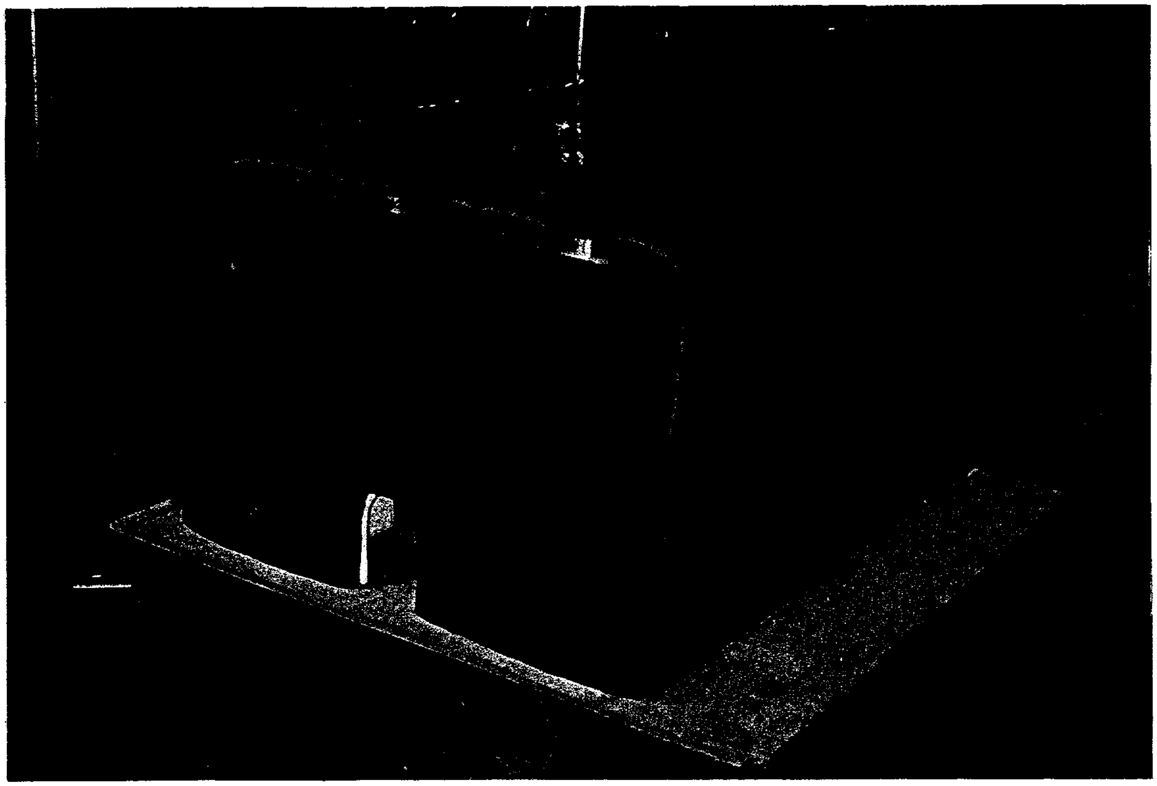
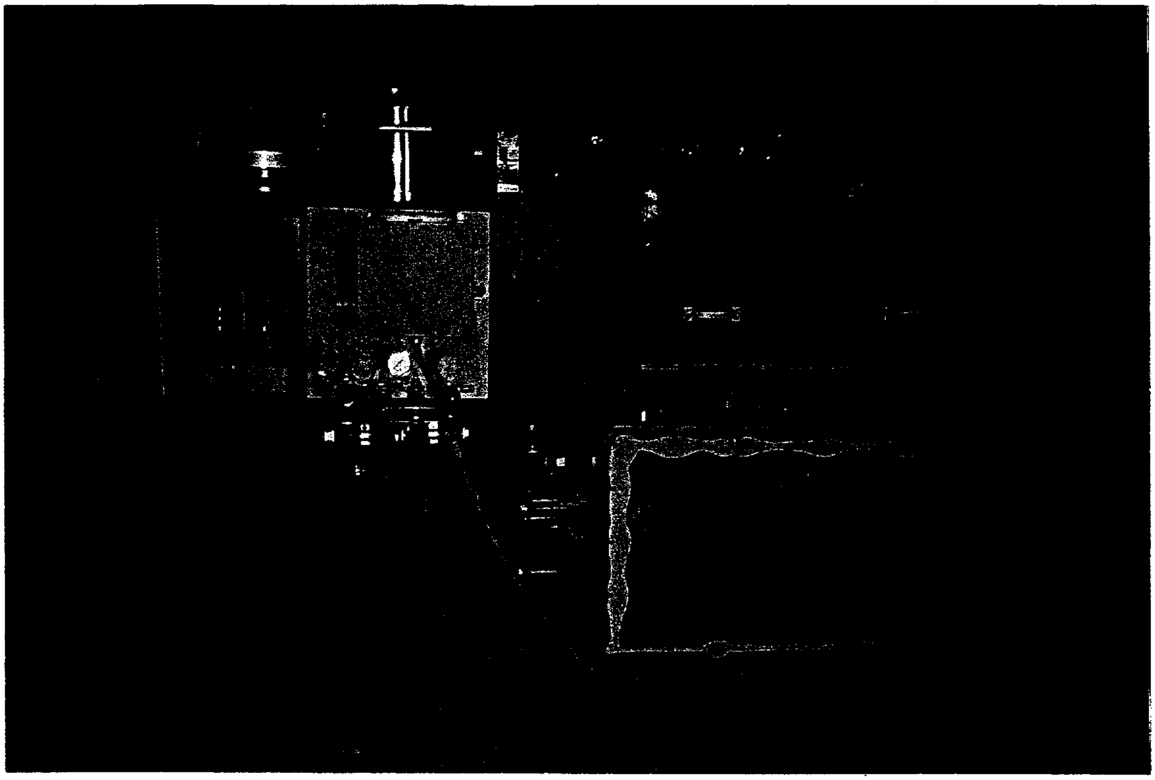


Figure 5.22 Phase III (Fall 1996) EHS unit. Side view: 1-DC power source and controls, 2-scabbling chamber, 3-PFN (inside soundproof box), 4-Flow system box, 5-drum-debris collector, 6-vacuum power heads, 7-forklift truck



Figures 5.23 PFN box with exterior soundproofing



Figures 5.24 Phase III (Winter/Spring1997) EHS unit

- As shown in Figures 5.19, and 5.24, most flow system components are also truck-mounted using a welded platform and a plastic enclosure that is arranged over the truck battery and drives. AC boards/connectors, air manifold with pressure regulators, and most process controls are positioned around this enclosure.

- The only flow system component not mounted on the forklift but connected by hoses and manifolds, is the cover of the water/debris collecting drum. The drum itself is supported by a wheeled platform (or pallet truck) which can be moved independently of the forklift.

- To move the EHS unit to the next segment of floor to be processed, the scabbling chamber must be fork-lifted a few inches above the floor. The fork-lifted components are connected with the components mounted on the truck by flexible hoses and cables.

6.0 EHS TRIALS/DEMONSTRATION AT THE EVERETT SITE

The Everett trial was the first in a series of two medium-size demonstration trials which, taken together with the earlier Fernald trial, provide an opportunity to evaluate the prospects for the industrial use of EHS technology.

6.1 TRIALS OF CHARACTERIZATION

The trial was conducted over the old 8" thick non-contaminated concrete floor in the Building 2. The month-long (February 1997) program included both shallow and deep scabbling of a 400 sq. ft. floor area. The total number of operating days was 16, with maximum scabbling rates of 60 sq. ft. per day.

Preparation for these trials included equipment upgrades, most of which are described in Section 5. More specifically, for this task.

- Capacitance of PFN-L was increased to improve power utilization, and combined air/water cooling installed for the airgap switch.
- Optional 50 kV DC power supply/charger (ALE 802-50) was provided for PFN-H, cooling of the PFN enclosure was improved, and new sets of coated electrodes prepared.
- Pulsing/scabbling "optimization" runs were conducted for both PFNs. Variables included pulse frequency, operating voltage, electrode gap and scabbling module travel mode.

Smaller modifications, adjustments and changes in operating parameters were implemented during the trial program itself. Without these changes and the switching of equipment between two electric subsystems the trial duration would be significantly shorter.

About 80 sq. ft. was scabbled to 3/4"-1 1/4" depth using the low voltage electric subsystem, which had 32 kV AC power available and provided 30 kV, (5 kJ) pulses and other 330 sq. ft. area was scabbled to 1/4"-5/8" depth with an 8 kW electric subsystem B, providing higher voltage, 120kV, and lower, 1 kJ energy pulses.

The 20 x 20 sq. ft. floor area assigned for scabbling was subdivided into eight parallel strips, each 2.5 ft wide and 20 ft. long, as shown in **Figure 6.1.** To decrease the tilt of the scabbling chamber due to formation of deep scabbled trails, most of the area was scabbled in "every other" strip sequence; alternatively, U-shaped fiberglass "rails" were laid out over the uneven floor surface.

In **Figures 6.2 and 6.3,** the EHS unit is shown at the beginning and near the end of the trial program (over strips A and strip H, respectively).

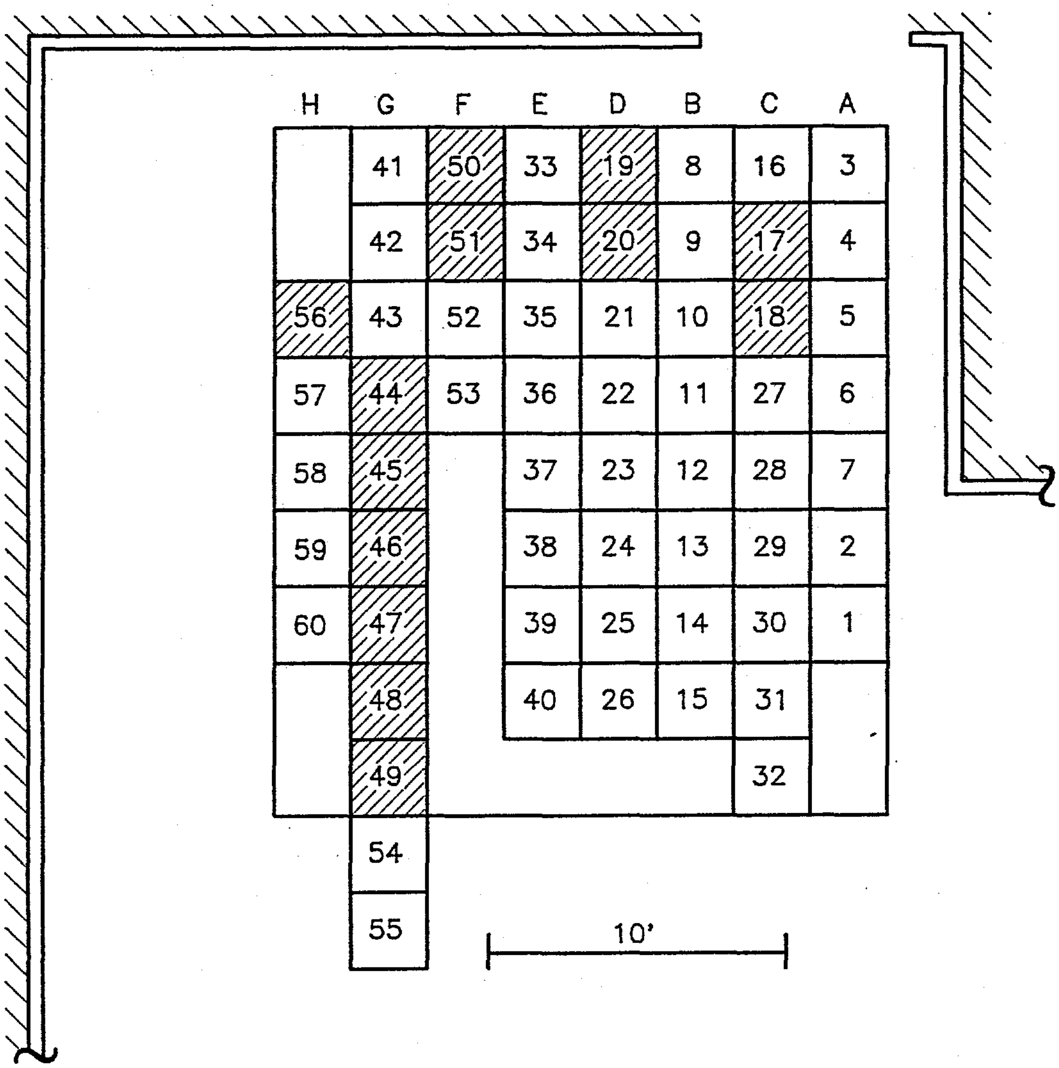
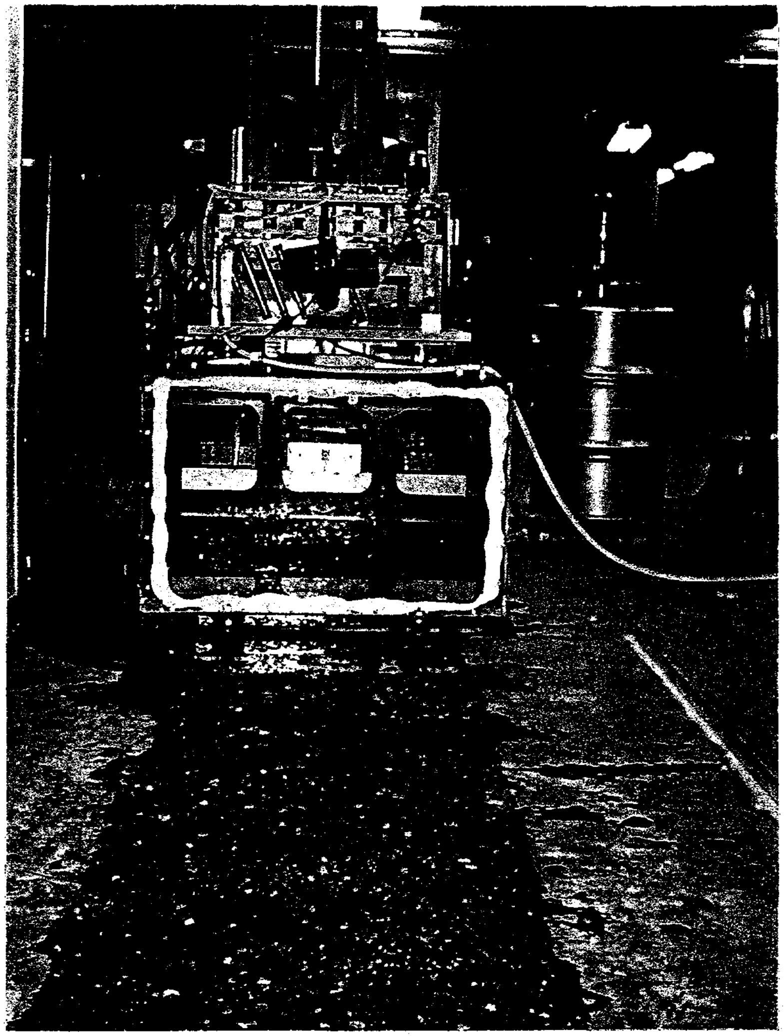
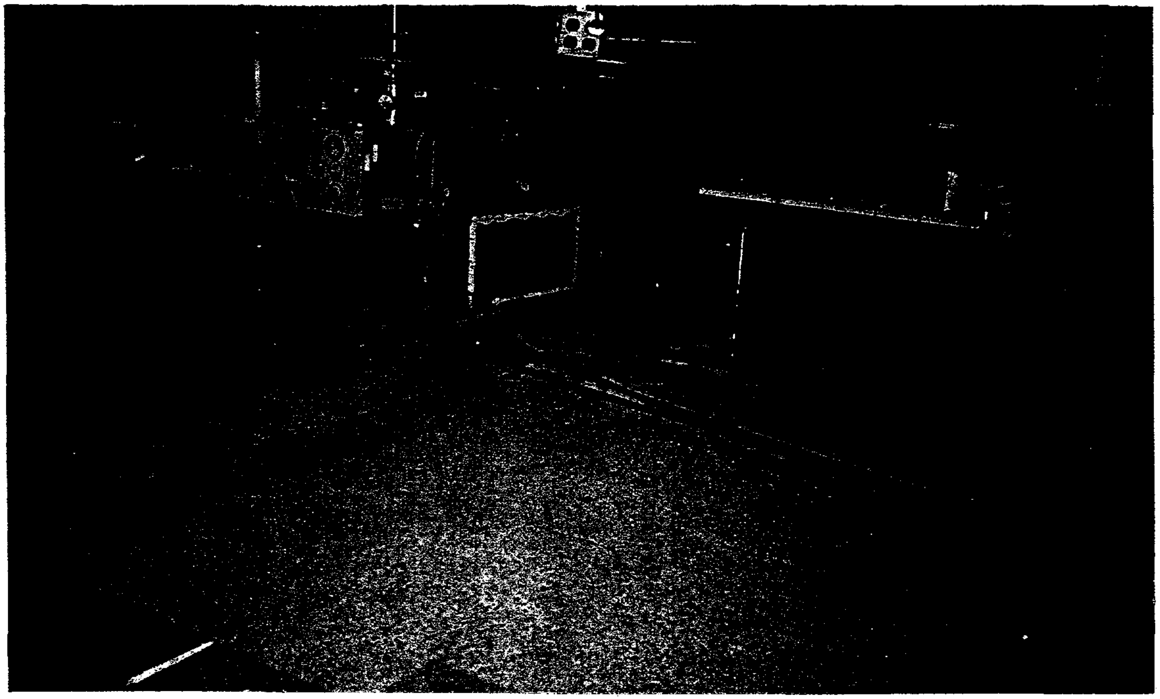


Figure 6.1 Floor area plan and scabbling pattern in the Building 2 on the Textron Everett site.
Scabbling sequence (run numbers) are shown over floor segments (with segments unnumbered not processed). Scabbler was moved mostly along A,B,C etc. rows.Segments scabbled deep by PFN-L pulser are shaded



(a)



(b)

Figure 6.2 EP Scabbling unit with PFN-H (open) on the forklift at the Everett test site.
a) Over raw A at the beginning of the test series
b) Over raw H with most assigned floor area already scabbled

6.2 OPERATING PARAMETERS AND FEATURES

This section provides data characterizing the scabbling process and summarizes experience with operation of EHS unit.

Ranges of conditions selected for shallow and deep scabbling are given in **Table 6.1.** **Table 6.2** contains information on several characteristic runs made within the program, while the next two subsections comment on the scabbling operation.

6.2.1 Shallow scabbling

For the "shallow" - 1/4" to 3/8" - scabbling, runs made with PFN-H electric unit the following features were observed and measured:

- With 32" long electrodes of two configurations - flat and angled (see Figure 5.17) - there was no remarkable difference in performance.
- The unit operates equally well with the 8 kW power supply operating at almost full power - constant 0.67 A charging current, 11-12 Hz frequency,- as with the 32 kV power supply operating at partial power - limited charging time reducing the effective charging power to 0.7 - 0,8 A, and the pulse frequency to 12-14 Hz.
- In this pulsing mode and semi-continuous positioning, i.e. periodic go-stop-go cycloidal motion of the X-Z-X positioner and uninterrupted pulsing, typical operating parameters are as shown in Table 6.1
- Processing of the 32" x 31"= 1,000 sq. in. = 7 sq. ft. concrete area (available within each position of the scabbling chamber) takes 9 to 12 minutes.
- Increase of pulsing time, i.e. number of pulses per each position, results in only moderate, less than linear, increase of the scabbling depth. Increase of DZ over 0.7" causes undesirable periodic depth variation in the direction of scabbling.
- Increase of the pulse frequency above 12 - 15 Hz does not lead to substantial gains in either scabbling rate (at a fixed scabbling depth) or in scabbling depth (at a fixed scabbling rate).

As a consequence, at least with the current design, the time to scabble 7 sq. ft. to a depth of 1/4" cannot be reduced below 6 or 7 minutes. The observed limitation of the specific (i.e., per unit area) power input is discussed in Section 8.

Table 6.1

Ranges of Operating Conditions for EH/EP Concrete Scabbling

Parameter	Low Voltage - (PFN-L) Water Breakdown Mode	High Voltage - (PFN-H) Concrete Breakdown Mode
Operating Voltage, kV	26 - 31	110 - 120
Storage Capacitance, μF	11 - 15.5	2.0
Pulse Energy, kJ	3.5 - 6	0.7 - 1
Pulse Duration (period, μs)	30 - 40	4 - 5
Pulse Repetition Rate, Hz	4 - 6	10 - 15
AC Power (average), kW	24 - 28	6 - 7
Scabbling Path Width (electrode length), cm	30 - 32	30 - 32
Main air sparkgap, cm	0.8 - 0.9	0.85 - 0.92
Inter-electrode gap, cm	1 - 1.5	1.5 - 2.2
Traverse step, cm	1.25 - 1.75	1.8 - 3.0
Per electrode position - number of pulses	180 - 250	80 - 130
- pulsing time, s	45 - 90	7 - 13

Table 6.2

Operating Conditions for Characteristic Shallow and Deep Scabbling Runs

Run, Data #	Floor Segment	Charger/ Pulser	Charger Voltage/ Current, kV / kA	Pulse Energy/ Frequency kJ/Hz	Gap Air/Water, in.	Electrode Coating	Step Δx,	Duration Pulsing min.	Scabbling Rate Nominal	Scabbling Depth in.	Water Flow
Feb 7 #19	C2	30kW PFN-L 15.5μF	28 /1.8	5.7 / 4.5	0.33/0.5	Angular Partial RTV	1."	40 sec 21 min	19 / 12	0.72	Flow-through 6 gpm
Mar 3 #47	G7	30 kW PFN-L 11μF	29 /1.7	5.0 /5.0	0.30/0.5	Angular Full RTV	0.9"	45 sec 24 min	24 / 10	0.95	Recirculation/ 8 gpm injection
Feb 4 #4	A4	8 kW PFN-H 2μF	28 x 4 0.6	0.8/10	0.36/0.7	Narrow Angular Partial RTV	0.75"	11 sec 12 min	34 / 15	0.23	Flow-through 6 gpm
Feb 18 #39	E7	12 kW PFN-H 2μF	29 x 4 0.85	0.9/12	0.36/0.65	Flat Partial RTV	0.65"	9sec 10min	40 / 22	0.28	Flow-through 8 gpm

The next few observations are related to the air and water flow system:

- There were no long-term performance problems when the open-loop (no water recirculation) mode was used, and scabbling took place in a relative "clean" water.

- When the process water is recirculated back into the chamber without removing suspended concrete fines, the scabbling performance deteriorates: to maintain scabbling depth and uniformity either the scabbling rate had to be reduced or scabbling of the same segment repeated before moving the chamber.

- Rate of the deterioration depends on the water treatment. Coarse (>0.5 mm) rubble - more than 95% of the total - is removed in the drum by filtration and sedimentation. If remaining finer fractions as well as dissolved alkalis were not removed, only 3 - 5 floor segments (20 to 35 sq. ft.) could be processed without changing the water. The deterioration can be slowed down substantially when fresh (or properly filtered and/or de-ionized) water is injected at a substantial rate (6-10 gal/min.) directly between the scabbling electrodes.

- Fine (5 to 100mm) cartridge filters installed in the water return loop improved water quality (as evaluated by the turbidity level), but these filters were blocked (and, consequently, water flow slowed down) in a short time (after few segments were processed) by the retained particulates or soluble chemical components.

- Substantial reduction of electric conductivity as well as turbidity could be achieved by installing water de-ionizers filled with cationic resin. Because filter/de-ionized combination was used only in a few runs, it is difficult to predict longevity of these water purifiers and their practicality for maintaining process water quality.

- The enclosure evacuation/water retention system worked well, but manual manipulation of the combined air/water flow valving by an experienced operator is needed to avoid occasional water loss/carryover.

- After-scabbling removal of debris accumulated in the scabbling chamber can be achieved by power washing, using a low flow, moderate pressure (2 HP) portable electric unit.

With this technique, 3 - 4 kg (about 50%) of debris formed by scabbling was transferred into the collecting drum together with 4-6 gal. of water, (the other half, having been already removed with water flowing during/after scabbling proper). Dry vacuuming performed after the runs and power washing was able to collect very little residue - less than 0.3% of the total scabbling-generated rubble.

6.2.2 Deep scabbling

Deep scabbling removed a thick -3/4" to 1 1/4" - layer of concrete using an electric pulser equipped with PFN-L. The main features of these trials are summarized below:

- The electrodes (32" long, as used for shallow scabbling) of angled configuration should have re-enforcement to avoid bending/gap changes due to strong shocks.

- Ranges and selected values of operating conditions for 32 kW DC supply which was used with PFN-L and delivers up to 75% of the installed power, are given in Table 6.1. There is no marked difference in scabbling performance whether the PFN-L used 2 or 3-capacitors. A 2-capacitor unit was used in most tests.

- Processing of the 7 sq. ft. concrete area took 20 to 30 min.

- In spite of the larger amount of debris generated by deep scabbling, the operation is less sensitive to the water quality. Still, scabbling is more efficient and uniform when water is clean.

- The deterioration of performance manifests itself mainly by worsening scabbling uniformity in a lateral (Y) direction: scabbling depth recedes in the direction of one (or both) swath edges.

- Injection of fresh water in the electrode gap improves scabbling quality; but a more efficient measure is insulation of the electrode/water interface area. Unfortunately, protective coatings are damaged by strong shocks, cavitation and turbulence even faster than with the less intense pulses delivered by the PFN-H.

Only 3-4 segments could be processed without deterioration of performance before electrodes or coating are replaced.

- With PFN-L in operation, other components of the scabbling chamber, especially foam gaskets at the chamber bottom, are affected by the strong shock waves. The gaskets are vulnerable also because their working conditions are more severe when deeper swath is formed. To prevent water leakage from the chamber, we had to install denser foam gaskets, provide higher negative pressure in the chamber, and to block lateral propagation of shocks by side baffles. Operation with three storage capacitors delivering (at lower frequency) 7 kJ pulses is even more difficult.

- Concrete debris was removed by the same pressure washer as for shallow scabbling. Because the debris bed is thicker, washing time had to be longer (4-5 minutes). A more powerful (4 HP) washer should shorten the cleaning time.

6.3 QUANTITATIVE EVALUATION

Summary data in **Table 6.3** provide information on the electric and flow parameters, duration of specific operations involved in the shallow and deep scabbling, processing rates, energy and water consumption, and debris formation, separation and size distribution.

Table 6.3
Summary of EH/EP system performance in the Everett site trials

	Low voltage		High voltage	
Parameter	(PFN-L) Range	EH system Average	(PFN-H) Range	EP system Average
Floor area scabbled, ft^2		90		315
Scabbling depth, in.	0.75 -1.30	0.95	0.20 - 0.65	0.33
Scabbling rate, ft^2/hr				
net (pulsing)	15-22	20	32-44	40
effective		12		20
Area scabbled per day, ft^2		NA		60
Energy consumption*, kWh/ft^2		1.2		0.2
Water consumption**, gal/ft^2				
without recirculation		24		15
with recirculation		7		7
Concrete debris(wet, per segment), lbs				
generated		80		27
collected in drum		76		24
carried -over with water		4		2

*Pulsing/scabbling only, not including air/water flow system
** Including initial scabbling chamber fill-up

These data are obtained by averaging through about three quarters of the scabbling runs not marred by malfunctions or deliberate variations of procedures and operating parameters.

Few comments are appropriate:

6.3.1 Scabbling rates

- The main parameter - concrete processing rate - is defined only partially by the scabbling proper: one half of the total shallow scabbling time and one third of the deep scabbling time is occupied with the auxiliary operations. Speeding up of these operations is at least as important as acceleration of scabbling.

- The effective rate of deep scabbling is only about two times lower than that for shallow scabbling despite the four times larger amount of removed concrete; this is due to the higher power input achieved in this case, and almost equal auxiliary times.

- The estimated actual EHS rate for the operating days at Everett - only 7 sq. ft. per hour for shallow scabbling - is low, due to time spent for equipment relocation, changing of equipment blocks and components, characterization measurements, changes in operating parameters and other tasks which would not be necessary in regular commercial applications.

6.3.2 Energy consumption

- Energy consumption is low -1kWh/sq. ft. is a reasonable "ballpark" number for medium-deep scabbling. Electric pulse energy constitutes 60% and 83% of the total for shallow and deep scabbling, respectively.

- Specific energy - joules per unit volume or unit mass of concrete removed - which characterizes efficiency of the electric pulse processing is two times lower for the high voltage operation, presumably due to higher efficiently of the direct concrete breakdown.

- The specific energy numbers are, in fact, exaggerated because during each processing cycle pulsing continues through the module positioning period, and part of the pulses are "dummy" due to the current leakage. Actual numbers should be about 2 times lower for shallow and 1.5 times lower for deep scabbling.

6.3.3 Generation of waste and water consumption

- The main waste generated by EHS is wet concrete debris consisting of gravel (mostly of original size) and mortar (cement, sand) which is ground to various degrees by crushing and cavitation.

Particle size distributions, obtained by screening for both shallow and deep scabbling, are shown in **Table 6.4**. The proportion of finer particulates formed by shallow scabbling is larger, presumably due to higher mortar content in a concrete surface layer.

- 3 to 7 percent of the debris, consisting of particulates smaller than 0.5 or 1 mm (depending on size distribution and on the wire/cloth filter installed in the collecting drum) is carried by the exhaust or recirculating water. This portion amounts to 0.5 kg for shallow and 1 kg for deep scabbling. If cartridge filters (5 to 100 mm pore size) are installed downstream, the amount of solid carryover is further reduced 5 to 10 times; it is reduced another 3-4 times by using de-ionizing columns.

- In the open-loop operating mode used to maintain water "quality", water consumption (including water used for power washing) is high, amounting to 100 gal per 7 ft^2 for shallow scabbling and 200 gal per segment for deep scabbling.

- In the closed-loop (recirculation) mode, water consumption is ten times lower; it is determined mainly by the volume of water remaining in the drum with debris (20-30% by weight); this volume is approximately equal to that used for pressure washing; accordingly, the washing water can be used for make-up.

Table 6.4
Particle Size Distribution for Concrete Debris

% Under Size, mm	EVERETT SITE			FIU SITE
	Shallow Scabbling	Deep Scabbling	Medium Scabbling	Shallow Scabbling
12	98	91	95	98
4.5	85	65	48	51
3.4	57	40	50	81
1.4	38	22	31	49
1.0	26	16	22	33
0.5	13	8.5	10	21
0.3	9.0	48	6.3	15
0.15	4.8	1.9	2.5	10.5
0.05	0.62	0.22	0.35	1.1
0.025	0.18	0.10	0.13	0.23

6.3.4 Scabbling quality

The appearance of the scabbled floor segments is illustrated in **Figures 6.3 to 6.5.** A simple depth measuring technique using manual gauge/profilometer is demonstrated by **Figure 6.6**, to measure depth profiles of longer floor spans, an 18" gauge is attached to a solid bar with its two ends resting on the non-scabbled floor areas. Several profilometer traces taken from segments scabbled to various depths are shown in **Figures 6.7.**

Besides local depth variations due to the inhomogeneous structure of concrete, large scale depth variations, including unscabbled islands, appear when shallow scabbling was performed with recirculated, non-filtered water, or when deep scabbling was performed with electrodes which had lost a substantial part of their insulating coating.

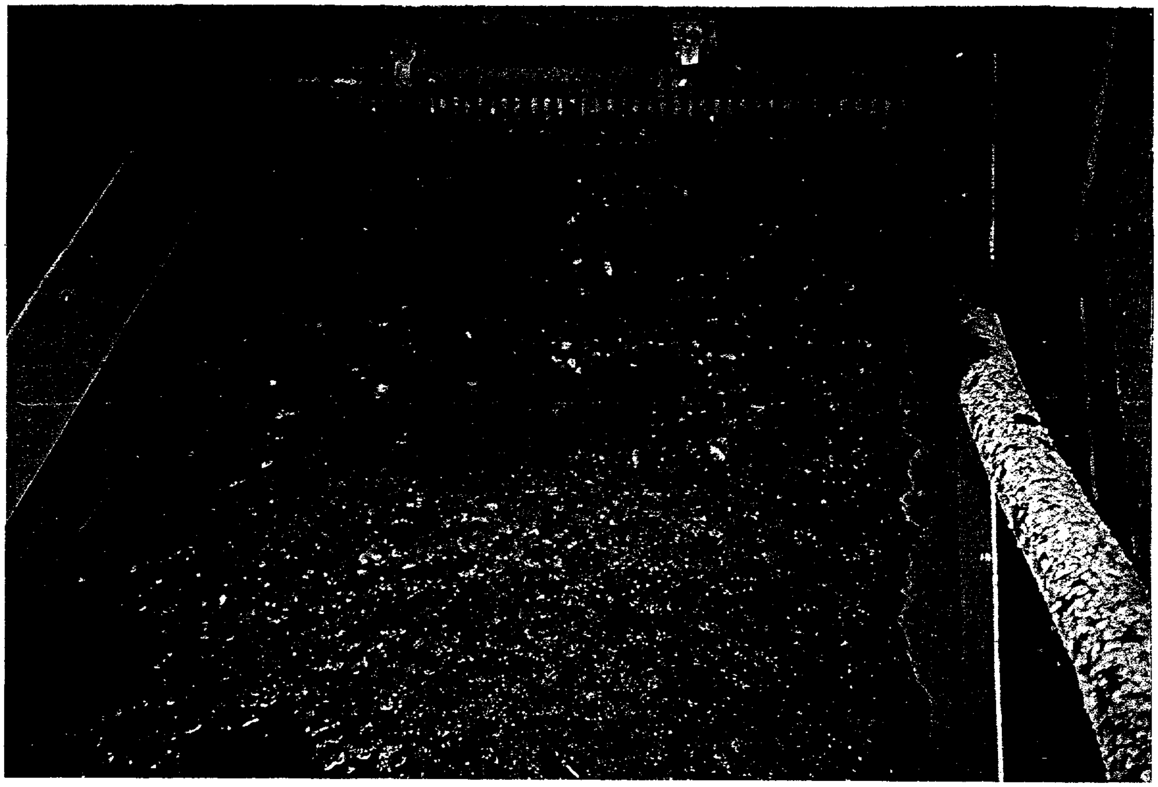
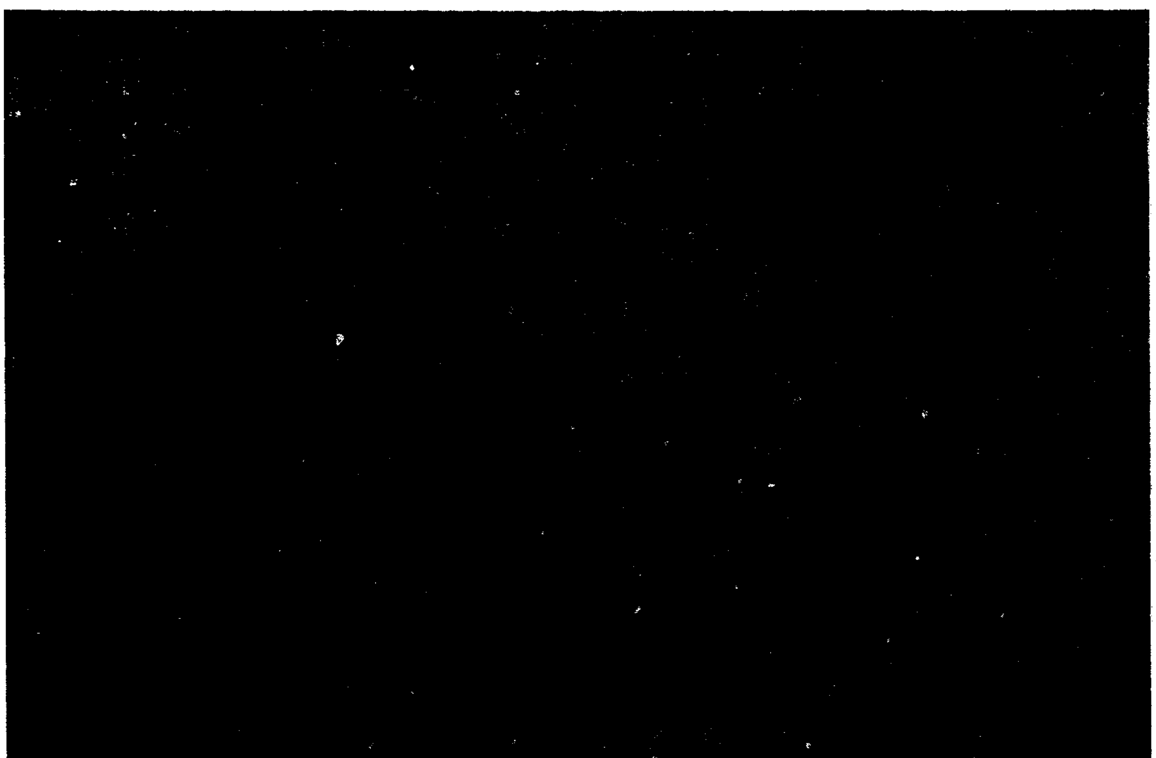


Figure 6.3 Floor segment scabbled to 7/8" depth shown after process completion with water and rubble removed from the enclosure by a combined pressure washing/vacuum suction

Figure 6.4 Scabbling to 3/8" depth with EP (PFN-H) pulser.

(a)



(b)

Figure 6.5 Scabbled segment appearance after 1.25" deap scabbling
a) Depth contour revealed by back illumionation
b) A close-up surface photo

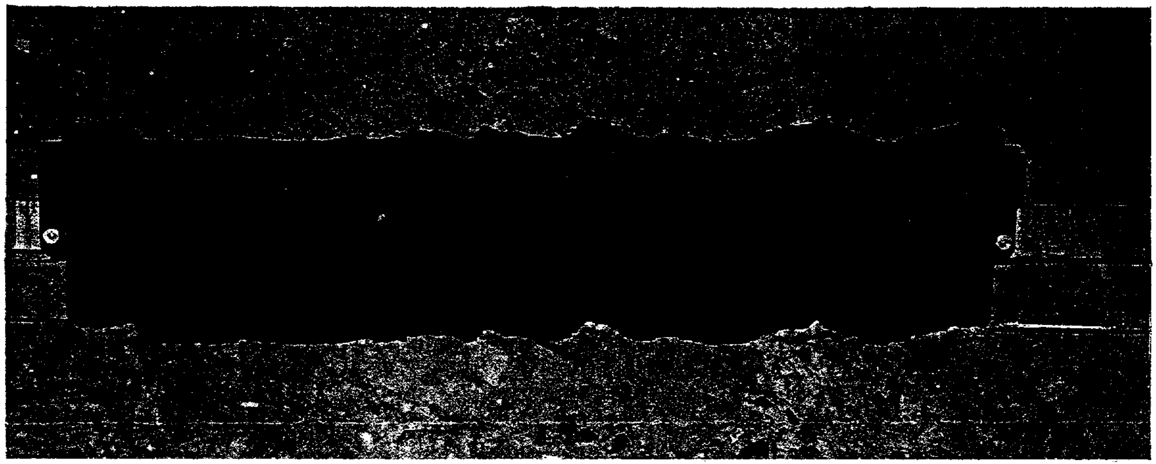


Figure 6.6 Scabbling depth profile measurement with "stretched" manual probe. Average depth along this section is 1.25"

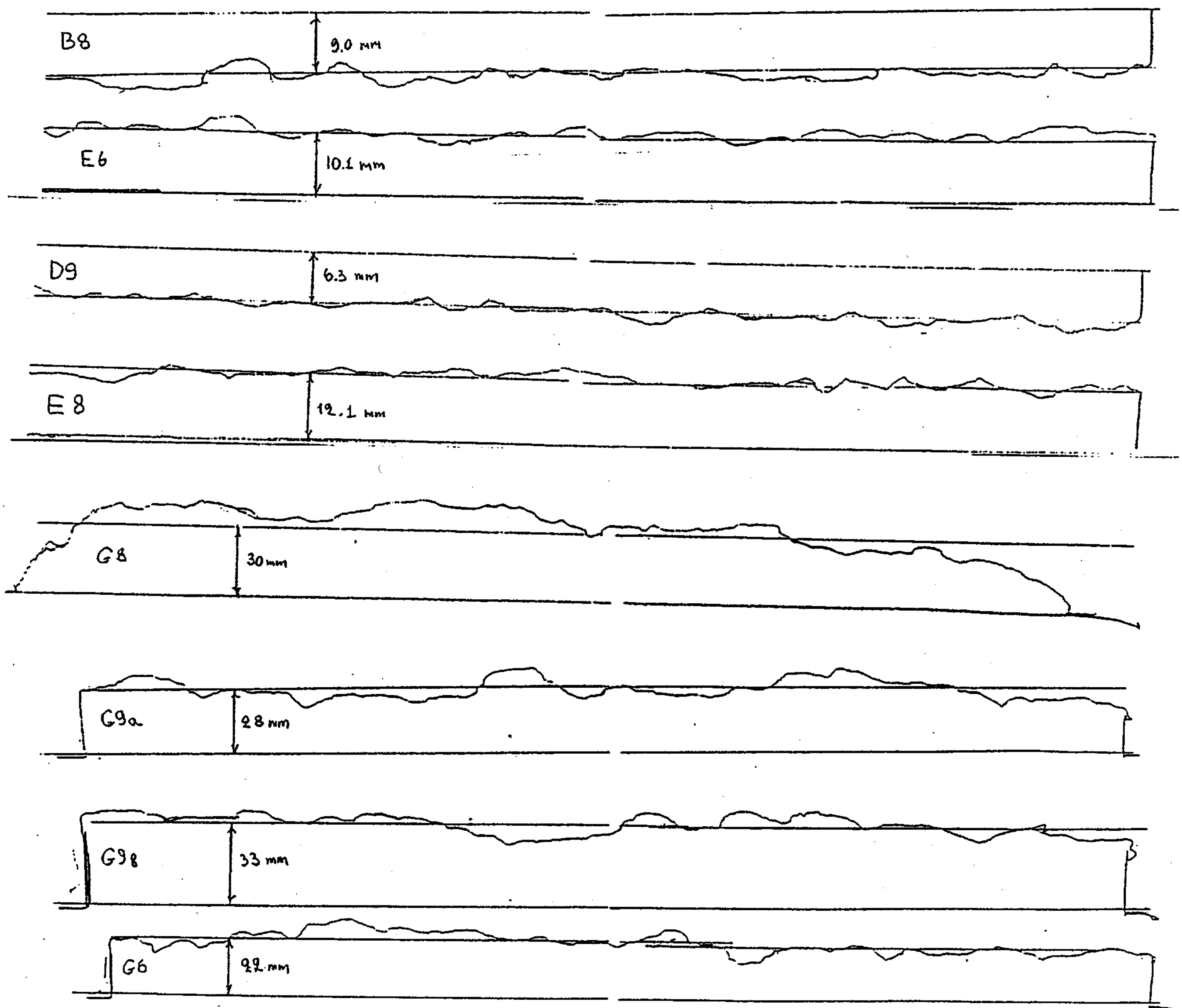


Figure 6. 7 Depth profiles for shallow (1 to 4) and deep (5 to 8) scabbling of several B,D,E and G floor segments. (Scales shown on the profiles differ due to variable 3 magnification)

If these irregularities are excluded, no systematic depth changes (>1/16" after averaging over local "hills and valleys") in either X- or Y-directions are present for a shallow scabbling mode beyond 1/2" - wide zones along the Y-edges; these edges disappear after parallel scabbling lanes are processed with 1/2" edge overlap.

For deep scabbling, the zone along the Y-edge with gradual 1/8" -1/4" depth decrease toward the edge can be 2-3 inches wide.

6.4 GENERAL CONCLUSIONS

The Everett trials provided an opportunity to evaluate the prototype EHS unit by scabbling uncontaminated concrete floor areas which were large in comparison to previous tests. The unit operated in two versions, low voltage and high voltage, used for deep and shallow scabbling, respectively. Operating configurations and conditions were established for both versions.

Though there were no major hardware breakages or serious malfunctions, some "weak" design/operating features were discovered. Appropriate changes in the system components and in procedures were made to improve performance and reliability in future, larger scale trials and demonstrations.

The relatively long trails revealed some weakness affecting EHS operation and performance in its current design. To improve the EHS system, two important performance-affecting issues need to be addressed. These are:

- Limitation on the specific power input/pulse frequency and

- Deterioration of performance (and/or increase of water consumption) due to changes in the process water electric conductivity and breakdown voltage.

7.0 EH/EP SCABBLING DEMONSTRATION TRIALS AT THE FIU SITE

The EHS demonstration trials were conducted at the DOE - assigned Florida International University (FIU) site as a substitute for the earlier planned demonstration at Fernald.

The main difference between the two sites was that the FIU site had clean concrete vs. contaminated concrete at Fernald. Accordingly, only the scabbling, not the scabbling and decontamination, capability of EHS could be demonstrated at FIU.

On the other hand, several techniques for concrete surface processing can be evaluated at the FIU site under identical conditions, and this provides an opportunity for more direct comparison of EHS with other, mostly commercially available techniques. With respect to EHS capability to remove uranium contamination, we still must refer to the positive results of the small scale 1995 trials at Fernald.

7.1 FIU TRIAL LOGISTICS

Demonstration trials at the FIU site were conducted in April 1997. The trials involved scabbling 700 ft^2 of concrete, and were the largest scale trials yet conducted of the EHS technology. Preparation for the trials included the following:

- Technical preparation. Preparation of the EHS unit was based on the results of the Everett trials, and included some changes of hardware and materials, and selection/acquisition of several new components and spare parts.

- Site inspection. An early visit to FIU in March, 1997, provided useful information about the site location, condition, services and utilities available. Demonstration program and work requirements were discussed with the site host.

- Documentation. The following site/equipment-specific documents were prepared (or modified) earlier:
  - NEPA document
  - Equipment description and operating procedure (full and short versions)
  - List of utility requirements
  - Schedule/calendar plan (discussed and confirmed by DOE project management)

- Transportation of equipment. Provisions were made for delivery and return of the main EHS equipment and auxiliaries.

- Formation of the demo trial team. The TSC team included 5 people: manager and two technicians from TSC who built and operated the EHS unit, and two engineers from the TSC subcontractor - St. Petersburg (Russia) Technical University - who took part in the development of the electrical subsystem. Regular EHS operation required two persons, with two others occupied with ancillary functions, such as, servicing utilities, discarding accumulated waste or making records and measurements.

7.2 SITE SPECIFICS AND CHRONOLOGY OF EVENTS

The FIU open test site consists of several 40 x 20 sq. ft. lots covered by 6" thick concrete with (rather shallow) steel wire enforcement. The lots are subdivided (see **Figure 7.1** from Ref. 4, and other figures below) by one foot high barriers. Most of the lots had been already processed using other techniques. Some surfaces were uncoated, some painted with (blue) aliphatic urethane coating.

Concrete at FIU site has small - about 3/8" -and soft limestone aggregates which produces finer debris and higher alkalinity process water than granite/river gravel aggregates we encountered in out earlier tests*.

Of the two lots (A and B) assigned for the TSC effort, Lot B (coated) was empty, while half of the Lot A was occupied by a tent. The tent provided convenient cover for non-used equipment and materials, and protection from sun and rain when - quite frequently - required. On the other hand, the tent limited mobility of the scabbler over the uncoated area which had to be scabbled first. Also, some time was required to relocate scabbler and utility supplies to the second lot in the middle of the trial period.

Only very basic utilities were available at the site:

- 115 V, 15 A electric power supplied via 80 ft. cord from portable generator:
- water supplied from a faucet in a small-diameter pipe faucet via 300 ft. long garden hose at maximum 6 gpm flow rate. (This rate was an order-of-magnitude lower than quoted in the FIU site description).

It was necessary to install a second hose and to use intermediate water drums to reach 10 gpm flow and water reserve needed for some processing stages.

Absence of an on-site telephone was an inconvenience, resulting in delays in communication with the site office, TSC, trucking company, and suppliers of pre-ordered parts and materials

* According to our brief survey with ready-mix concrete manufacturers, graniteor is used in the northern and central US, while (hard) limestone is characteristic for southern locations.River gravel is used inproximity to the rivers which is also typical location for many nuclear facilities

On the positive side, availability of a forklift truck and help provided by the FIU personnel on many occasions, especially in equipment loading/unloading, was appreciated.

Two utility items had to be rented from a local supplier:

- AC (40 kV, 115/208 V, 1/3 phase) generator **Figure 7.2** to power the pulser, vacuum heads and water pumps. The power was sufficient for all needs, but multiple cables and wires were quite inconvenient, limiting mobility of operators and equipment, and were sources of safety concerns in a rainy weather.

- Compressor **Figure 7.3** to provide air for positioner, airgap switches and PFN cooling (useful in hot/sunny days). Capacity of this compressor was more than sufficient, but it became a source of serious trouble in very wet and rainy weather when air flow turned to air/water mix intolerable for airgap switches.

Absence of a roof or other cover over the concrete lot or, at least, over the EHS unit was another source of concern, and of periodic work delays. While EHS technique does not require a dry, clean concrete surface, operation in rainy weather may be detrimental for EHS units which are not weatherproof, and unsafe for operators dealing with HV equipment.

Of course, 3-phase power, compressed air and roof over the floor are available at most industrial locations which may require EHS decontamination. When this is not the case, the commercial EHS unit can be equipped with convenient interfaces and "weatherproofed".

The EHS equipment was delivered to the test site in Miami on March 31 and unloaded. In accordance with the advice of DOE management, the high voltage option EHS, which is better suited to shallow scabbling, considered to be a first priority, was selected.

On April 1, the main unit was assembled as shown in **Figure 7.4** and connected to the generator and compressor. On April 2 and 3, after equipment check-up, initial scabbling runs were made. It was discovered that, due to specific concrete and debris properties, the scabbling pattern was irregular (**Figure 7.5a**) and operation in the water recirculation mode was barely possible.

After the unit configuration was changed to open flow loop, and operating parameters were re-adjusted, regular runs began April 4 and continued over Lot A through April 8. A total 200 sq. ft. area was processed (see **Figure 7.5b**) with scabbling quality improving toward the end of this series of trials due to changes made in electrode and water injection systems.

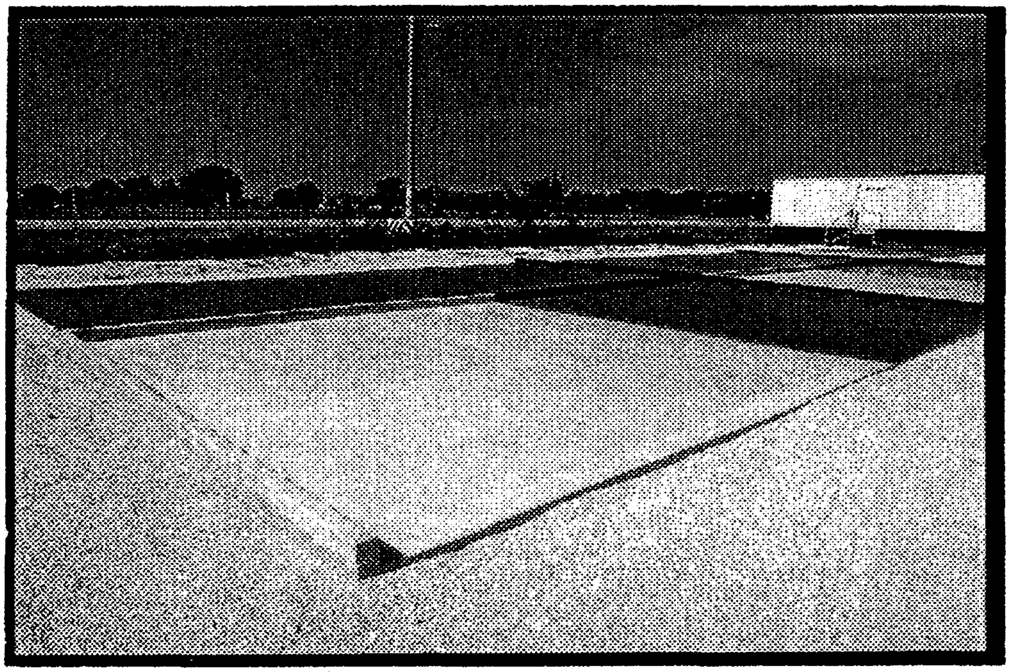


Figure 7.1 Concrete "floor" test site at Florida International University with individual section for each technology

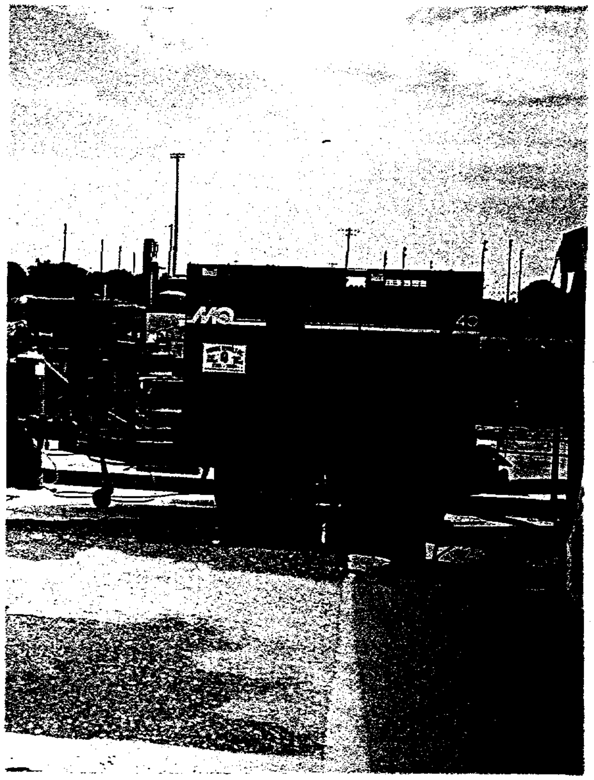
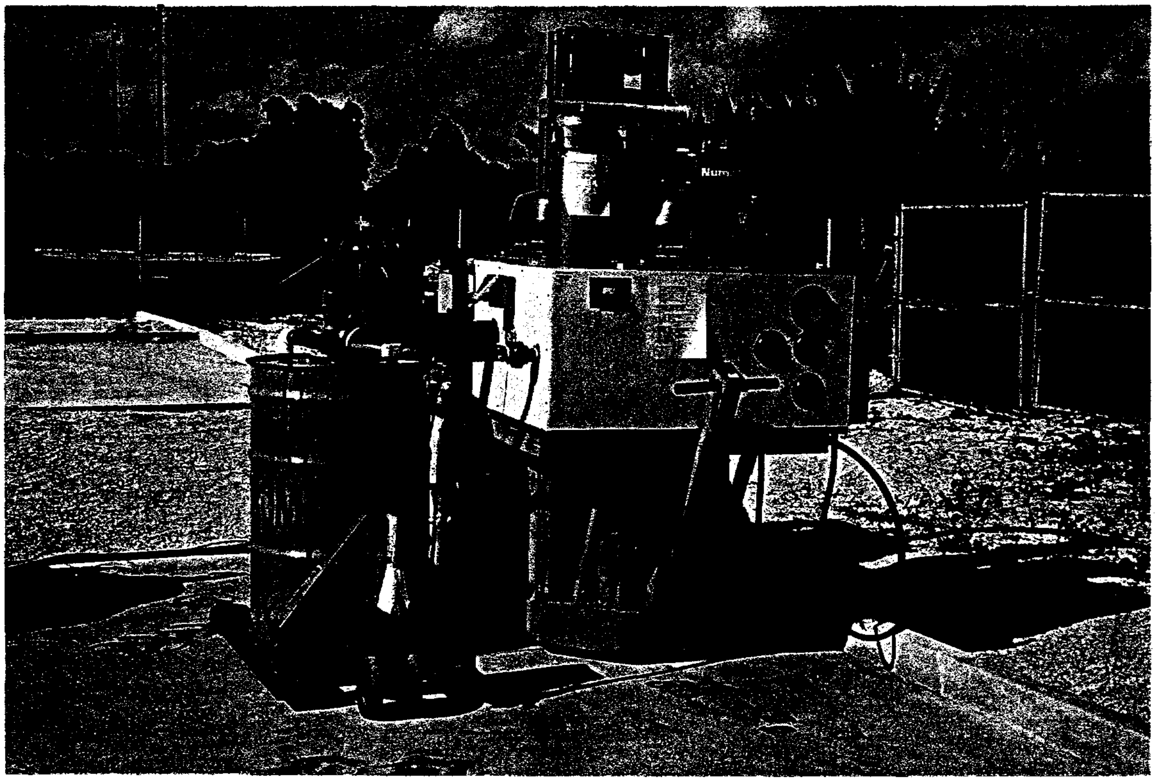


Figure 7.2 A 40 kW 110/208 V, one/three phase AC generator, rented and used as a main power source

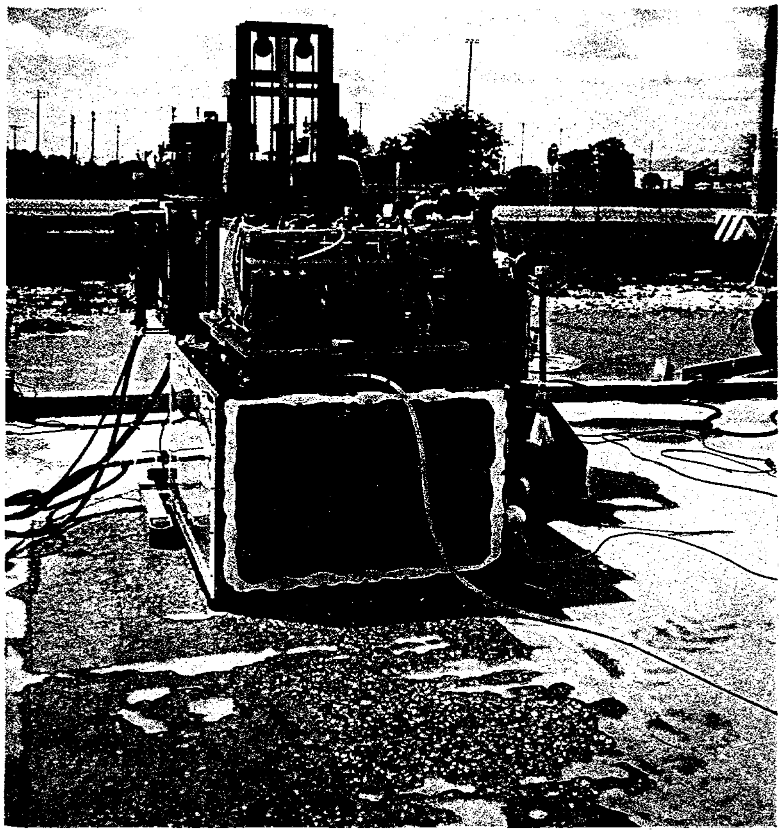
Figure 7.3 Compressor rented and used to supply air for positioners, actuators, spark gaps and PFN cooling

(a)



(b)

Figure 7.4 EP scabbling unit delivered and assembled at the FIU site.
Shown at Lot A initial position with water-filled scabbling chamber.
(a) - side view; PFN-H on the forklift, not covered
(b) - same, rear view



(a)

(b)

Figure 7.5 FIU site, Lot A scabbling
(a) - preliminary runs: parameters still not optimized, surface pattern with occasional unscabbled "islands"
(b) - 200 sq.ft. processed, and scabbler moved to Lot B (dark/light surface appearance depending on dry /wet condition

On April 8, the scabbler and auxiliaries were re-located to the second (painted) concrete Lot B; Lot B processing started April 9 and was finished on the morning of April 16 with about 500 sq. ft. area (70 segments) scabbled. On April 16 and 17 the equipment was disassembled, packed, truck-loaded and returned to Everett on April 22.

In the next section, the scabbling operation is described in detail.

7.3 EP UNIT OPERATION

7.3.1 Lot A: shake-down and regular runs

The preliminary runs, plus about one third of the regular scabbling runs, involved processing of 200 ft^2. (29 segments - see **Figure 7.6** layout) of unpainted concrete over Lot A. This made up the first part of the test program. Even after adjustments to specific concrete properties were made, modification of hardware and procedure continued in order to optimize performance: scabbling rate and quality.

Data in **Table 7.1** characterizes operating features and some results of the Lot A runs.

Scabbling depth was measured by a manual gauge. Example of depth profiles over segment #9 with scabbling defect - an "island"- are shown in **Figure 7.7.** In addition to the gauge measurements, the depth averaged over a larger area was obtained from the weight and volume of collected wet debris. **Table 7.2** illustrates this approach; in this case debris was collected (from the drum and cartridge filters) over segments 8 to 18; the average scabbling depth - 0.55 cm (0.22") - is within the range obtained by gauging.

In summary, the assigned area was scabbled to a suggested average 1/4" depth with deviations within +/- 3/32" due to condition/parameter variations - either deliberate or uncontrollable.

Per one 7 sq. ft. segment, the net scabbling (pulsing) time was 11.5 minutes. The effective processing time (which includes auxiliary operations and occasional 2nd passes, but not maintenance, changes and repairs) was 31 minutes. The "total" processing time i.e. time spent on the lot and directly related to the EHS unit runs, maintenance, repairs, relocations and equipment changes was 66 min per segment.

Processing of Lot A revealed some problems with EHS unit operation at the FIU site. They relate partially to the site conditions - specific type of concrete, inconvenient utility supplies - and partially to the EHS process/unit itself. The main concern is difficulty in maintaining system performance and scabbling quality in a water recirculating mode. Reasonably uniform processing with small defects (e.g. unscabbled "islands") constituting only about 1% of the total area could be achieved but at the expense of high water consumption or by a second pass removal of the surface defects.

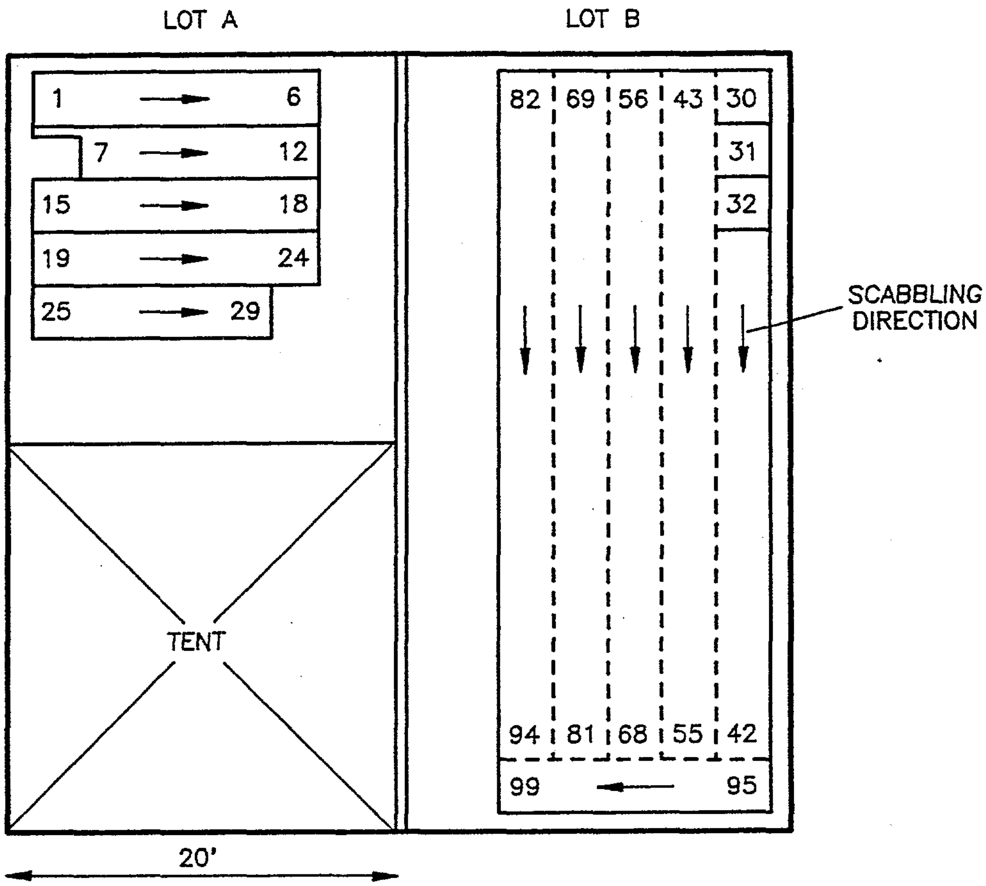


Figure 7.6 Layout of "floor" segments and scabbling sequence/direction at the FIU site

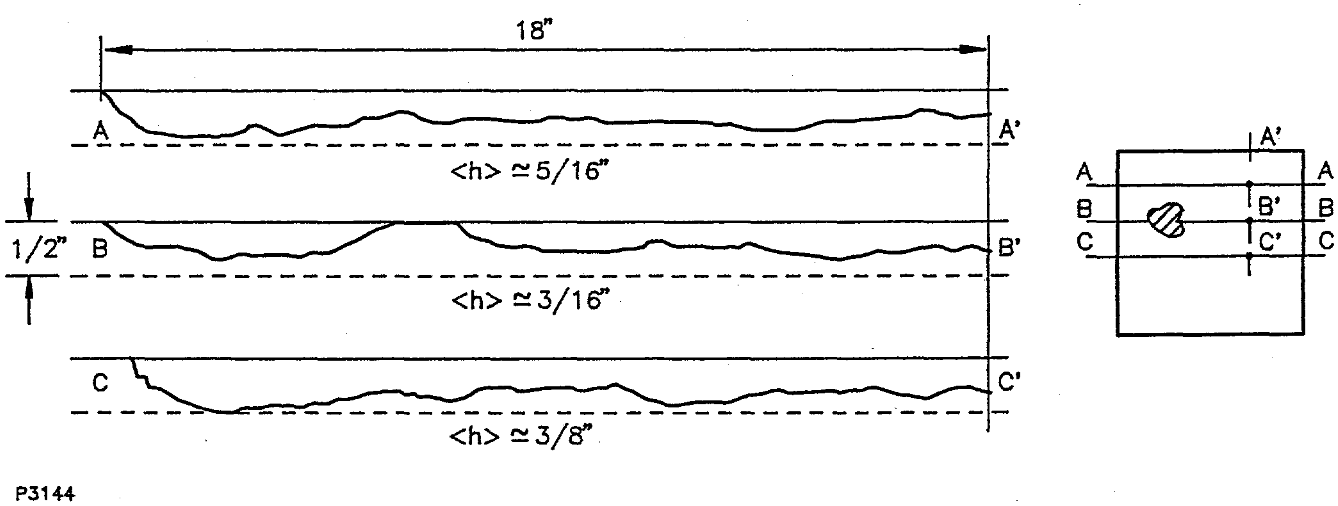


Figure 7.7 Scabbling depth profiles over three segment A9 cross-sections.

Table 7.1 Lot A Operating Features

Segment #	Date	Operating Features, Changes		Maintenance Repairs, Replace	Scabbling Quality
		(1 to 7) - Shake-down trials			
1	2; pm	El: regular*, 8 kW	Fl:OL**		OK, h=3/8"
2	2; pm	"	Fl:CL		SD
3	3; am	"	Fl:OL	Drive belt	Low
4	3; am	El: 12 kW	"		SD, 1/4"
5	3; pm	El:12 kW	"		OK
6	3; pm	EL: regular 8 kW	"	Sump pump	OK
7	2; pm	"	Fl:CL		Low quality
		(8 to 29) - Regular operation			
8	4; am	" water injection		Cartridge filter installed	OK, 1/4"
9	4; am	" "			SD
10	4; am	" "		Water reserve drum installed	SD
11	4; pm	" "		Electrode edges grind	SD
12	4; pm	" higher w.level		Filter removed	SD
13	5; am	" longer w. inject. tubes		Electrode coat, and replace	OK
14	5; am	" "		Cable disconnect	SD
15	5; am	" "		Drive problem	OK
16	5; am	" "		Add w. gap insert	OK
17	5; am	" add. w. supply hose		Drum/ pump empty., clean	OK
18	5; pm	" "		Compressor: water Debris collected	SD
19	5; pm	" "		New electrodes, module height change	OK
20	5; pm	" "			OK
21	7; am	" "		Compressor: water	Low quality

Table 7.1 Lot A Operating Features (continued)

Segment #	Date	Operating Features, Changes		Maintenance Repairs, Replace	Scabbling Quality
		(1 to 7) - Shake-down trials			
22	7; am	"	"	Belt drive	OK
23	7; am	"	"	Electrode re-coat Module adjustment	OK
24	7; am	"	"		SD
25	7; pm	"	Fl:CL		Low quality 2nd pass-OK
26	7; pm	"	Fl:OL		OK
27	8; am	"	Fl:CL		SD, 5/16" 2nd pass-OK
28	8; am	"	Fl:CL	Cable disconnect	SD 2nd pass-SD
29	8; am	"	Fl:Cl	Equipment relocated to Lot B	SD 2nd pass-OK

* Regular electric conditions:
One ALE-802 charger, PFN-H with 9 mm air gap, 27 x 4 operating voltage, 0.67 A charging current, 4.8 ms pulse duration, 12 Hz pulse frequency.
** Water flow modes: OL-open loop, flowthrough; C:-closed loop, recirculation
" sign means- no changes; voids -no maintenance/adjustments made

Table 7.2 Comparison of scabbling depth values (a)- measured (selectively) by manual profile gauge and (b)- calculated from the volume/weight of collected debris*

Floor Segments	Scabbled area, m^2 (ft^2)	Wet debris collected, kg (lbs)	Average depth, cm (in)	Measured directly **
A8 to A18	6.9 (74)	94 (206)	0.55 (0.22)	0.51 (0.20)
B43 to B55 (second raw)	7.4 (87)	120 (264)	0.66 (0.26)	0.71 (0.28)

* Bulk concrete density 2.15g/cm^3 = 134 lbs/ft^3
Wet debris density (measured) 1.33g/cm^3 = 83 lbs/ft^3
Debris loss (filters etc.) - estimated 7%
Water content in debris 20% - obtained from drying weight loss
** Averaged over 2 points per segment

Another issue was persistence of several minor and trivial design/assembly problems that disturbed the operation and were time-consuming to eliminate.

7.3.2 Lot B: main trials

About 500 sq. ft. - 75 segments - see Figure 7.6 - of painted concrete surface was scabbled. The scabbled area was limited by the EHS unit geometry, which does not allow processing closer than 1 ft. from the obstacles, as well as by auxiliary equipment located at the Lot A/Lot B barrier. Because most necessary system modifications were already implemented during the Lot A processing, Lot B scabbling proceeded faster and in a more orderly manner. Also, operation benefited from larger freedom for maneuvers, including longer unit traverse lanes. Unfortunately, these advantages were offset by rainy/stormy weather prevailing through the April 9 - April 15 period.

Progression of scabbling over the succession of lanes is illustrated by **Figures 7.8 and 7.9**; photo **Figure 7.10**, was taken after all accessible Lot B area had been scabbled.

Operating features of the Lot B runs are provided in **Table 7.3**.

7.3.2.1 Equipment performance/malfunctions and site-related arrangements

Annoying malfunctions remained the same as for Lot A runs: positioner's belt drive and HV cable faulty connectors. In addition:

- A new, higher power, sump pump failed. The specific model appeared to be sensitive to stray HV currents.

- Permanent troubles with wet compressor air were amplified by the rainy weather.

  (It has been shown, though, that for the only function where water-free air is needed, the compressor can be substituted by a low power blower).

Based on the bad weather experience, the following lessons were learned:

- Power supply cabinet: the cabinet was located in the semi-open tent, this arrangement is sufficient,

- PFN: operation can be reliable and safe with forklift equipped by a small cover. The only PFN damage - two burned resistors - was from an electric short induced by water blown into the enclosure with compressor air.

(a)

(b)

Figure 7.8 Lot B scabbling; wet, after-rain concrete surface
a) At the beginning of the second raw
b) In the middle of the second

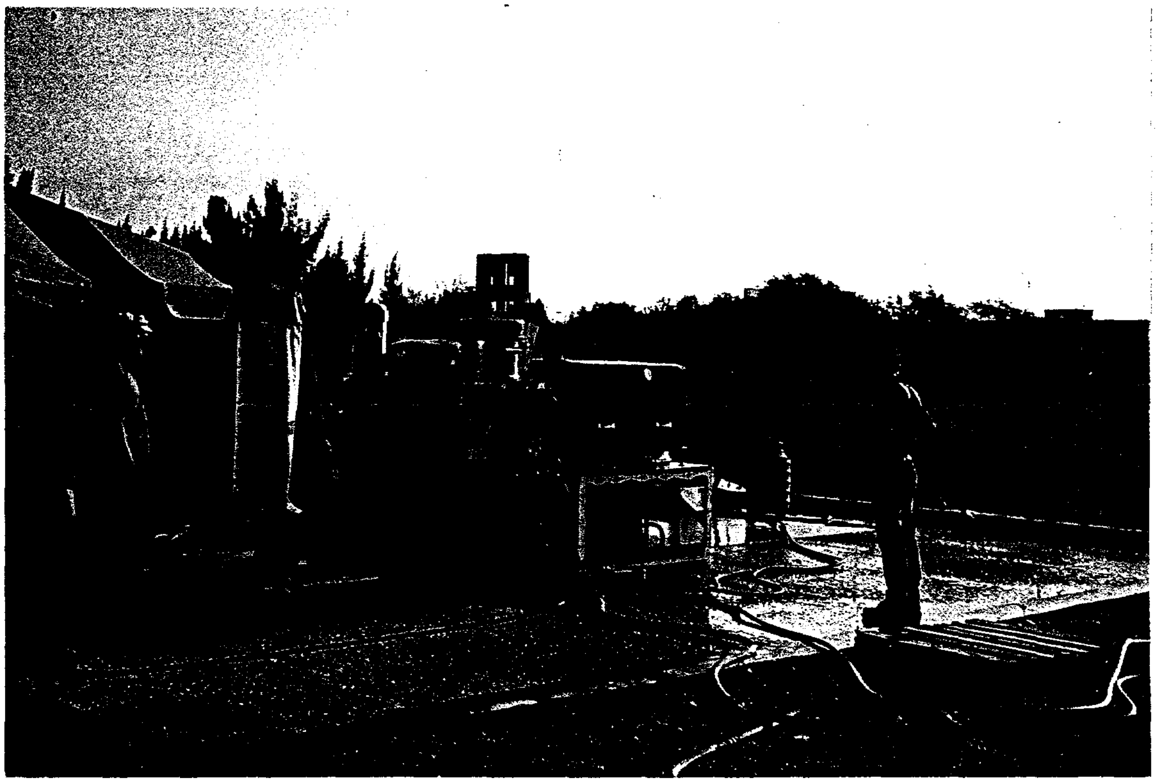


Figure 7.9 Lot B scabbling: EP unit in operation over raw 4

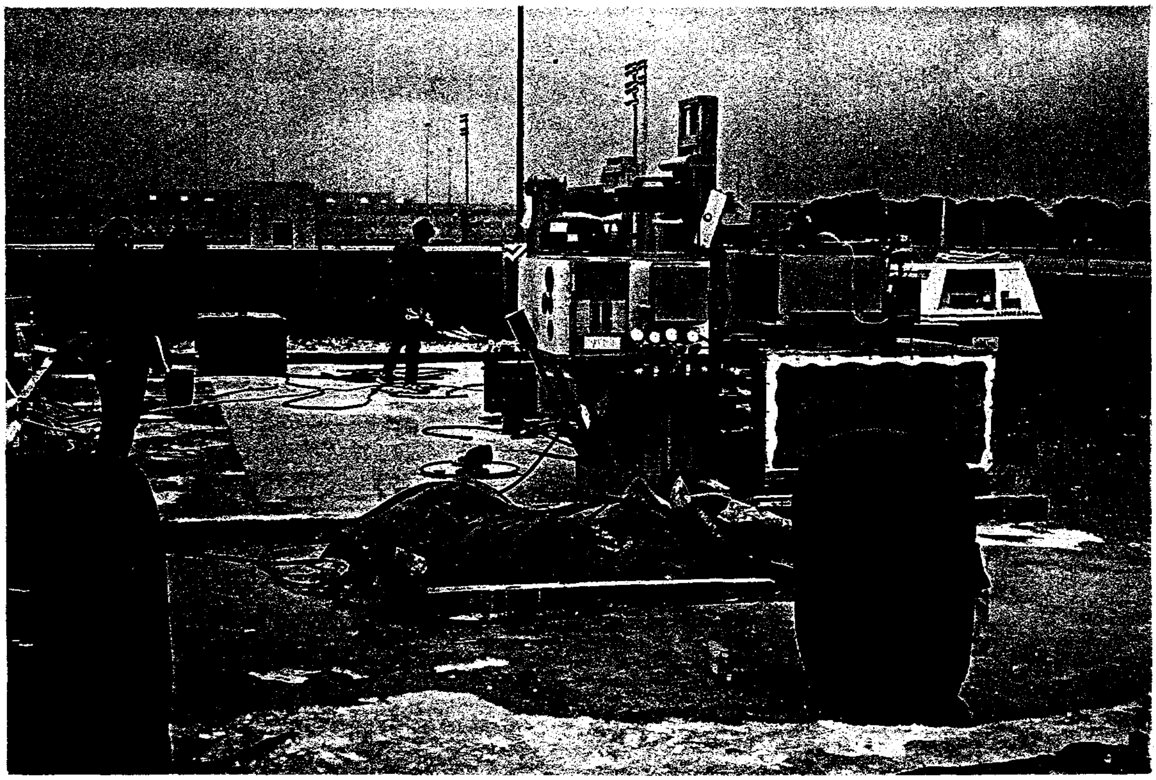


Figure 7.10 Lot B scabbling is finished, equipment diss-assembling/packing starts
Acc mulated concrete debris is stored under blue tarpoline in a forefront

Table 7.3 Lot B Operating Features

Segm. #	Date	Operating Features, Changes	Duration, min Pulse/Total	Maintenance, Repairs, Replacements	Scabbling Quality
30	9; am	Regular*, 8kW Fl: OL	9/24 32	New electrodes, (flat, G10/RTV cover)	OK
31	9; am	"	9/25 29		OK
32	9; am	"	9/23 28		OK
33	9; am	"	9/22 27		OK
34	9; am	"	10/34 42	Hose damage	OK
35	9; am	"	8/23 41		OK
36	9; am	"	9/25 38		Small defects related to exposed armature wire
37	9; pm	"	9/24 37		OK
38	9; pm	"	8/24 34		
39	9; pm	"	8/26 37		OK
40	9; pm	"	9/26 34		OK
41	9; pm	"	9/26 35		OK
42	9; pm	"	9/25 35		OK
42a	9; pm	"	8/24 NA		OK Last in 1st lane, 15" long
43	10; am	"	10/22 26		OK
44	10; am	"	10/22 25		OK
45	10; am	"	10/22 32		OK
46	10; am	"	9/22 26		OK
47	10; am	"	10/24 30		OK
48	10; am	"	10/20 26		OK
49	10; am	"	10/24 30		OK
50	10; am	"	9/23 31		OK
51	10; pm	"	11/26 32	Increased pulse duration	OK
52	10; pm	"	11/26 30		OK

Table 7.3 Lot B Operating Features (continued)

Segm. #	Date	Operating Features, Changes	Duration, min Pulse/Total	Maintenance, Repairs, Replacements	Scabbling Quality
53	10; pm	"	10/24 29		OK
54	10; pm	"	11/24 29		OK
55	10; pm	"	12/24 27		OK
55a	10; pm	"	8/13 NA		OK Last in 2nd line
56	11; am	"	11/24 28		OK
57	11; am	"	12/29 59	Minor chamber closing problem	OK
58	11; am	"	11/24 31		OK
59	11; am	"	10/24 30	Compressor water!	OK
60	11; am	"	14/29 33		OK
61	11; am	"	11/35 32	Minor cable problem	OK
62	11; am	"	12/29 33		OK
63	11; pm	"	12/29 39	Compressor water!	OK
64	11; pm	"	11/27 31		OK
65	11; pm	"	11/23 29		OK
66	11; pm	Fl: CL	12/32 32	Some water recirculation New pump installed	SD
67	11; pm	Fl: CL	11/26 40	Water recirculation, Surface evaluation	Low quality
68	11; pm	Fl: OL Higher flow	11/24 28	Add new pump	OK
68a lane	11; pm	Fl:CL	15/40 NA	Drive problem	Last in 3rd OK after 2nd pass
69	12; am Rain storm	Fl:OL	11+5/45 Electric	Forklift battery discharged breakdowns, unsafe	OK after 2nd pass
70	13; am	"	12/34 57	Drive problem, repair	OK
71	13; am	"	12/32 71	"	OK shallow?
72	13; am Rain	DX =0.55"	14/26 30	Shortened step	OK
73	13; am	"	13/25 32	"	OK

Table 7.3 Lot B Operating Features (continued)

Segm. #	Date	Operating Features, Changes	Duration, min Pulse/Total	Maintenance, Repairs, Replacements	Scabbling Quality
74	13; am	DX =0.8"	10/24 NA	Increased step Installed water filter	OK
75	14; am	"	10/25 31		OK
76	14; am	DX=0.7"	9/24 35	Compressor water! Removed water filter	OK
77	14; am	"	10/23 27		OK
78	14; am	"	10/27 32		OK
79	14; am	"	10/22 24		OK
80	14; am	DX=0.8"	9/21 26		OK
81	14; am	"	9/21 24		OK Last in 4th lane
81a	14; am	"	5/19 NA		OK
82	14; pm	"	10/25 27		OK
83	14; pm Rain	"	12/33 40	Minor positioning problem	OK
84	14; pm Rain	"	9/22 26	Compressor water!	OK
85	14; pm	"	9/22 NA		OK
86	15; am	PFN air switched from compr. to blower	NA 90	Drive problem.	OK after 2nd pass
87	15; am	"	10/24 32		OK
88	15; am	DX=0.7"	11/27 32		OK
89	15; am	"	11/26 28		OK
90	15; am	"	9/24 27		OK
91	15; am	"	9/24 27		OK
92	15; pm	"	10/24 26		OK
93	15; pm	DX=0.8"	8/23 28		OK
94	15; pm	"	8/ 24		OK
94a	15; pm	"	5/14 Move to transverse lane		OK Last in 5th lane
95	15; pm	"	9/24 27	Cable disconnect	OK

Table 7.3 Lot B Operating Features (continued)

Segm. #	Date	Operating Features, Changes	Duration, min Pulse/Total	Maintenance, Repairs, Replacements	Scabbling Quality
96	15; pm	DX varied 0.6-0.8"	16/35 88	Drive problem Cable disconnect	SD
97	15; pm	DX=1"; Fl:CL	7/20 NA		Low quality
98	16; am	DX=0.7";Fl:OL	9/25 28		SD
99	16; am	"	10/26 NA		OK Last Lot B segment

* Regular conditions:
Electric:
One 8 kW, 30 kV ALE-802 charger, 0.67 A charging current;
PFN-H with 9 mm first airgap, 4.8 ms pulse duration, 12 Hz pulse frequency
Other :
X-positioning with DX=0.70" step
Water flow modes : either open loop (OL) or closed loop(CL)-recirculation
Debris removal by pressure washing
Processing times:

T(1)/T(2) pulsing/all operations
T(3) time interval between sequential runs
" sign means no changes; voids mean no maintenance or repairs made

- AC generator: preferably stationed under some roof or tent.

- All open space AC and, especially, HV cables should be protected by flexible (polyethylene etc.) hoses.

- During operation with a remote low-capacity power supply, a "web" of long, small diameter hoses and water storage drums is inconvenient and might be unsafe.

Encouraging (and more important than the minor malfunctions and site/weather related inconveniences) was the reliable performance of the electric power supply and PFN components - capacitors and airgap switches. Despite weather conditions, from rain to shine, these components required only moderate cooling, and were not sensitive to high humidity.

The very low electrode erosion rate and relatively high service time of combined (RTV+ fiberglass) electrode coatings and other electrical and mechanical components - relays, positioner, foam gaskets. etc - hold promise that the low maintenance time required for industrial EHS unit can be achieved.

7.3.2.2 Processing rates

Because the processing conditions did not vary significantly, averaging of scabbling duration data is representative. The following (per segment) times were obtained:

- Net scabbling (pulsing + module positioning) T(1) = 9.8 min.

- Processing (net scabbling, water in/out, debris removal and chamber transfer) T(2) = 24 min.

- Full cycle duration (time between starts of sequential runs, including maintenance, minor repairs and adjustments) T(3) = 31 min.

The processing rates are 45, 18 and 14 sq. ft. per hour, respectively.

These numbers compare favorably with 38, 18 and 6.5 sq. ft. per hour values obtained for Lot A, and reflect improved performance due to stabilization and optimization of the operating procedure and parameters, and especially, substantial reduction of time spent for maintenance and repairs.

7.3.2.3 Features of scabbled concrete

The scabbling process itself was not affected by the paint - at least we did not "detect" any differences. Appearance of the painted Lot B scabbled concrete surface also did not differ from the appearance of the unpainted concrete surface, except that edges of the scabbled area and defects are defined with higher contrast.

Several pictures were taken to show scabbling defects. The defects were formed only over a few segments where either deviation from the regular procedure were made deliberately (i.e. to re-try water recirculation, or to find upper limit of the traverse speed) or positioning was irregular due to drive malfunction, or, finally, where concrete reinforcing wires were very close to the surface. The total area of all these defects was 2 - 3 sq. ft.

Figures 7.11 a and b show surface segments (deliberately not re-run for illustration purposes) scabbled with process water recirculation. It is evident from the fact that even the paint is not removed, that either the breakdown discharge takes place far from the surface or strong leakage current through the "dirty" water prevents breakdown altogether.

According to the **Figure 11b** pattern, even with the breakdown occurring at each electrode position, the pulses may be distributed unevenly over the electrode length, leaving unscabbled islands. Straight paint scratches visible in **Figures 11**, clearly show sequential positions of the electrode edges.

Figure 7.12 demonstrates effect of a shallow reinforcing wire exposed by the scabbling: minor edge defects appear, presumably due to the tendency of the breakdown pulses to concentrate in the vicinity of the conducting wire.

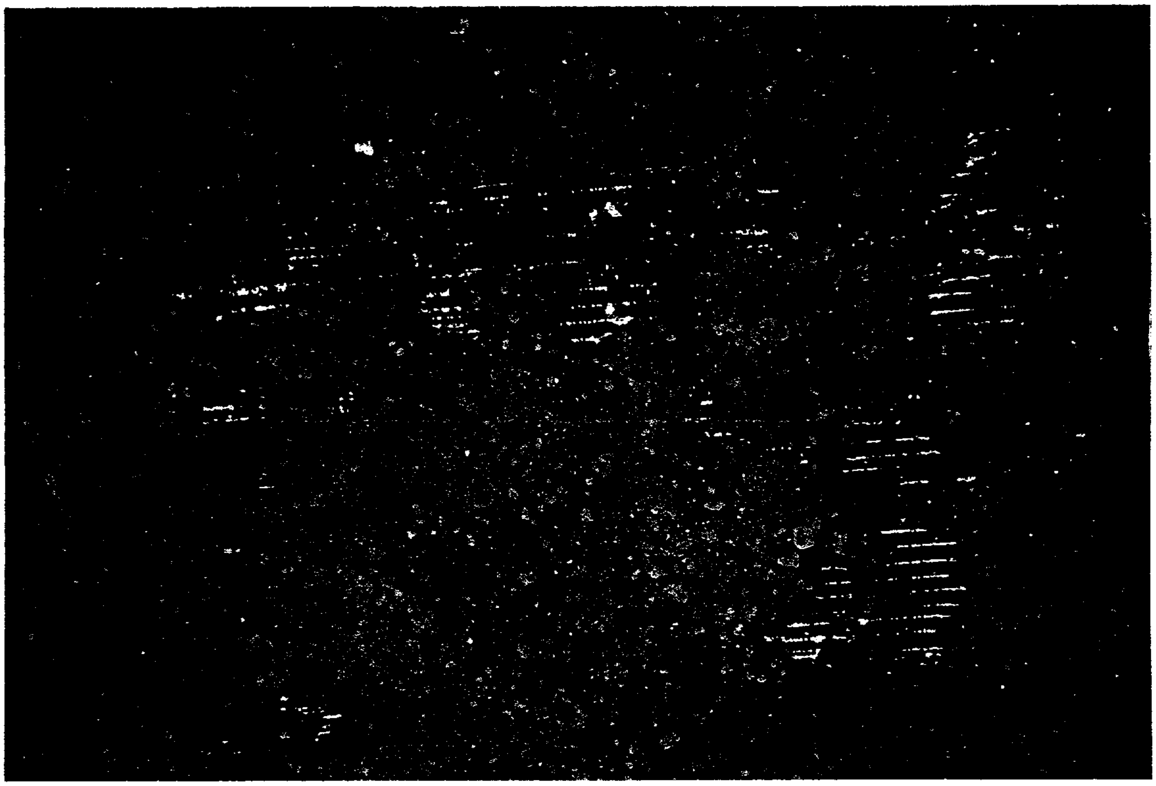
The scabbling depth measurements were made at selected locations only - see **Table 7.4** for characteristic depth values. Due to the faster pace of processing, there was no time for more frequent and systematic measurements; besides, the depth did not change substantially.

Several sample depth profiles measured by the 18" long gauge along lateral Y direction within three surface segments are shown in **Figure 7.13.**

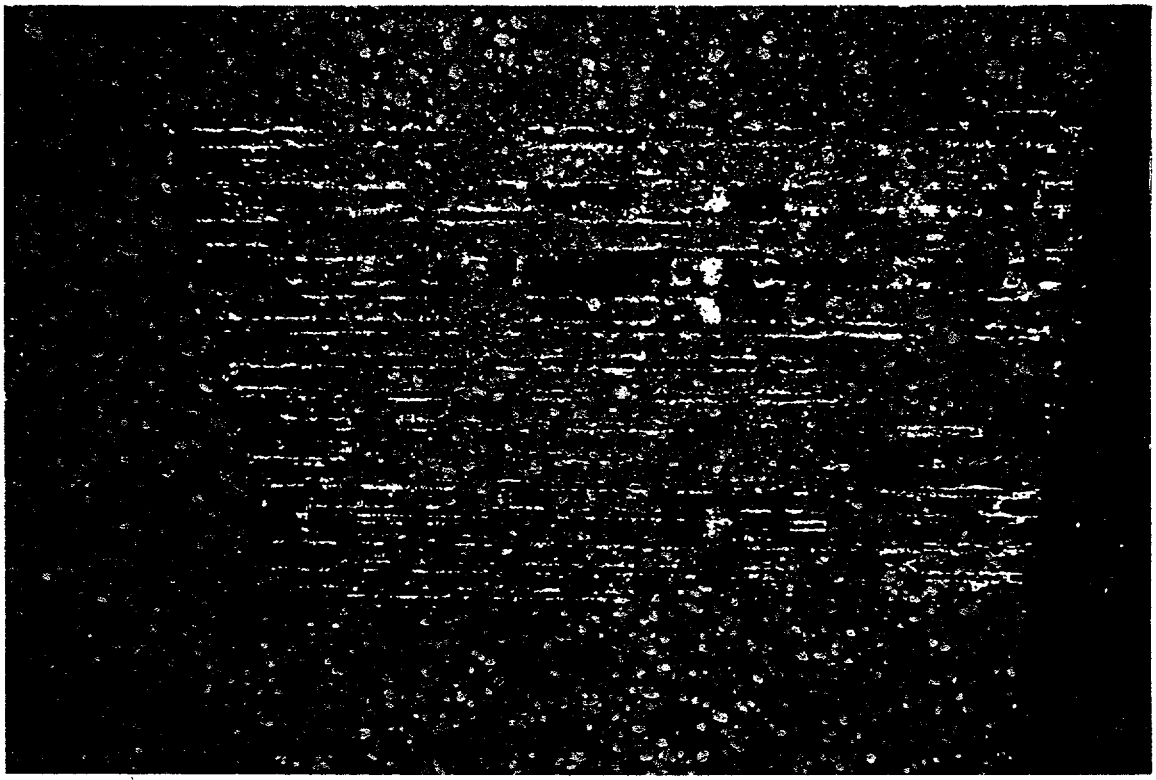
The number of depth measurements and readings is not sufficient for serious statistical analysis or for establishing quantitative relationships. Nevertheless, two conclusions can still be drawn:

- Local depth variations are substantial; within a single profile maximum/minimum deviation from an average depth is of the order of +/-25% (there is about 1.5 times difference between maximum and minimum depth readings), and average deviation is +/-13%.

- There is a negative correlation between the traverse step DX and scabbling depth. Correspondingly, depth is in a direct relation - weaker than linear - to the segment processing time (and number of pulses delivered per unit surface area).



(a)



(b)

Figure 7.11 Surface defects characteristic for scabbling with high debris content/high conductivity recirculated process water.Some pulses are "void", not producing localized discharge or are'not distributed uniformly over the gap length. Defects could be "cured" by a second fast run over the same segment

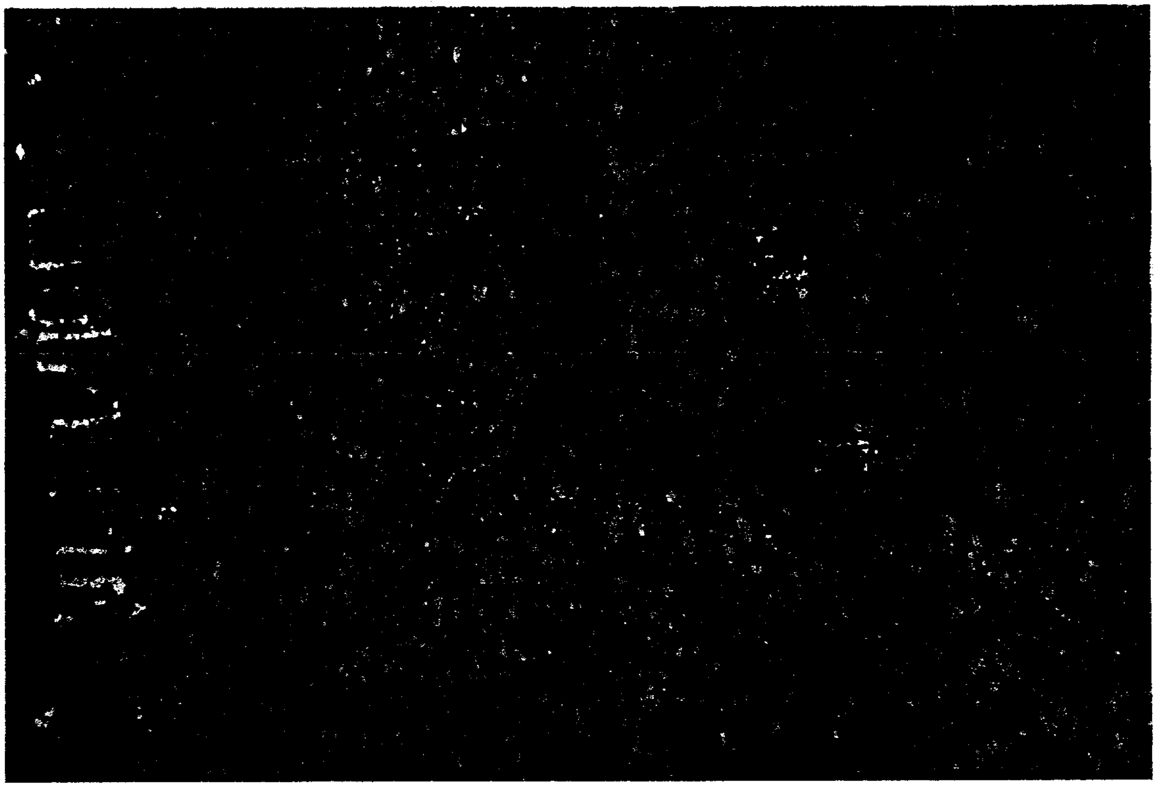


Figure 7.12 Scabbling reveals shallowly-placed reinforcing wires. Discharge to the wire results in the minor defects at the segment periphery.

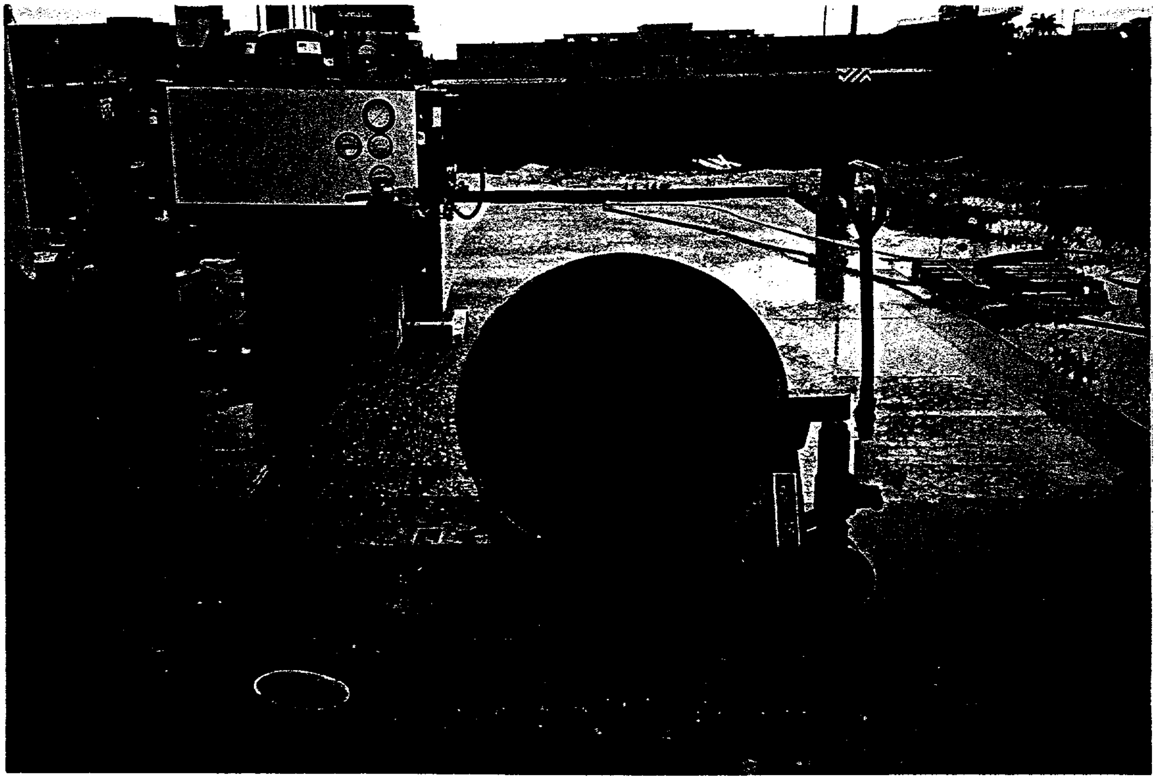


Figure 7.14 Wet concrete debris collected in the drum is discarded when it is ~1/2 full (or whenever it is convenient, e.g. at the shift or the raw end)

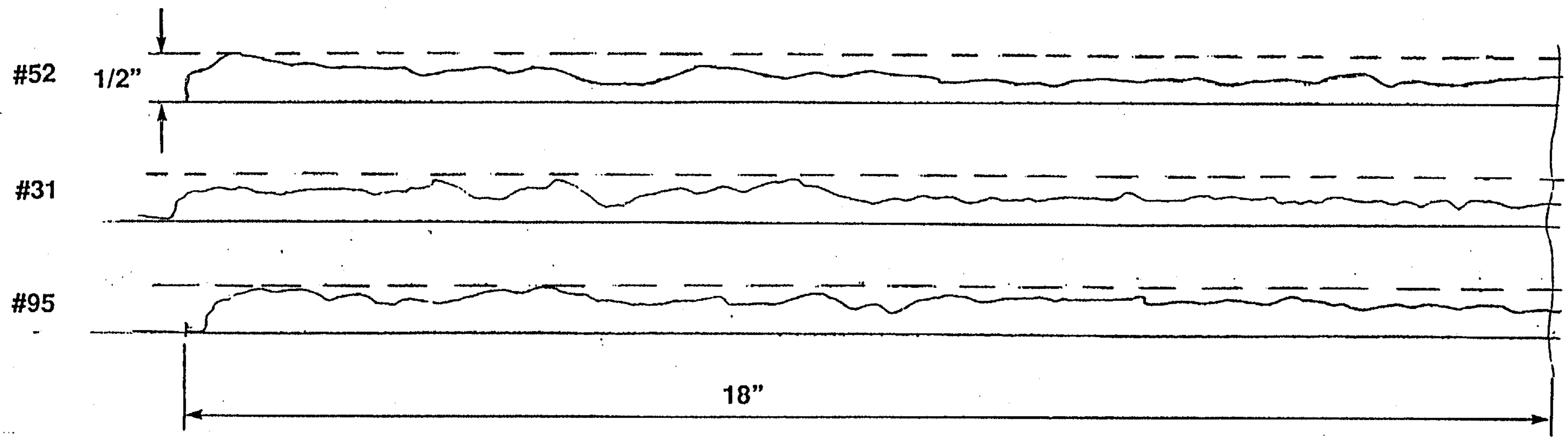


Figure 7.13 Depth profiles along 18" long surface stretches over floor segments #31,#52 and #95 (0.64% size reduction)

Table 7.4
Depth Measurements

Segment #	Average Depth, <h>, inches	Pulsing Time, Δx step	Remarks
30	0.23	9	0.70
31	0.27	9	0.70
42	0.22	9	0.70
43	0.25	10	0.70
48	0.28	10	0.65
52	0.28	11	0.65
61	0.21	11	0.65 cable disconnect
70	0.23	12	0.65 drive problem
72	0.30	14	0.55
73	0.29	13	0.55
75	0.23	10	0.80
95	0.25	9	0.80

7.3.2.4 Water/debris flow and properties

Quantitative characterization of water/debris flow and properties was only incidental. While two additional efforts to operate with process water recirculation were made, they failed: not more than 2-3 segments could be processed without surface defects. The defects could be removed by another (faster) pass in the opposite direction, but that would reduce the effective scabbling rate. Therefore, flow-through mode was practiced regularly: water was flown into the scabbling chamber directly from the supply hose at 6 to 10 gpm rate, and in addition, to increase the flow rate up to 18 -25 gpm, was pumped from two pre-filled 55 gal drum.

From the drum, water was extracted by two pumps and, after passing through a coarse (1 mm size opening) filter, and, in rare occasions, a fine/filter (25µm), exhausted.

Exhaust water analysis provided: Hardness number = 15 GPG (grains per gallon) and pH number = 11. In comparison, input fresh water had 5 GPG hardness and pH=7.5. Dissolved calcium is responsible for high hardness, its content in exhaust water is about 0.5g/6. Increase of hardness was accompanied by an increase of the electrical conductivity by a factor of 4-6. Due to the silt - fine suspended particulates - present in the exhaust water it's turbidity was high: 300 and 900 units with and without fine filter, respectively.

Debris was collected in a drum continuously during scabbling, and by after-scabbling pressure washing. As in the Lot A trials, 95 to 97 percent of debris was collected in the drum; with the fine filter, less than 1% of debris was exhausted.

The drum was emptied (see **Figure 7.14**) and debris piled and stored for subsequent evaluation, after scabbling of each lane had been completed. The weight of each portion of wet debris, obtained by weighing the drum before/after water decanting and cleaning, varied between 240 and 280 lbs. The value was used to obtain average scabbling depth (see Table 7.2). The debris had the usual appearance of mixed sand/small size aggregate, in this case with admixture of irregular 2-6 mm slices of the blue paint. Size analysis data of debris made (in separate samples) for the drum content and for silt deposited in the fine filter are shown in Table 6.4. Comparison with data obtained for the Everett site debris in Table 6.4 shows that FIU site debris is significantly finer.

7.4 SUMMARY

After the completion of demonstration trials of the EHS system at the FIU site, their progress and results can be briefly summarized. Additional evaluation of operation and of the scabbled area, expected to be made by FIU site personnel, was not available at the time of this reporting.

- Surface of a 700 sq. ft. concrete "floor" area was scabbled to the recommended 1/4" depth.
- The trials lasted 9 (full) operating days with participation of 3-person team involved in the equipment operation and auxiliary activities - maintenance, utilities and management.
- The scabbling was conducted by a high voltage version of the 8 kW EHS unit only, and proceeded in a batch mode with 7 sq. ft. segments processed at each location of the unit.
- EHS equipment operated without major breakdowns, and with low wear of critical components; at the same time, minor malfunctions slowed down the processing, especially during the first trial days.
- The equipment was able to operate under rather difficult conditions: unprotected lot, rainy weather/wet concrete surface, limited/inconvenient supplies of electric power and water.
- Stable operation rates of 45 and 18 sq. ft./hr were achieved, based on duration of scabbling proper and on duration of scabbling plus ancillary operations, respectively.

Negative features of the trial include the following:

- Within the time/conditions limits, it was impossible to re-configure AC and DC power supplies, and to change equipment components. Therefore:

  a) For the HV option, higher power input could not be tried to increase scabbling rate,

  b) Deep (1") scabbling (defined as a second but desirable priority) could not be tried at all.

- It was discovered that EHS debris formed by scabbling of the FIU site lime-based concrete has high electric conductivity and high content of fine silt. As a consequence, a uniform, "defectless" scabbling was possible only without recirculating process water. The open-loop water configuration results in order-of-magnitude higher water consumption.

For the high voltage EHS option used in the FIU trials the effects of the calcium-rich and silty (high turbidity) FIU site water was stronger than could be expected on the basis of scabbling trials at the Everett and Fernold sites and on the estimated increase of the process water conductivity.

The effectiveness of the FIU site trials would be higher without the above "negatives". It would also be better for DOE to provide test sites with weather protection, utilities, and concrete properties more typical of industrial environments. Scabbling trials involving contaminated concrete would then provide much more complete and decisive comparative evaluation of various techniques.

In spite of these shortcomings, we consider the relatively long duration/large area demo trial at the FIU site helpful towards comparative evaluation of EHS and towards its further development.

8.0 DIRECTIONS AND PROSPECTS FOR DEVELOPMENT OF AN INDUSTRIAL EP/EH SYSTEM

8.1 SHORT-TERM IMPROVEMENTS OF THE PROTOTYPE UNIT

Due to extended testing at the Everett and Miami sites, some shortcomings of the prototype scabbler design became evident. Some of these caused operation inconvenience and annoying delays while other resulted in excessive maintenance or frequent repairs.

The first priority changes that would improve EP/EH unit operation and performance include the following items:

- Power source(es):
  - no changes, except that more operation controls should be transferred to the power cabinet. Also, using single, more universal cabinet by incorporating two - 8kW and 32 kW - power supplies (operating at same 480 V AC voltage) for both shallow and deep scabbling, respectively, is suggested.

- PFNs:
  - locate resistors more compactly and improve distribution of cooling and deionizing air flows.
  - consider use of a separate blower or exhaust air from the power vacuums to make operation independent from the quality of on-site air supply.

- Cables/connectors:
  - waterproof all AC and HV cables
  - locate cable/electrode connectors above water level in the scabbling chamber

- Electrodes:
  - install module-side baffles to protect foam gasket from the water shocks

- Positioner:
  - install higher power/higher torque air turbine directly on the X- slide
  - protect air cylinders from water and debris
  - replace time delay relays in the control circuit by more precise and voltage surge-protected

- Air flow:
  - provide independent manifold/hose for scabbling chamber evacuation

- Water flow:
  - use higher power pump to secure high water flow (e.g. for chamber fill-up when on-site water supply is inadequate)

- Debris collection:
  - improve nozzles of the collecting manifold, eliminate debris-retaining "pockets"
  - provide higher pressure/higher flow (~2 times)washer
  - install finer (100-250 mm) bag-type or metal mesh filter in the water return or exhaust line

- Controls:
  - install better control for water level in the scabbling chamber
  - mount remote HV on/off control on the forklift panel

- Forklift truck:
  - increase diameter of straddle wheels
  - install new truck batteries

The prototype unit improvements listed above are straightforward and do not require changes in the basic design.

8.2 ISSUES TO BE ADDRESSED

Besides the simple measures suggested in the previous section for a short term EHS unit improvement without changing its design and basic operating parameters, more serious issues should be addressed. Two problems which were identified in the course of recent trials have to be resolved to make EP/EH processing faster, to improve scabbling quality and to reduce the secondary waste volume. Namely, revisiting of the physico-chemical phenomena involved in the electric pulse breakdown and electro-hydraulic effect by well-defined laboratory experiments, and additional full scale scabbling trials are desirable.

a) To provide higher energy input into concrete by increasing pulse frequency or/and by improving energy transfer from the electric discharge to concrete, and

b) To make feasible EP/EH scabbling with recirculated process water without degradation of performance.

8.2.1 Status of Process Knowledge

It has been shown that an increase of the pulse frequency, even when allowed by the power supply capacity (i.e. by the rate of storage capacitors recharging), results in a higher specific (i.e. per surface area) energy input only up to a certain frequency limit - about 5 and 15 Hz for low- and high-voltage operation, respectively. Above these limits larger and larger proportion of pulses do not result in the concrete removal. Oscillograms of these "void" pulses indicate that discharge current is aperiodic and fades rapidly. This is in a contrast to "normal" (active) pulses which have periodic structure and are scabbling-efficient. Shape of the void pulses indicates that instead of "strong" discharge - fast and narrowly localized breakdown, current leaks between two electrodes involving large exposed electrode surfaces and bulk of water in the electrode gap.

While energy of the leakage (or "quiet" discharge) may be similar to that of the breakdown, the leakage current is not concentrated in local channels, does not generate shock waves through water or concrete layer and, therefore, scabbling does not take place. In fact, as Lot B trials at FIU demonstrate, even the paint layer may remain intact in this mode.

Whether strong or quiet discharge occurs depends on the competition involving voltage, stored energy, electrode shape, material and surface on a part of a strong discharge, and electrode gap length d, electrode gap resistance and associated current on a part of the leakage.

It has been shown, for instance, that the strong discharge "wins" over leakage when voltage and stored energy is higher (for the gap width remaining constant). For constant voltage and energy, strong discharge prevails for shorter gaps. On the other hand, the lower is water resistance the higher is probability that a capacitor-stored energy dissipates even before the strong discharge has time to form.

Obviously, the inter-electrode resistance itself is lower for smaller (water-exposed) electrode areas, and for higher water conductivity. Therefore, to avoid leakage, electrode surface - except electrode edges where breakdown is initiated - should be insulated and water resistance should be kept high.

8.2.1.2 Water breakdown vs. concrete breakdown

We will assume that conditions are such that no substantial current leakage occurs and fast, streamer-mode discharge takes place. Location of the breakdown and of the developed discharge channel has an immediate effect on the concrete scabbling process. With electrodes contacting concrete and electrode voltage rising after PFN switch is activated (either by a trigger or by overvoltage) the discharge develops where - either in water or in concrete - the dielectric strength is exceeded first. Volt-second characteristics (the dependence of the breakdown voltage on the voltage rise time) shown in **Figure 8.1** (Ref. x) of several materials show that dielectric strength of water (as well as transformer oil) is higher than for some rocks to the left of the volt-second curve crossings i.e. for short, <1 μs, times corresponding 200 to 400 kV/ms voltage rise rate dU/dt. Under these conditions, a bulk liquid (or liquid/solid interface) discharge is avoided and breakdown occurs via solid body (see Figure 2.1). In **Figure 8.2** U_b values are shown for several solids. There is no correlation between compressive strength and U_b. As shown in **Figure 8.3,** the U_b dependence vs. width of the electrode gap is non-linear and also depends somewhat on the nature of liquid.

Variability of water breakdown voltage should be taken into account as well. In addition to conductivity changes which, as described above, affects current leakage, the available (stored) discharge energy, presence of gas bubbles and suspended particles controls the onset of breakdown. Some of these factors are modeled in Ref. 5. In this model, breakdown proceeds in four stages:

(i) nucleation - formation of a low density site in liquid near the electrode,
(ii) expansion of this site until the local density is reduced below a critical density for impact ionization to take place,

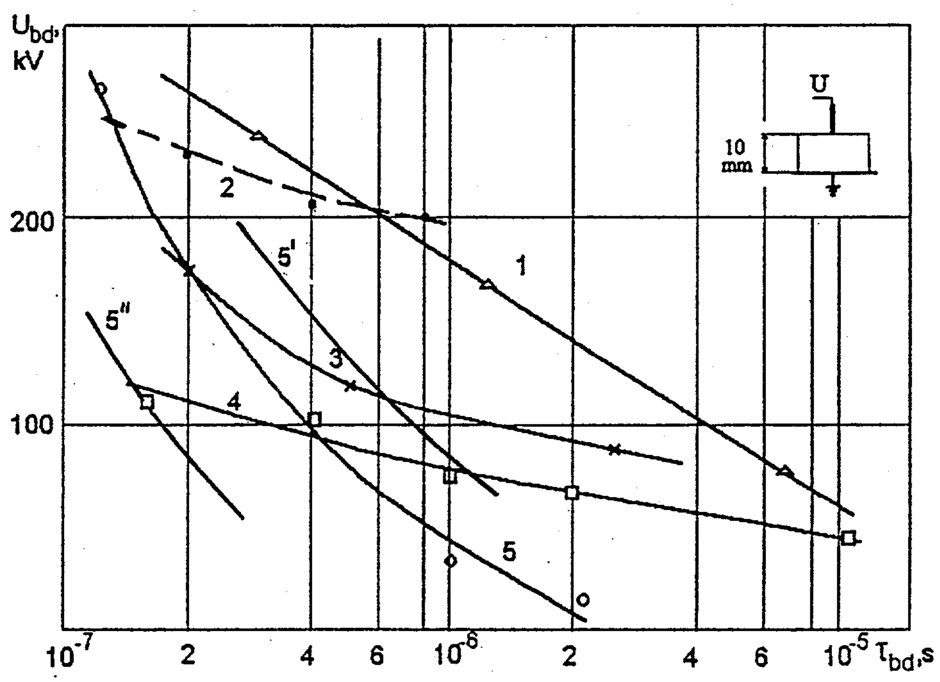


Figure 8.1 Voltage-time breakdown characteristics for solid dielectrics and water.
1-Transformer oil, 2-Quartz
3-Marble, 4-Sandstone, concrete,
5,5',5''-Water, with 2x10-4, 1x10-4 and 5x10-4 S/cm conductively, respectively

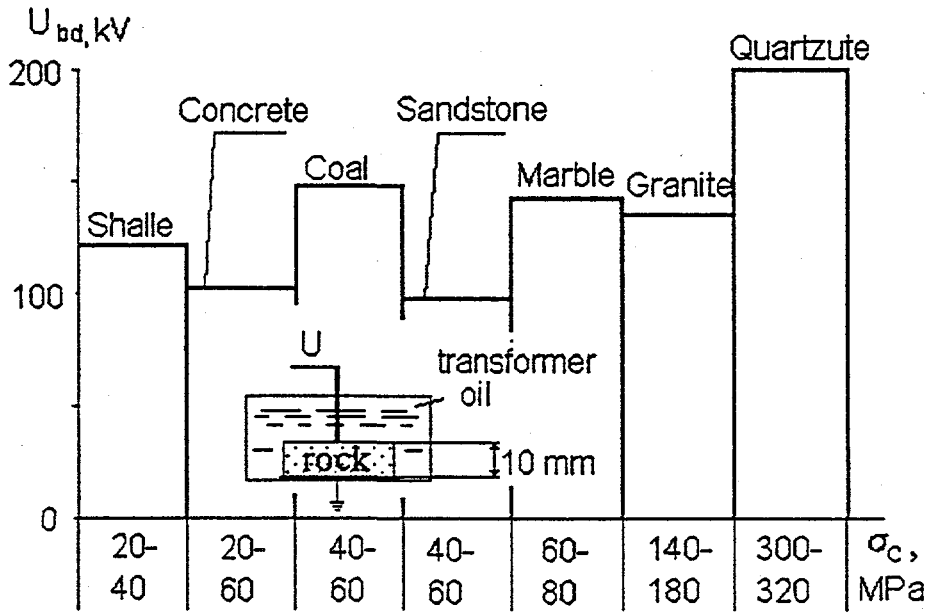


Figure 8.2 Breakdown voltages for selected materials

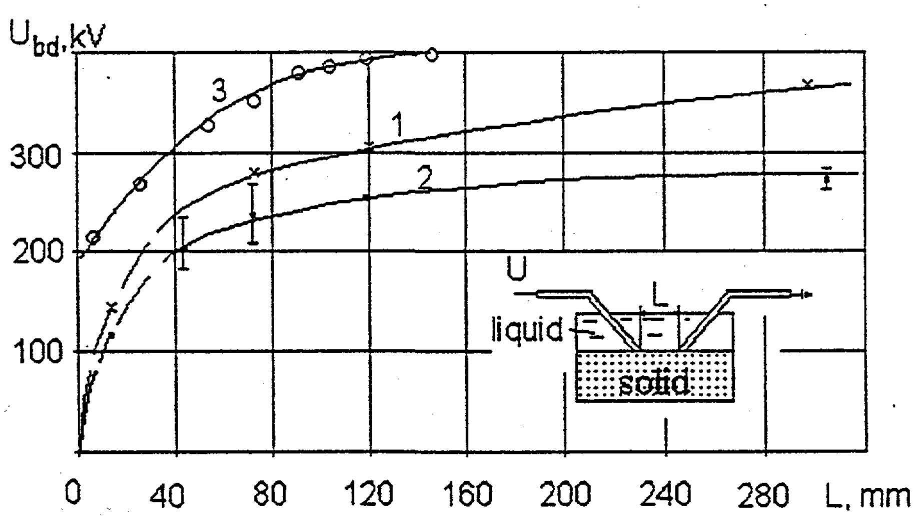


Figure 8.3 Breakdown voltage vs. interelectrode distance
1-Granite in transformer oil,
2-Concrete in transformer oil
3-Granite in water

(iii) growth of avalanche and its transformation into an ionizing front, and
(iv) propagation of the front via a sequence of processes occurring in the region ahead of the front, especially heating which lowers the liquid density, and bridging of the gap.

This picture leads to a total breakdown lag time that consists of four components of which the first and the last are decisive:

$$t_b = t_{nuc} + t_{ex} + t_{fr} + t_{br} = t_{nuc} + t_{br}$$

From the model, effects of conductivity and critical energy criterion were obtained. The nucleation is accelerated by high power density (supplied by the circuit), and is given by

$$t_{nuc} = 1/jE \text{ nsec}$$

With stored energy being 3-5 times higher for PFN-L pulser, the nucleation time should be shorter and the discharge more willing to occur in water vs. solid; (on the other hand, more intense water turbulence may remove bubbles more efficiently).

A significant fraction of t br is associated with increasing the conductivity behind the propagating ionizing front, therefore a minimum conductivity is necessary to maintain the energy flow to the front for heating the water. It follows from these considerations that high conductivity not only results in the current leakage, but also makes breakdown to take place with shorter time delay.

It is reasonable to assume that air and/or water vapor bubbles formed within the gap by a preceding breakdown make the following breakdown easier if the bubbles do not have time to dissipate or carried away by the turbulent water flow. Under our conditions, the water flow velocity is about 0.5 m/sec, the bubble residence time in the gap is ~40 msec, and pulsing at frequencies above 25 Hz may be difficult due to reduction of the effective breakdown voltage. It is possible that fine debris particles present in the vicinity of electrode edge also act as breakdown nucleation centers.

Shortening of both t_{nuc} and t_{br} in the bubble- and debris-containing and conductive water favors water breakdown over solid (concrete) breakdown. This is illustrated semi-quantitatively in Figure 8.1: in the "dirty" water several times higher voltage rise rate is needed for the discharge to happen through the concrete layer.

In our experiments and scabbling trials, voltage rise rate was 6-8 and 160-250 kV/ms for PFN-L and PFN-H pulsers, respectively. It is obvious that

a) With PFN-L pulser the voltage rise rate is low, while the energy density is high, and breakdown should take place through water.
The electro-hydraulic discharge generates shock wave and breaking concrete layer with relatively low energy efficiency.

b) With PFN-H pulser much higher voltage rise rate benefits direct breakdown and electric discharge through the concrete layer (EP mode). Still, presence of bubbles and high water conductivity may accelerate breakdown in water and bring the conditions to a borderline between two modes. The breakdown may well occur in any of the two adjacent media depending on such factors as electrode shape and gap, quality of electrode-to- concrete contact, changes in water conductivity, local concrete dielectric strength etc.

The situation when the breakdown/discharge location is sensitive to so many factors is unfavorable because it would affect the process stability. The most straightforward approach to avoid these transitional conditions is to boost voltage rise rate by increasing voltage, decreasing circuit inductance, or both.

8.2.1.3 Electric resistance of water /debris suspension

Water resistance is a key factor which determines whether concrete breakdown, water breakdown or current leakage takes place when the process water is recirculated back into the scabbling chamber. Water conductivity depends on concentration of salts which, upon dissolution, delivers the anion and cation current carriers. For water containing concrete debris, concentration of Ca^{++} cation originating from the weakly soluble carbonate $CaC0_3$ and hydroxide $Ca(OH)_2$ predominates (see water/debris suspension analysis data in **Table 8.1**). Calcium affects conductivity as well as water pH and hardness the most. For additives with a limited solubility-which is the case with Ca compounds (see **Table 8.2** from Ref. 8) - the solubility is the main factor controlling/limiting conductivity raise. **Figure 8.4** shows that with addition of cement dust the water conductivity saturates when a solubility limit is reached. This effect has been observed also in our experiments: when concrete debris is added to water in small increments, conductivity of the suspension raises strongly initially, reaches certain level and then saturates, i.e. stabilizes at this level despite of more debris addition. These experiments were conducted
when

a) directly in a scabbling chamber, with debris generated by scabbling and resistance between the electrodes measured, and

b) in a separate, resistivity and pH probes equipped container where scabbling debris concentration in the tap water was increased by the stepwise additions. Water resistance drops about four times when debris content reaches the level characteristic for the chamber water observed during scabbling operation (see **Figure 8.5**). The drop is initially higher when lime-based concrete debris (from FIU test site) is added, while saturation levels do not differ substantially. An effort was made to increase the resistance by neutralizing solution with acid. Addition of HNO_3 results in pH drop, but the resistance recovers very little. It is possible that better resistance recovery may be achieved by blowing carbon dioxide through the process water; this approach has not been tried.

Table 8.1 Process Water Analysis Data (Everett Site)

Roger Dwinell
U.S. Filter
10 Technology Drive
Lowell, MA 01851

Customer Name:	Victor Goldfarb
Customer Company:	Textron
Customer City/State:	Everett, MA
Sampling Date:	05-Mar-7
Test:	Laboratory Analysis (Catalog Test 350 6s)

Contaminant	Sample (MG/L)
Aluminum	0.812
Barium	0.065
Cadmium	< 0.001
Calcium	243.400
Chloride	14.440
Chromium	0.031
Copper	0.062
Fluoride	< 0.100
Iron	0.282
Lead	< 0.001
Magnesium	0.170
Nickel	< 0.010
Nitrate (AS N)	< 0.020
Potassium	4.334
Selenium	< 0.010
Silicon (AS Si02)	4.815
Silver	< 0.005
Sodium	25.890
Sulfate	11.060
Zinc	0.007

Additional Sample Information

Strontium	0.68 MG/L
Ph:	12.1
Manganese:	ND
Total Alkalinity:	180 MG/L
Phonolphthalien:	930 MG/L
OH:	1680 MG/L
CO3	ND
HCO3	ND
TDS:	~1300 MG/L
Hardness:	608 MG/L

Table 8.2
Solubility and Conductivity of the aqueous solutions of poorly soluble electrolytes

Chemical Compound	Solubility mg/400g H_2O	Conductivity of saturated solution
$CaSO_4$	89	2000
Ca/CH/$_2$	160	7500
$CaCO_3$	0.63	30
Mg/HCO$_3$/$_2$	80	750
Mg/CH/$_2$	24	2800
Mg/CH/$_2$	1,4	200
MgC_2O_4	30	200

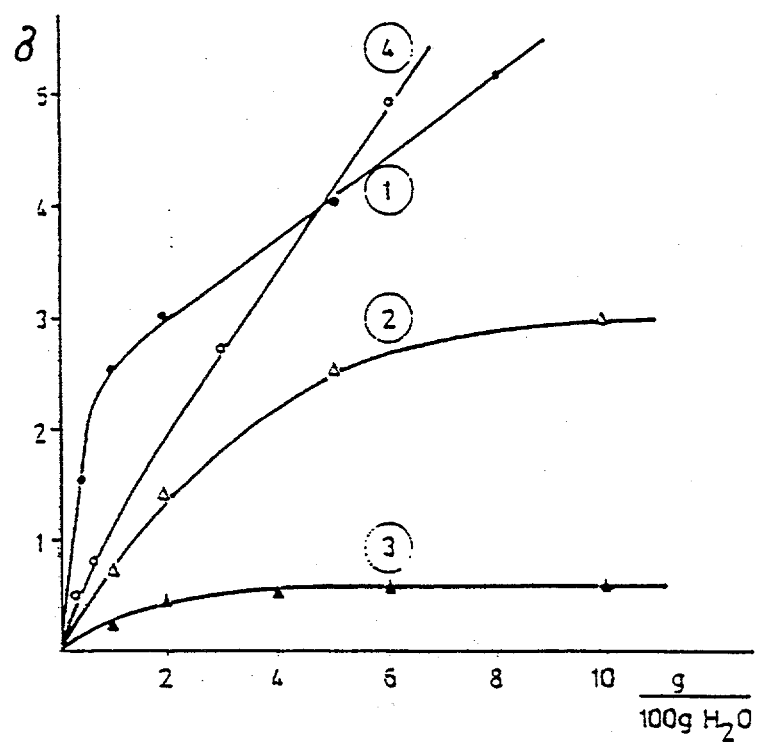


Figure 8.4 Relation between the conductivity of aqueous dust solutions and their concentration in water:
1-electric plant dust, 2-copper plant dust,
3-dust from a cement mill, 4-SiO2/MgSO4 mixture

In absolute numbers, maximum conductivity of water/concrete suspension is of the order of 10^{-3} S/cm. This is substantially higher than 10^{-4} S/cm conductivity of a "technical" or 10^{-5} S/cm of a good quality drinking water. For comparison: due to much higher solubility of alkali salts, conductivity of sea water is ten times higher - about 10^{-2} S/cm.

The factor 5 debris-related water conductivity increase is sufficient to change the discharge mode, especially in the range of electric parameters where breakdown/leakage transition is taking place.

Location of the transition zone is shown in **Figure 8.6**. When (for a given voltage) a discharge gap exceeds value $D_b = 0.05\ U^2\ C^{3/2}$ (in mm, kV, µF units) the discharge is changing from a leader mode to a thermal mode; further gap broadening results in the current leakage. Similar transition takes place when, for a given gap width, the voltage is decreasing.

For certain D_b/U_b combinations, the breakdown/leakage transition can take place within the water conductivity range characteristic for the concrete debris suspension.

8.2.1.4 Process water properties and treatment

Composition is of importance also in the event when water is not recirculated within the scabbling system but discarded. Particle size distribution in the debris, water turbidity and hardness, and, of course, carryover of contaminants removed with concrete defines classification of water as a regular or as a hazardous waste, and specifies required post- scabbling treatment methods. Typical debris size fractions shown in Table 6.4 indicate larger percentage of fines in the "softer" lime-based (FIU site) concrete than in the granite-based concrete (Everett site). Both hardness and turbidity of water leaving the scabbler (after passing a single 25 mm filter) is also substantially higher for lime-based concrete (see **Table 8.3**).

Treatment of the scabbler-discarded water to bring it to standards acceptable for a regular technical uses might be rather costly, especially if de-mineralization (softening) is required. Capacity of commercial size/small industrial water softeners is 200,000-400,000 grain which would be adequate for processing 10,000 gal. of water used for scabbling of 1,000 ft^2 of "regular" concrete. Such treatment would add about 0.5 $ (15 -25%) to other scabbling costs (see Section 9). Due to higher hardness and turbidity, this cost component for lime-based concrete would be even higher.

It was indicated in Section 7, that, at least at Fernald site, the insoluble uranium contaminant was contained in a debris and could be removed by the one-stage water filtration. The implication is that turbidity reduction treatment of the process water required either for recirculation or for the safe discard removes also the insoluble contaminant. In other words, the cost of uranium removal is included in the "de-turbidization" cost. Of course, the filtering elements removing contaminant would require specific disposal.

Table 8.3
Properties of Scabbling Process Water

Parameter	Location: Everett	Location: Miami
Hardness mg/L	500 - 700	3000 - 4000
Grain/gal	30 - 42	180 - 250
Turbidity	50 - 200	300 - 900

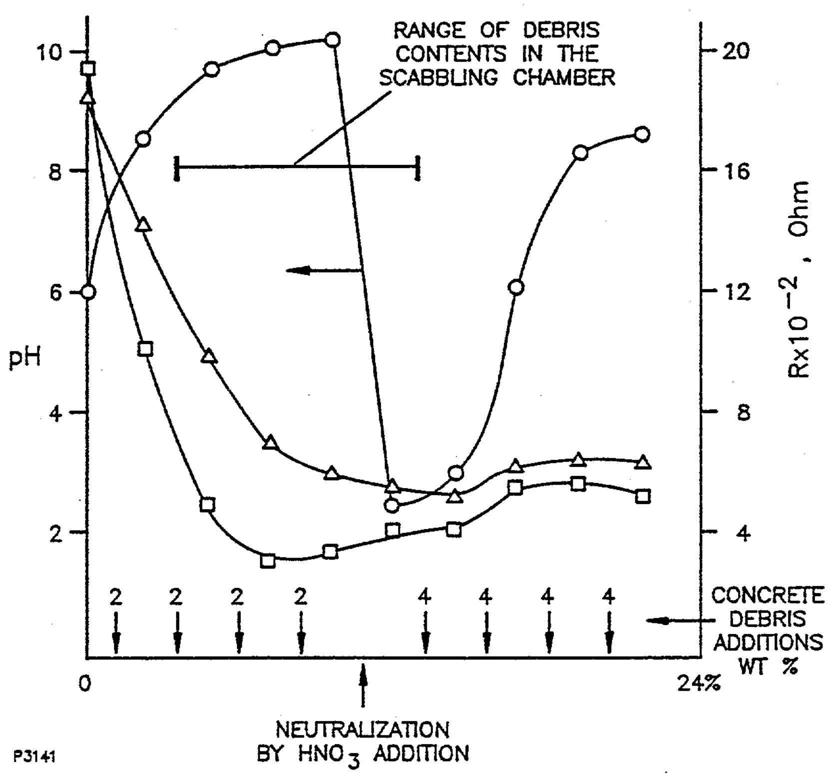


Figure 8.5 Electric resistance (-granite agglomerate, -limestone agglomerate) and pH (o) vs. concrete debris content in water

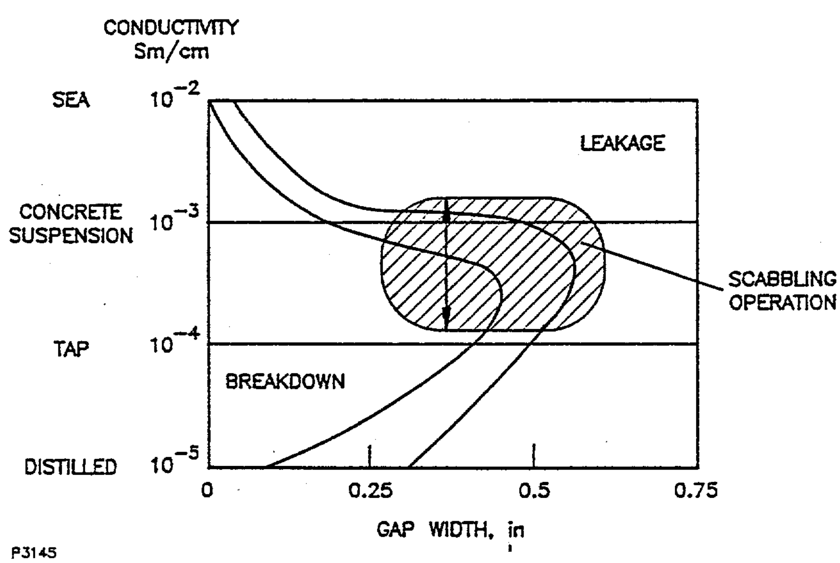


Figure 8.6 Discharge mode boundaries vs. water conductivity (the boundaries move to the right when voltage increases)

If the contaminant is water-soluble, and, accordingly, can not be removed by filtration, use of ion exchange resins is one of options. Again, this treatment might co-incide with a water softening procedure if resins used to remove calcium and metallic contaminants (e.g. cesium or strontium) are similar. If this is not the case, use of specific resins would add to the cost. As with turbidity, cost of discarding of contaminated resin should be taken into consideration.

It should be mentioned here, that after insoluble or soluble contaminant is separated from water by filtration or ion exchange, cost of further treatment of hazardous residue for becomes the same for dry and wet scabbling; even more than that: contaminant in the wet debris is already "prepared" for treatment by filtration or ion exchange.

8.2.2 Approaches to improvement of EP/EH technique

It should be evident from the previous section, that there still are uncertainties in understanding, especially quantitative, of some issues of the EP/EH materials processing, including concrete scabbling. This makes the equipment design and parameter mainly empirical - more an art than science - without expanded research. Nevertheless, on the basis of our trials and results of other authors related to the development of EH and EP applications, guidance for improvements could be outlined.

First, we conclude that direct electric breakdown through concrete is more efficient, promising higher processing rate, higher energy efficiency and - due to lower single pulse current and energy- lower adverse mechanical and erosive effects on the equipment. Low voltage,

To realize and improve operation in this preferred mode the following measures are desirable:

- For breakdown through concrete to prevail over liquid dielectric breakdown:
  - Higher voltage, faster pulses must be used
  - Breakdown voltage and resistance of the inter-electrode liquid layer should be increased by

    a) reducing area of electrode/liquid contact by insulating coatings and proper electrode configuration

    b) providing low conductivity (clean) water or by using other dielectric liquids (or additives, emulsions)

- The low voltage, EH mode of operation should be saved for deep scabbling when single pulse energy may be below the threshold for spalling thick concrete layer and, accordingly, insufficient for the one-pass processing.

- To make possible high frequency operation and higher specific energy input (for given electrode size capacitance and operating voltage) and, accordingly, higher processing rate, the discharge-generated bubbles, debris-associated particulates and conductivity-affecting solutions should be removed from the gap by a fast liquid circulation.

- To achieve higher utilization of the stored energy and provide - if necessary- deeper scabbling, inter-electrode gap should be as wide as permitted by the given voltage level. By the direct breakdown concrete is removed to a depth which is 30-50% of the inter-electrode gap width, therefore 2 -3" gap is appropriate for 1" deep scabbling.

The targeted numerical values of electric parameters are listed in **Table 8.4.** It can be expected that due to the higher specific energy input and better utilization of the stored energy (net) scabbling rate will be 5 to 6 times higher - i.e. 200-300 sq. ft. per hour for 3/8" deep scabbling- than achieved with a recently tested prototype unit.

Additional design effort and more trials will be necessary to confirm feasibility of this approach and performance expectations. Protection against HV breakdown within PFN and scabbling module components is expected to require most attention in the design of the 200 kV EP system. If design and operation of such system appear to be a problem, or deep scabbling is difficult to achieve, EH i.e. low voltage/high current operating mode remains a viable option. With current leakage issue resolved by the measures listed above, operating voltage increasing to 45-50 kV and electrode gap increasing to about 3/4", a 60 kW system operating at 10 Hz should provide net scabbling rate in the vicinity of 70 sq. ft. per hour. While EH energy consumption is still expected to be 2-3 times higher than for EP scabbling and, due to higher pulse current, lifetime of some components may be shorter, simpler PFN design of provides some compensation.

Shortening of the full cycle duration is the second priority: even with projected here faster scabbling, the effective processing rate remains low without reducing duration of the other processing steps. Targeted duration of the main steps is shown in **Table 8.5.**

To make the full cycle that short (about two times shorter than available with prototype unit) the hardware components and controls should satisfy the following conditions:

- Vacuum power heads and water pumps should provide sufficient pressure drops, and cross sections of hoses and manifolds should be increased not to limit flow rates, especially in a debris suction line.

- Speed and torque of X-and Z scabbling module positioners should be increased.

- High pressure water nozzles should be positioned inside the scabbling chamber at "strategic" location and provide high momentum to transport debris towards the entrance of collecting manifold.

- Forklift track should have continuous speed control and transfer the scabbling chamber according to pre-set program.

Table 8.4 Electric parameters suggested for an industrial EP/EH unit

Parameter	Shallow Scabbling	Deep Scabbling
Charging voltage*:	50kV	50kV
Operating voltage:	200kV**	50kV
Maximum current	10 kA	50 kA
Capacitance	0.2 x 4 μF	6 μF
Discharge gap	4 - 6 cm	2 cm
Pulse energy	1 kJ	6 kJ
Pulse duration	2 μs	15 μs
Pulse repetition rate	30 Hz	10H
AC (average) power	30 kW	60 kW

* This voltage can be provided by resonance circuit chargers of the type used in this project

** Should be obtained by using Marx-type PFN; lower than optimum but acceptable charging and operating voltages voltage value are 40 kV and 160 kV, respectively.

Table 8.5 Duration of processing cycle steps suggested for an industrial EP/EH unit

Processing Step	Duration, min 1/4" Scabbling	1" Scabbling
Enclosure vacuuming, water fill-up and initial module positioning	1.5	1.5
Pulsing time	2.5	15
Module stepwise re-positioning (total for all steps)	2.0	2.5
Removal of water and suspended debris	1.0	1.5
Removal of remaining debris and surface cleaning by high pressure water	2.0	3.0
Re-positioning of the enclosure	1.0	1.5
Total	**10**	**25**

- Air and water flow valves and regulator should be equipped with relays and actuators operating in a pre-programmed sequence

8.3 SUGGESTED DESIGN OF AN INDUSTRIAL UNIT

Information obtained through Phase III tasks, especially by the demonstration trials, allows to introduce an upgraded design of the industrial EP/EH unit. In this upgrade, we will not deviate substantially from the "old" concepts and from the general configuration of the tested prototype or to introduce new unchecked ideas. Nevertheless, the re-designed unit (see schematical drawings in **Figure 8.7**) will differ from the prototype in more than minor improvements listed in section 8.1. We will meanwhile assume that process water recirculation and limited power input problems are addressed and resolved by the measures suggested in section 8.2.

The first industrial unit for concrete floor decontamination by the electric pulse scabbling to 0.2" - 1.25" depth will have the following systems and components:

8.3.1 Electro-mechanical System

1. DC Power source

The will be increased for both EP and EH modes. For this purpose, a single, compact, water-cooled 30 kW charger (i.e. ALE-303, 480 V AC model) operating at (max.) 50 kV DC can be used with either 50 kV or 200 kV pulsers. This unit has convenient charging time control allowing variation of the average output current and of the pulse frequency.

The charger is enclosed and electrically-insulated in a cabinet which is about two times smaller than the one used for a prototype unit; it is mounted, together with a control console, on a wheeled platform.

2. Pulse Forming Networks

As in the prototype unit, the system can be equipped with either a low-voltage or high-voltage PFN, depending on it's expected predominant use for shallow (0.2 -0.5") or deep (0.5 - 1.25") scabbling/decontamination. The PFN electric schematics are similar to those used in the prototype, but several design improvements are made.

Components of both PFN are mounted on identical platforms and enclosed in similar soundproofed boxes to make them interchangeable. Cable connection between the power cabinet and PFN are made by a waterproofed low current capacity HV cable. The PFN platforms are mounted and weight-centered on the top cover of a scabbling chamber. Dedicated cover-mounted low pressure blower supplies de-ionizing air to all sparkgap switches (one in PFN-L and four in PFN-H). The PFN box interior, especially capacitors and resistors are cooled by the air exhausting from the vacuum power heads. The PFN boxes have temperature probes and overheat indicators.

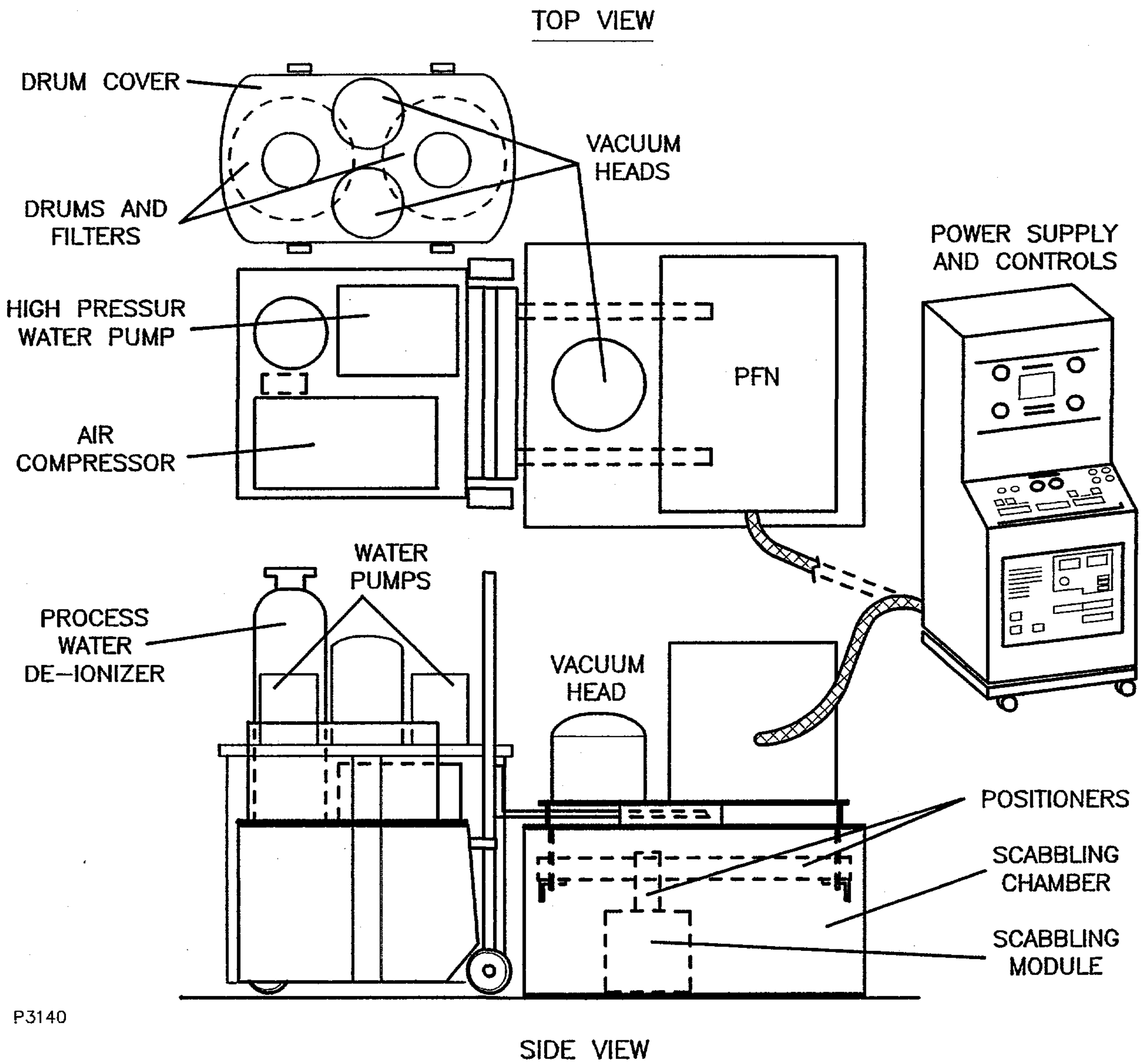


Figure 8.7 Configuration of an industrial EP/EH concrete scabbling unit

Width-adjustable sparkgaps have electrodes made of special W-Cu alloy featuring low erosion rate.

PFH -L has 3 storage capacitors 5 μF each; depending on a required (up to 9 kJ) pulse energy, 1, 2 or 3 capacitors connected in parallel can be used. With 2 capacitors, maximum pulse frequency is variable in 3 to 15 Hz range. Depending on electric parameters, single pulse period varies between 20 and 40 μsec.

Thermally-loaded PFN-L sparkgap has additional water cooling. Two heavy but flexible cables connecting this PFN with scabbling module are also water cooled. The cables join long solid copper bars bolted to the electrodes.

PFN-H has four 0,5 μF capacitors in a Marx circuit quadrupling voltage output. Maximum single pulse energy - 2 kJ - is higher than available currently. Pulse frequency can by varied in 5 to 20 Hz range, with pulse duration from 2 to 4 μsec.

Lighter uncooled cables - two for each polarity - provide connection to the scabbling module. As in PFN-L design, connections to the electrode bars are located above the water level in the enclosure.

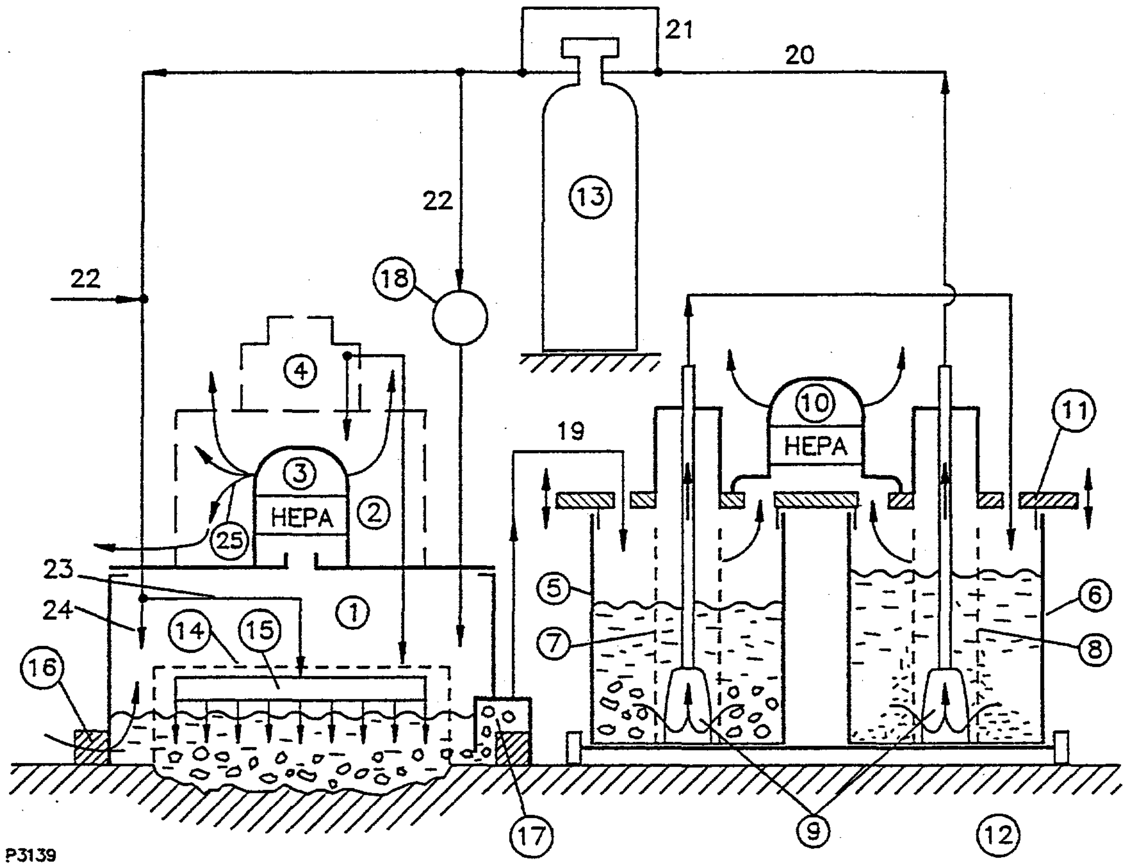
3. *Scabbling chamber, positioner and scabbling module*

Configuration of the scabbling chamber and the positioner remain basically unchanged. Improvements include 6" elongation of the chamber in X-direction, better utilization of the footprint area and extension of X-positioner allowing increase of scabbled segments area to 10 sq. ft. = 36" x 40". Chamber frame and gaskets are redesigned to improve access to surrounding walls - reduce minimum distance between the edge of scabbled floor area and the walls to 8". In addition, air tightness of the chamber is improved by stiffening the upper cover and using industrial-quality feedthroughs for all cables and hoses.

Re-design of the scabbling module allows easier maintenance (re-coating of the electric insulation and gap adjustment) and replacement of the electrodes. Scabbling electrode length is increased moderately by 4", and their shape is changed to reduce water-interfaced area and to make possible manufacturing of spares by a steel casting technique. An alternative maintenance procedure - periodic replacement of the whole module with pre-attached replacement electrodes will be also considered.

8.3.2 Air-water-debris flow and debris removal.

This system (see **Figure 8.8**) is subject to most intense redesign providing lower pressure in the scabbling chamber, and allowing faster operation in both open-loop and closed-loop modes without permanent involvement of the operator.



1. Scabbling chamber/water enclosure
2. PFN box mounted on the enclosure cover
3. Vacuum power head (equipped by HEPA filter
   to evacuate the enclosure
4.Compressor to supply air to airgap switches and module positioners
5.Drum I- water and coarse debris collector (55 or 80 gal.)
6.Drum II- water and fine debris collector (55 or 80 gal.)
7. Coarse filter
8. Fine filter
9 Water pumps (retractable)
10. Vacuum \power heads to reduce pressure in the drums and
    suck water/debris from the enclosure
11.Drum cover mounted on a lifting support (not shown)
12. Wheeled platform
13. Process water treatment (de-ionizing) column
    (optional, the independent support)
14. Scabbling module
15. *Water manifold with water injection nozzles*
16. Foam gaskets
17. Water/debris collecting nozzle and manifold
18. High pressure pump for water washer
19. Air/water /debris flow line
20. Process water return line
21. De-ionizer bypass line
22. Water makeup line
23. Water line to washer (inside the enclosure, not shown)
24. Water line for the cycle start fill-up
25. Vacuum head exhaust air to cool PFN

Figure 8.8 Schematics of air/water/debris flow and separation system

1. Air flow

As in the prototype unit, pressure in the scabbling chamber is reduced by a vacuum power heads. To avoid pressure drop along the connecting hoses (or use a very bulky ones) and allow individual adjustment of flows and vacuums, we suggest to dedicate each of the heads to a single specific container. One of the heads is positioned directly on the scabbling chamber cover. Two other vacuum heads, operating independently from the first one, are mounted over each of two drum collectors (see below). A total installed "vacuum" power is increased to 9 kW (from the current 7 kW); for "real" decontamination tasks, HEPA filters are installed in each of the heads.

Other modifications include:

- A motor-driven compressor is used to provide air to sparkgap switches and positioners (turbine X-drive and Z-air cylinders).
  This addition makes the unit partially autonomous, not dependent on the quality of a site air supply.

- Part of air exhausting vacuum heads (via HEPA filters) is ducted into the PFN enclosure for purposes.

- An air-actuated solenoid valves are used for air flow control.

2. Water/debris flow.

The water/debris flow diagram shown in **Figure 8.8** differs from the one of the prototype in several points:

- Higher flow rate/higher pressure water pump is used to shorten fill-up and recirculation times; the same pump is used to provide localized water injection into the interelectrode water gap.

- Water level and flow rate indicators/controls are added.

- Configuration of a water/debris collector in the scabbling chamber is modified to provide stronger suction and removal of water down to 1/8" level.

- Two 55 gal. drum collectors are installed (replacing single larger - 90 gal. used with a prototype unit) on an ancillary wheeled platform under common cover which also supports vacuum power heads and water pumps. A first drum is equipped with a coarse filter, and will collect most of debris removed by vacuum suction from the scabbling chamber. A pedestal-type sump pump transfers water containing mid-size debris into the second drum, which has finer filter. Another sump pump transfers double-filtered water either outside the system as a waste (to be, in most instances, treated before disposed or returned to the scabbler as a makeup) or back into the scabbling chamber.

Both drums - the first one more frequently - should be replaced after being half-filled with wet debris. To do that, first, the sump pumps are retracted into the head spaces provided in the drum cover, and, second, the cover is opened (by rotating, manually or by a motor drive, in the hinges), allowing the drums to be removed (e.g. by an auxiliary pallet truck) and replaced by the new ones.

- Provision is made to install a de-ionizing column (i.e. water hardness/ conductivity reducing treatment device) in (the de-ionizer in a water return loop); if not needed the column can be by-passed). The column is positioned on the rear forklift platform.

3. Scabbled surface cleaning/removal of residual debris

Most debris will be removed from the scabbling chamber with circulating water, and deposited in the filter-equipped exchangeable drums. To remove a residual debris bed formed over the scabbled surface, pressure washer nozzles are installed in the chamber sidewalls close to the floor level; they provide strong fan-shaped water jets moving debris toward the collector located at the chamber's sidewall bottom where it is less obstructed by the scabbling module. The "wash" water pressure (as fresh water makeup or filtered/treated process water) is boosted by an additional pump installed on the rear forklift platform.

It is not precluded that debris removal by the stationary nozzles is not complete; in this event, the chamber cover is lifted and cleaning finalized by a manual wand.

8.3.3 EP/EH Carrier - Forklift Truck.

A forklift truck remains the main platform for the most of equipment because it is able to provide both horizontal and vertical movements.

Two minor improvements of the currently used truck are envisioned:

- the truck should have larger diameter straddle wheels to move it easier over uneven (scabbled) floor, and

- a variable speed (with very low minimum) drive should substitute currently used on-off motion control.

In addition, configuration of the flow system platform is changing to accommodate new components.

Power source cabinet and control console are apart and independent of the forklift, and, due to a long and flexible cable connectors, scan be relocated rather infrequently.

Convenient transfer/replacement of the drum platform is a difficult problem: on the one hand, due to inflexible connection to the drum, it's movement together with forklift greatly reduces maneuverability of the unit, on the other hand, more flexible smaller diameter connector would reduce crucial air flow rate. We are suggesting to consider this part of the design as site- and task-specific, provisionally providing for a simple disconnect between the drum cover and the main air manifold, and for independent - on a manual or motorized pallet truck- transfer of the drum aggregate.

A custom-designed (or customized commercial) carrier may be made more convenient to operate, and may accommodate all system components more compactly, but it's cost would be much higher and it's availability uncertain. Among many possible configurations three are promising for the future use at large open sites:

1) "Double forklift" track with a scabbling chamber centrally located and supported from both ends; this symmetrical system would provide more uniform concrete surface loading and eliminate water leaks still occasionally taking place with one side supported chamber.

2) EP/EH system mounted on the elevated runway (gantry) (see **Figure 8.9** from Phase I Topical Report). In this configuration all many components and connecting cables, hoses etc. would be overhead, not interfering with operation at the floor level.

3) At last, more universal (and more sophisticated) robot (e.g. Remote Work Vehicle-Rosie) can be employed as carrier and manipulator of a (appropriately modified) EP scabbler.

8.3.4 Process Controls

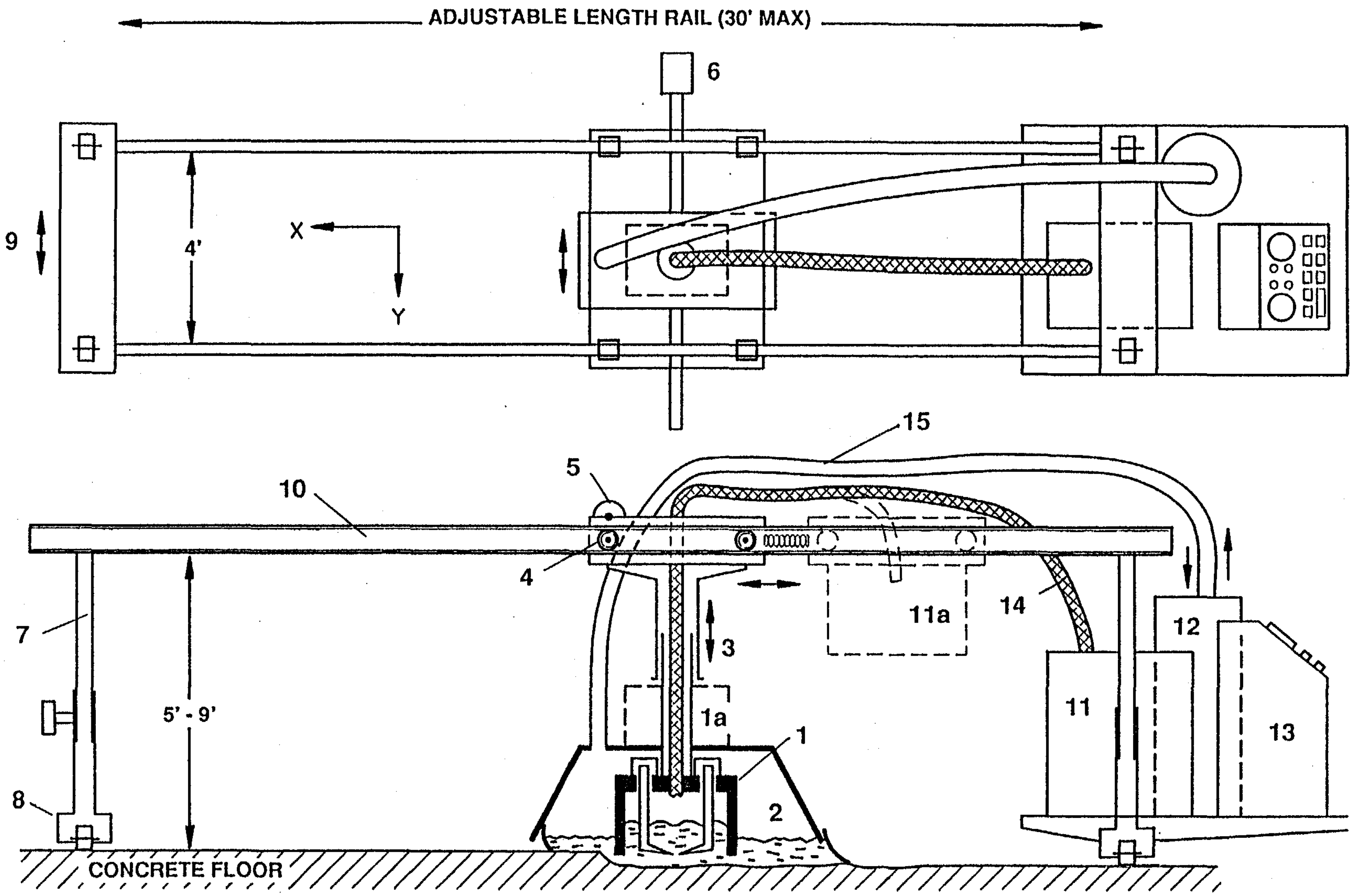
Additional meters, indicators and controls are added to make EP/EH operation and adjustment more reliable, convenient and less labor-intensive. The new control elements include:

- Electronic indicator to level the scabbling chamber against the floor surface
- Indicator of the module position on the horizontal slide
- Indicator of electrode-to-floor position
- Chamber water level indicator and control
- Water flow meters (2)
- Drum water level indicators (2)
- Platform weight scales for debris collecting drums (2)
- Timers characterizing main operating steps

Most controls are concentrated at the console attached to the DC power source. The power source has electric controls - on/off, voltage regulator, and current and voltage displays - on their front panel; remote on/off control is also available.

Console switches and indicators include those related to:

- Electrode module X- and Z-positioning: relay system)
- Pressures in air lines and air flows: gauges and valve actuators
- Water flows: pump switches, flowmeters
- Module position indicator
- Timers



1	DISCHARGE CHAMBER	6	MOTOR DRIVE y	11a	PFN
1a	SAME IN MAINTENANCE POSITION	7	GANTRY COLUMNS	12	WET VACUUM SYSTEMS AND PUMPS
2	ENCLOSURE	8	GANTRY WHEELS	13	CONTROL STATION
3	SUPPORT HYDRAULIC COLUMN	9	MANUAL TRAVERSE	14	CABLES
4	CARRIAGE	10	ELEVATED RUNWAY	15	HOSES
5	MOTOR DRIVE x	11	DC POWER SUPPLY		

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Figure 8.9 EP/EH unit concept based on the elevated runway

Other controls as well as some duplicating switches and indicators are located directly on the forklift-mounted components.

8.4 ELECTRIC PULSE PROCESSING BESIDES FLOOR SCABBLING

Applications of EP/EH scabbling technology other than scabbling/ decontamination of large open floor areas considered in this project are envisioned. Some of proposed applications are straightforward and feasible (technically, at least), while the others are hypothetical and not proven experimentally. Most of applications briefly described below would not require substantial changes of the pulser, but design of the processing head/tool, chamber and positioned in most cases will be different.

1. Processing of concrete surface irregularities - cracks, joints, indentures and other small areas.

In many instances, heavy concrete contamination is localized and is deeper in these areas while "open spaces" contain less and shallower deposited contaminants. For defect/small area scabbling, a unit which integrates scabbling tool with small size water enclosure/debris removal device has been suggested. It would have a pair of rod-shaped or short strip electrodes mounted on a motorized or walk-behind cart (accommodation of commercially-available mowers etc. seems possible). With small enclosure perimeter and strong air/water suction, a continuous traverse along the one-dimensional defect (crack, joint) at the pre-set or operator-controlled speed should be possible. With a current 30 kW power supply, one inch deep, two inches wide groove can be formed at 1.5 to 3.0 m/min traverse speed.
Minimum proximity to the wall (or other floor protrusions) for this type of tool is expected to be 3-4 inches.

2. Scabbling of concrete walls.

This type of processing would require scabbling chamber either mounted on some robotic arm (as shown, for instance, on Figure 8 of an initial conceptual EHS unit drawing), or supported by a stationary or mobile scaffold. The scabbling chamber should be smaller than used for the floor processing but, for area scabbling, larger than described above. The main problem be resolved is water retaining: stronger enclosure vacuuming should be used to compensate for the absence of gravity assistance. Another option is not to prevent water from flowing downwall and to collect water and debris in a trough installed at the wall-to-floor juncture.
The rest of the EP/EH wall unit would be similar to that of a floor scabbler.

3. Scabbling interiors (wall and/or bottom) of open pools, reservoirs and trenches; removal of brittle solid deposits.

Walls and bottoms of pools used as storage for radioactive materials are usually covered (at Hanford site, for instance) with heavy deposits that are difficult to remove. The EHS technique could be used to remove these deposits, especially the brittle ones.This is relatively simple task because in most cases there is no water supply/circulation and debris removal issues. Power equipment and scabbling module would be similar to the ones used for floor scabbling. It can be mounted-on and positioned-by a platform moving on rails installed over- or by the side of the reservoir. The debris collected over the pool bottom would be removed by an independent subsequent task. Because no separate positioning, enclosure manipulations, vacuuming and debris removal operations are involved, an effective processing rate should be 2 -3 times higher than for floor scabbling.

4. Treatment of isolated concrete items.

Large concrete blocks (wall panels, pool covers etc.) could be conveniently treated by placing them in the water pool - incidental or specialized for EP/EH treatment.
As an example of applications in this area, a unit designed by High Voltage Research Institute (Tomsk, Russia)(9,10) for concrete/rebar separation and subsequent concrete crushing, and also used at TZN GmbH, Germany (see Refs. 11) is shown in **Figure 8.10 a, b.**

5. Crashing and grinding of concrete debris/rubble

Electro-Hydraulic system can help to recycle concrete generated by scabbling of contaminated concrete surfaces or, more general, some demolition processes. The crashing/grinding device can use same or similar power supply as used for scabbling. The process reduces coarse rubble to a size required for making new concrete. It is conducted in a water tank with continues feeding of concrete rubble. While mostly used for clean concrete recycling, it may be also useful for preparing lightly contaminated rubble for subsequent compacting and making high-rad waste containers.

6. EP/EH boring and drilling

Boring of rocks or heavy concrete walls, panels, floors or other structures can be an important part of demolition. The EP/EH technique is well situated for these operations. For instance, for shock waves propagating in enclosed space the EH efficiency is higher, while EP boring un can be conducted in low-conductivity liquids (oils, emulsions). Drilling/boring diameter may vary in a wide range from few inches to several feet with efficiency increasing with diameter. This is shown in **Figure 8.11** where specific energy is plotted vs. interelectrode gap (roughly vs. bore radius). For large diameters specific energy is lower than for more traditional techniques. Drilling rates up to 15 m/hr were achieved for 10" hole diameter(10).

7. Washing concrete surfaces, removal of paints and other deposits from conducting substrates.

Low-to-moderate intensity pulses through the water layer which covers concrete or other dielectric surface, some deposits like coatings and can be removed without scabbling the substrate. An ultimate (and demonstrated) case is intense surface washing and cleaning which inadvertently takes place within the enclosure-isolated

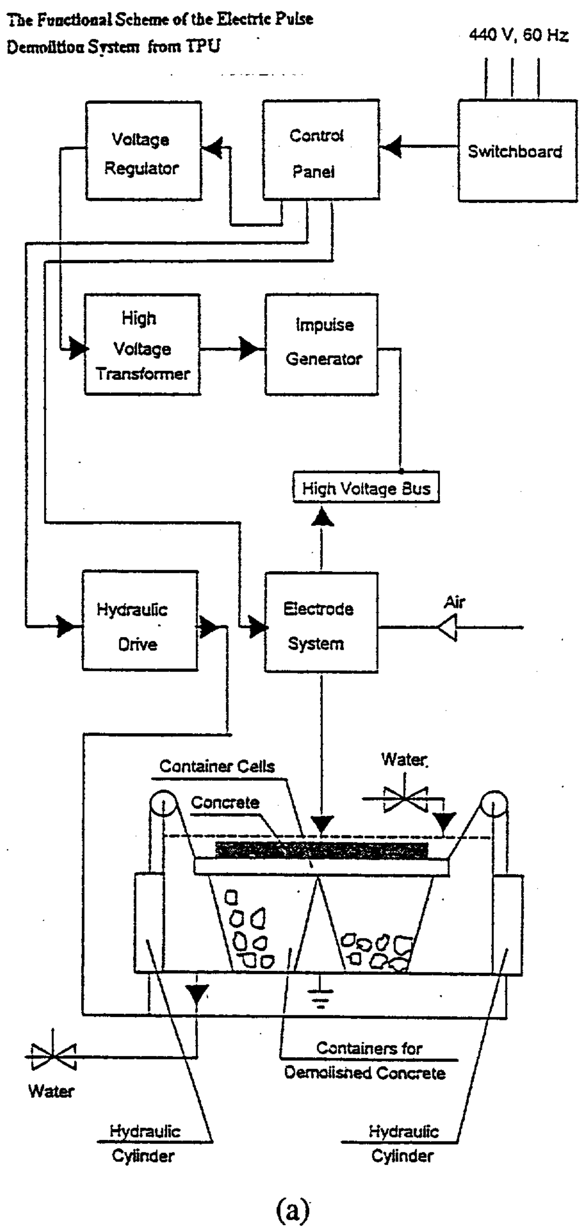

Figure 8.10 Commercial material reduction and crushing system a - Functional schematic, b-unit for concrete/armature separation

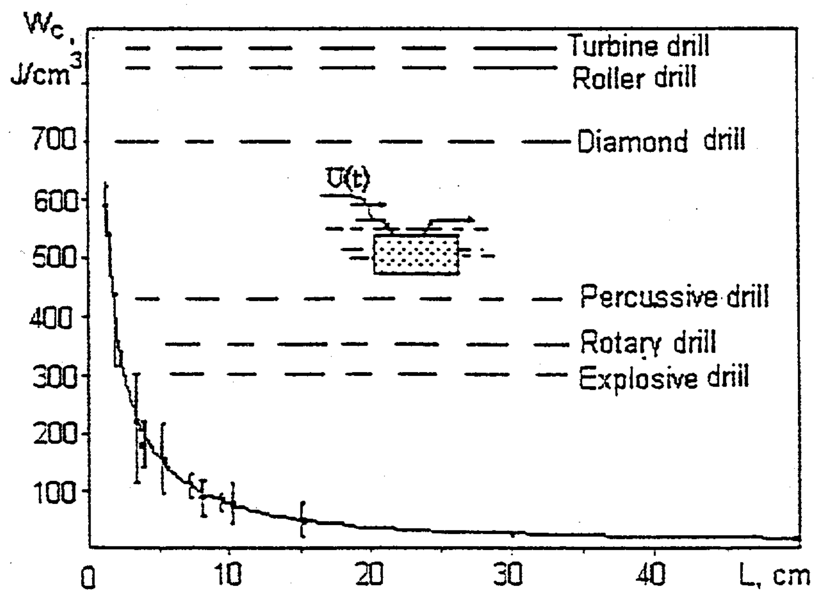

Figure 8.11 EP Rock drilling energy consumption vs. hole diameter. For comparison, energy required by other techniques is shown.

floor area at the periphery of the scabbled segment. Intense turbulent water circulation and bubbling provides cleaning and removal of oily deposits.
Heavier deposits can be removed from conductive (metallic) surfaces as well as form cavities, holes, seems etc. by the EH device with the metal part acting as one of discharge electrodes.

8. Destroying hazardous organics released by scabbling.

When concrete contaminated with hazardous organic materials (oils, PCBs, resins etc.) is scabbled, these materials are entering the water layer (as a solution, or, more likely, as a suspension of small particulates), and are exposed to the intense UV radiation and cavitation generated by EH discharges. By proper selection of pulsing conditions, water circulation flow pattern, and scabbling chamber residence time, at least some hazardous organics could be destroyed by irradiation. Alternatively, the process water (recirculating or discarded) can be directed into auxiliary chamber where UV treatment parameters could be easily optimized. The EH scabbling pulser can be used for this treatment (i.e. during the intervals between scabbling stages proper). The EH ability to destroy organics, i.e. phenols, TCE, TCA, benzene, and toluene (some of them being spilled over and precipitated concrete blocks beforehand) has been demonstrated by the experiments conducted at Textron.

9. Other EP/EH uses

Several other, more problematic, uses of the Electric Pulse technology listed below may be of interest for D&D programs becides concrete decontamination:

- Use of EH discharge as a light source for spectrochemical elemental analysis:
  - in-situ analysis of water suspensions/solutions generated by scabbling (to monitor removal of contaminants)
  - in-situ analysis of liquids in subsurface basins
  - remote analysis of water (or other liquids) in contaminated reservoirs

- Use of EH discharge for removal of deposits and decontamination of pipe/tube etc. interiors

- EP drilling in rocks, soils, permafrost with a purpose to reach, sample, treat or analyze contaminated subsurface objects

- EP/EH generation of shock/seismic waves in grounds/soils to enhance fracturing/vapor extraction

- EH "washing" of contaminated soils and debris (based on intense mixing and destruction of organics)

Development of other-than-scabbling applications of the EP/EH technology would require additional efforts, but with general technology already developed, these efforts would have solid basis enchanting their chance for success and reducing their cost.

9.0 EVALUATION OF EP/EH TECHNOLOGY: PERFORMANCE, COST AND MARKET

9.1 INTRODUCTION

Projections for performance and operating costs of several types and sizes of EH/EP units were made in the course of this project. They were presented in Phase I and Phase II Topical Reports. In Phase III the prototype scabbler was re-designed and underwent more extensive testing, including relatively long demo trials at Everett and FIU sites. Although it is realized that further development is necessary, it is now plausible to re-visit the previous estimates and to obtain somewhat more reliable projections. It should be recognized that estimation of performance and, especially, operating costs still involves many uncertainties. Site and task specific factors, such as accessibility of process area and utilities, personnel and equipment protection requirements, task logistics and regulations, may affect costs more than process productivity and equipment reliability and maintenance.

9.2 PROJECTED PERFORMANCE OF THE EP/EH UNITS

Two scabbling systems are chosen for the performance projection:

1) Unit A: similar to the one participating in the recent trials but incorporating straightforward improvements suggested in Section 8.1. The unit A is considered operating in one of two modes: A-EP operating in high voltage (120 kV) concrete breakdown mode and providing shallow (1/4") scabbling (as at FIU site), and A-EH operating at low voltage (30 kV)/water breakdown mode providing deep (1") scabbling.

   As practiced in the past switch between two modes involves only change of the PFN block; both chargers (8 kW and 30 kW) can be installed, if necessary in a single power supply cabinet.

   It is assumed that the A unit operates without water recirculation: the process water is exhausted after removal of the coarse (>0.1 mm) debris by filtration; if desirable, it could be returned and re-used by the unit by a conductivity-reducing treatment outside the system.

2) Unit B: upgraded according to Section 8.3 recommendations to allow better utilization of installed power higher frequency operation and tolerable to the process water.

   A higher voltage (50 kV) DC power supply allows operation at 200 kV (with Marx PFN) which is projected to be efficient for both shallow and deep scabbling. In a sense, the B unit can be considered as an "universal" one operating regularly in the more efficient EP mode, but with a direct 50 kV operation available when needed. In addition, the B unit can operate - either with a flow-through or recirculating water. In the latter case, water consumption is reduced 5-6 times but the flow loop contains additional filters/de-ionizers which require frequent replacement of the "cleaning" elements.

Only shallow scabbling is considered as sufficient in many instances. Comparison between A-EP and B-EP systems allows to evaluate degree of the projected improvement. Performance for other depths can be extrapolated, in a first approximation on the basis of volume of concrete removed.

Projected performance data are shown in Table 9.1. The following features should be mentioned:

- Scabbling rate (ft^2/hr) for A-EP unit is projected to be somewhat higher than demonstrated at FIU due to slightly higher pulse frequency (which should be made possible due to improved electrode coatings and better gap water injection), larger floor segment area and shortening chamber/module relocation and debris removal times.

- Scabbling rate for A-EH unit is two times lower but volume of concrete removed (and rubble generated) is four times higher than A-EP.

- Higher (net) scabbling rate is a key issue for deep scabbling, while shortening of auxiliary operations is more important for the EP mode/shallow scabbling.

  Under conditions where scabbling can be performed without enclosure and/or without immediate removal of debris and water circulation (e.g. in water pools), effective processing rate would be at average two times higher.

- Energy consumed for scabbling *per se* is rather low, especially for shallow, EP mode scabbling where it comprises only one third of the total. The rest of electric power is spent for water/debris movement, enclosure air pressure reduction, air gap de-ionizing, air cooling and positioning (in this sequence by the power consumption).

- In a no-recirculation mode, the water consumption is high. Not only this is undesirable due to increase of a waste volume, but also due to the cost of water itself.

9.3 PROJECTED SCABBLING COSTS

9.3.1 Assumptions

The EP/EH processing costs are estimated for A and B units under the following set of assumptions:

- Performance of the units are specified in **Table 9.1**

- Capital costs of the equipment are as shown in **Table 9.2**

Table 9.1
Design and typical operating parameters for EP and EH units

Item	Prototype		Industrial
	A-EP Mode	A-EH Mode	B-EP Mode
Unit dimensions, LxWxH, ft	8 x 4 x 5*		9 x 4 x 5*
Unit weight**, lbs	1700		1900
Power (installed AC), kW, Charger Auxiliaries	8 10	30 14	30 14
Operating voltage, kV	120	30	300
PFN capacitance, µF	12	1	36
Electrode width, in.	34		36
Scabbled segment area, ft^2 per cycle	7.5		10
Pulse: Energy Duration, µs Repetitionrate, pps	 1 4 15	 5 30 6	 0.5 2 25
Scabbling depth, in	1	1/4	1/4
Characteristic processing times, min. per cycle: -Pulsing/Scabbling -Water circulation/debris removal -Chamber re-positioning -Cycle duration, total	 7.5 8.5 2 18	 20 13 2 35	 4.5 7.0 1.5 13
Effective scabbling rate, ft^2/hr #	25	13	46
Concrete removed, lbs per segment	20	80	27
Energy consumption, kWh/ft^2: Scabbling Auxiliaries Total	 0.13 0.27 0.4	 1.3 0.5 1.8	 0.18 0.22 0.4
Water consumption, gal/ft^2	12	30	12 (2)#

* 7 ft with forklift truck

** Forklift truck - 900 lbs additional

\# The effective scabbling rate takes into account scabbling proper, unit re-positioning,water fillup/removal and debris removal times as shown in the table; under conditions of multi-cycle per shift (or per day) operation schedule an initial set up time is insignificant

\## Lower consumption corresponds to water recirculation/treatment mode

Table 9.2
Estimate of capital (equipment) costs of the EP/EH units

Item	SYSTEM Cost, $000's		
	A-EP	A-EH	B-EP
1. Electric Pulser			
DC Charger	8	30	35
Capacitors	2	3	4
Spark Gap Switches	4	3	5
Cabinets, Cables, Resistors, etc.	3	3	4
Subtotal	17	39	48
2. EHS Module			
XZ Positioner	3	3	4
Scabbling Module	4	4	5
Scabbling Enclosure	6	6	8
Subtotal	13	13	17
3. Slurry Management System			
Electric Rad Vac System	6	7	8
Rubble Collector/Separator	4	5	7
Water Pumps	2	3	4
Auxiliaries (flow/pressure controls, hoses, filters)	5	5	9
Subtotal	17	20	28
4. Carriage and Controls			
Self-propelled Carriage	9	9	10
Process Controls	10	10	12
Subtotal	19	19	22
SUBTOTAL components, parts	66	91	115
SUBTOTAL System Assembly, Integration and Testing (labor)	44	39	60
TOTAL UNIT COST ($ 000's)	**110**	**130**	**175**

- Most components have five years lifetime with some of the components (about 20%) requiring once per year replacement; the replacement cost is added to the yearly amortization costs of the basic equipment

- Labor cost - which is a major cost component - is calculated as follows:

  - net operating (scabbling) time is 6 hours per day (or per shift)
  - two hours are spent for equipment setup and maintenance, and
  - two persons - the main operator and a maintenance person operate the scabbler
  - direct labor cost (average) is \$22 per hour (40 K\$ per year at 1820 working hours. No overhead etc. indirect costs are included. This approach is selected to make possible comparison with processing cost estimates made in Refs. 6 and 13 .

- Cost of waste (mainly wet concrete rubble + process water) disposal is not included
- Costs of Health & Safety and sampling/analytical services are not included

9.3.2 Estimated EP/EH Scabbling Cost

Main EP/EH performance data and scabbling costs projected for three cases outlined in Section 9.2 are presented in **Table 9.3.**

We conclude that according to these estimates based on our moderate scale/short time trials, cost projections are 2 to 3 $\$/ft^2$ and 6 to 7 $\$/ft^2$ for shallow and deep EP/EH concrete scabbling/decontamination, respectively. The labor cost - prevails over other components, especially for smaller scabbling units. Further process automation can reduce costs to $\$1.5$ $\$/ft^2$ by reduced labor requirements and higher scabbling rates. Cost of utilities, especially, of the electric power, is very moderate and not decisive. Therefore, the installed electric power can be increased substantially to increase scabbling rate without raising capital and operating costs.

Whether a serious effort should be made to provide complete water recirculation capabilities within-the-unit depends on the following factors:

- progress in achieving effective scabbling in process water
- extent and cost of water treatment within a recirculating loop
- specific site conditions such as water supply cost, restrictions for process water disposal
- availability and type of on-site water treatment facilities (which may allow eventual return of the treated water to the scabbler)

All costs are substantially lower if the EP unit is relieved from the water and debris removal/treatment task. This might be the case where a) water and debris removal and treatment is a separate (simultaneous or delayed) task, e.g. combined with other D&D activity at the site, or
b) Concrete is scabbled for other than decontamination purpose, and water supply is unlimited/inexpensive.

The associated increase of scabbling rate to almost 100 sq. ft. per hour would make the EP technology one of the most productive. In addition, for the "scabbling only" application EP/EH unit much simpler in design and operation is need. Combination of these factors would result in total operating costs which are almost two times lower than the ones including "full service" scabbling & debris removal operation.

It should be mentioned in conclusion of this section that the current performance and cost estimates are in general agreement with those presented in the Phase I and II evaluations

Table 9.3

Projected performance parameters and operating costs for EP/EH units

Item	Performance and Cost				
	A-EP Mode	A-EH Mode	B-EP Mode	**	*
Scabbling Depth	1/4"	1"	1/4"		
Scabbling Rate (effective) ft^2/hr	25	13	46		***90***
Processed area ft^2/year		20,000	70,000		***137,000***
Concrete removed ft^3/year	780	3,100	1,440		
Capital (amortization) cost $/ft^2	0.7	1.6	0.6		***0.4***
Labor Cost $/ft^2	2.1	4.0	1.15		***0.5***
Utilities:					
Electricity	0.05	0.50	0.05		
Water	0.10	0.30	0.10	(0.02)	
Consumables	0.15	0.30	0.30	(0.25)	
Water Treatment	N/A	N/A	N/A	(0.80)	
Utilities Total Cost $/ft^2	0.3	1.1	0.45	(1.15)	***0.35***
Total Cost $/ft^2	3.1	6.7	2.2	(2.9)	***1.25***
$/ft^3	150	80	70	(90)	***0.40***
Operating Cost Per Unit $/year	118,000	134,000	154,000	(203,000)	

* Number (bold italics)in this column are for a"scabbling only" (i.e. not involving debris removal) EP system

* * Number((in parenthesis) in this column are for system with water treatment (filtration and de-ionization) in recirculation loop

9.4 COMPARISON WITH OTHER SCABBLING TECHNIQUES

Several techniques have been proposed for concrete decontamination or complete demolition of concrete structures. They are listed in **Table 9.4.** Less traditional non-mechanical (i.e. thermal and electrical) methods of concrete treatment are presented in **Table 9.5.** In Ref. 1,2, detailed description and evaluation of these technologies is provided. Some decontamination techniques are able to remove hazardous chemicals and/or radioactive materials from the concrete surface (e.g. together with paint or coating), while others extract contaminating materials leaving the concrete structure intact. When it is known (or suspected) that the contamination penetrates the concrete at least 1/8" deep, a thicker, usually 1/4" to 1", surface layer of concrete should be removed. We are limiting our comparison only with methods known as scabbling - the category of processing techniques which provides a deep decontamination capability. Many commercially available or developmental technologies are listed and characterized with respect to performance features and processing costs in Ref. 1.

Table 9.4

Concrete demolition and decontamination techniques

Mechanical	-	Chains and Saws
	-	Pneumatic Tools
Explosives	-	Small Multicharges
Thermal	-	Flame Jets, Plasma Jets
	-	Laser and E-Beams
	-	Microwaves
Blasting	-	Dry Scabbling: Abrasives
	-	Frozen Pellets
	-	High Pressure Water Jets
Electric	-	DC or Induction Heating of Re-bars
	-	Microwaves
	-	Wet Scabbling: Electro-Hydraulic

Table 9.5

Classification of thermal and/or electrical methods of concrete demolition

Boring and Cutting Concrete with High Temperature Flame, Plasma, and Laser	Cracking and Peeling Concrete by Electronically Heating Reinforcing Steel	Breaking and Peeling Concrete by Directly Applying Electrical Energy to Concrete
Thermal Flame Lance Powder Flame Lance Jet Flame Lance Plasma Powder Flame Lance Plasma Jet Laser Beam Electron Beam Arc Heating	Direct Electrical Heating of Reinforcing Steel Induced Electrical Heating of Reinforcing Steel	Microwave High Frequency and High Voltage Electric Discharge

As it is usually the case, a direct comparison is difficult due to many factors, such as, incomplete data, variety of operating conditions, specific applications and operating scales, difference in evaluation methodology, different levels of technology development. For instance, while information on commercial equipment and technique is available, it is usually based on applications where conditions are far from the one typical for contaminated sites. Also, commercial equipment is rarely equipped with auxiliaries - in fact, a very central components of decontaminating equipment - for removing scabbling-generated debris.

***Tables* 9.6 *and* 9.7** which are compilations from the Ref. 6, list several decontamination methods which are probably capable of reasonably deep concrete penetration. It is obvious that this is an odd set of information with processing rates and cost data spanning over two order-of-magnitude ranges. A more recent FIU Report(12) is based on direct, if incomplete, comparison of several concrete decontamination technologies. **Table 9.8** is a short summary of technologies for shallow and deep decontamination. **Table 9.9** provides some data and conclusions resulting from evaluation of five technologies capable of removing concrete beneath the epoxy coating.

The following comments may be helpful when considering results of trials at the FIU site, and specifically, data in Tables 9.8 and 9.9

- When comparing EP scabbling with commercial technologies, it should be taken into account that some of inherent advantages of EP technology still could not be realized at the developmental stage and prototype level unit. Besides EP scabbler, all other systems tested at FIU are of a commercial grade, and, presumably, underwent substantial design development as well as modifications to make them fit the decontamination environment.

TABLE 9.6 CHARACTERIZATION OF SELECTED CONCRETE DECONTAMINATION TECHNOLOGIES

Technology	Stage of development	Processing rates	Secondary waste generation	Estimated cost per ft^2	Removal efficiency[a]	Limiting conditions	Comments
Hand brushing	Commercial	Variable	~0.003 ft^3/ft^2 (solids)	~$5.00 - 10.00	Up to 100%	Waste-processing system	Waste production rates depend on media/surface combinations
Hand grinding, honing, scraping	Commercial	Variable	Variable	$0.50-1.00	Variable	Limited to decontamination of small areas	Remote operation will improve efficiency
Chipping hammer/paving breaker	Commercial	20 yd^3/day (90 lb hammer)	Variable	Variable	Variable	Leaves surface very rough; large amount of dust produced	Used to decontaminate small inaccessible areas; primarily used in demolition activity; can be used to decon surfaces
Concrete milling	Conceptual	Unknown	Top 6-25 mm of concrete removed	$0.75	Unknown	Suited for horizontal surfaces only	Equipment is available but has not been used for decontamination purposes
Scarification	Commercial	200-400 ft^2/h	0.078 gal/ft^2 at 1/16-in. removal	$1.85-2.50	1/16 in. per pass	Noise pollution	Collects 99.5% of all debris
Multi-unit scarification	Commercial	20-300 ft^2/h	0.078 gal/ft^2 solids at 1/16-in. removal; needle gun only 0.03 gal/ft^2	$1.85-2.50	1/16 in. per pass	Noise pollution	Integration of several pieces of scabbling equipment
Soft media blasting	Commercial	60-100 ft^2/h	0.001-0.01 ft^3/ft^2 (solids)	$10-12	90-99%	Uses large amounts of water	Successful in mixed waste decontamination
Plastic pellet blasting	Commercial	4 ft^2/min	Similar to other scabbling/blasting processes	$0.20-2.15	Unknown	Demonstration of specific medium needed	Pellets need to be optimized; widely used as an alternative to grit blasting
Soda blasting ($NaHCO_3$)	Demonstration	120-240 ft^2/h	0.007 ft^3/ft^2 (solids) 1.9 gal/ft^2 (liquid)	$5.00-7.00	95-99%	Multiple units required for secondary-waste processing	Commercially available for non-rad cleanup
Grit blasting (sand blasting)	Commercial	~47 ft^2/h Dependent on grit used	0.03 ft^3/ft^2 (solids)	~$5.00-10.00	Up to 100%	Waste-processing system	Waste production rates depend on media/surface combinations
Shot blasting	Commercial	30-3000 ft^2/h	Variable	$0.04-5.02	10-100%	Airborne debris; system for processing waste needed	Conventional decontamination equipment; removes ~1/4 in. of concrete per pass
High-pressure water	Commercial	~370 ft^2/h	0.03 ft^3/ft2, 4-100 gpm liquids	$0.06-2.00	Variable	Uses large amounts of water	Water reuse/recycling system is needed
Ultra-high-pressure water	Commercial	1 ft^2/min	3-5 gal/ft^2 liquid	~$2.00	Unknown	Water recycling system	Robotics control is in development; numerous non-rad decontaminations
Superheated water	Commercial	Variable	0.4-2 gal/min liquids	$0.50-2.00	Variable	Uses large amounts of water	Robotics and water reuse/recycling system are needed
Plasma torch	Developmental	Unknown		~$1.00	Unknown	Spalling of concrete	Technology currently used to decontaminate hazardous surfaces
Microwave scabbling	Demonstration	40 ft^2/h	0.15 ft^3/ft^2 solids	~$2.00	100% 2 in. per pass	Removes top layer of concrete	Technique has not been optimized. Not available in the private sector
Laser heating	Developmental	2.5 ft^2/h	Unknown	$1.00	Unknown	Currently used to decontaminate metallic surfaces	Decontamination of large surface areas with minimum amount of waste generation
Laser ablation	Developmental	85 ft^2/h	75% waste reduction is projected	~$1.00	Unknown	None identified	Currently building a full-scale prototype

Table 9.7

Estimated costs for emerging concrete decontamination technologies

Technology	Estimated Capital Cost, $	Estimated Operating Cost, $/ft^2	Estimated Labor Costs, $/hr	Comment
Scarification	110K	5 to 12.6	43.75[a]	
CO_2 blasting	300K	0.90 to 1.75	15 to 300 (includes operating cost)	Higher cost range estimates are for application to radioactive contaminants.
Soda blasting	unavailable	5 to 7	43.75[a]	Operating cost estimated at $5.62/ft^2 at K-25 demonstration.
Centrifugal cryogenic CO2 blasting	100 to 200k	0.075 to 0.75	unknown	Technology may require up to ~$750K for concrete application development.
Supercritical CO2 blasting	150K	1	43.75[a]	
Grit (sand) blasting	unavailable	5 to 10	43.75[a]	
Shot blasting	4M	0.04 to 5.	0243.75[a]	Capital cost estimate is based on the cost to design and build a pilot facility.
High-pressure water	50 to 75K	0.06 to 2	43.75[a]	
Superheated water	175K	0.05 to 2	43.75[a]	
Concrete milling	11K	0.75	43.75[a]	
Laser ablation	~700K (up to 1M to develop prototype)	unavailable	unknown	It is likely that the process will be provided as a service by private industry.
Microwave	150K	2	43.75[a]	
Electro-hydraulic scabbling	unavailable	0.65 to 1.85	included in operating cost	Assumed that the process would be provided as a service by private industry.

[a] Labor cost estimate based on a 2-person team at $40K/year/person.
Sources: NEL 1993, 1994; Oak Ridge K-25 Site 1993; ORNL 1993.

Table 9.8

Competing concrete decontamination technologies

A. Shallow (surface, 1/16"):	Chemical "wash" Soft media (O2, ice, soda) blasting Water Jets (HP) Strippable coatings Electromigration Laser or flashlamp ablation
B. Deep scabbling (>1/4"):	Hydraulic hammers/Jackhammers Explosives Mechanical scabbling/scarification Shot blasting Plasma torch Microwave scabbling EHS scabbling
Main technology selection criteria Reasonable operating cost/high processing rate) Reduced waste volume Maneuverability Safety/environment protection (especially absence of airborne dust) Freedom from secondary cleaning operations	

Table 9.9

Comparison of Five Technologies Capable of Deep Scabbling

Technology	Scabbling depth, in (demonstration) Target	Achieved	Scabbling Rate ft^2/hr	Equipment Cost K$	Processing Cost $\$/ft^2$	Media; Cost [$\$/ft^2$]	Requirements/Limitations: Surface Requirements	Utilities; Portability	Noise Level	Other	Waste Removal (Current design)	Scabbling Quality	Main Positive Features
Vacuum Blasting. Commercial	0.25	0.2	48	63	2.1	Steel grit [0.3]	Dry	High power dry air Compressor. Forklift	High	Operator's fatigue	Vacuum removed dry dust. Media escape. Residues	Non-uniform (macro)	Short setup. Close wall approach.
Centrifugal Shot Blasting. Commercial	1.0	0.6 (1)	170	150	0.33	Steel shot [0.1]	Dry	3-Phase AC generator. Compressor Forklift	N/A	10" from walls	Dry dust. Shot escape possible. No provision for removal from collector.	Non-even (grooves) Path width 15"	High productivity. Short set-up. Least expensive.
Dry Scabbling. Commercial	1.0	0.55 (1)	33	160 (3)	1.6	[1.0]	N/A	High flow rate, dry air compressor. Custom carriage.	N/A	Strong vibrations Frequent mainten-ance	Vacuum - removed dry dust, sometimes incomplete.	Even surface, Variable path width.	Close wall approach (2). Even surface.
Ultra high pressure water. Commercial	0.25	0.17	42	160	1.5	Water 6 gpm [1.0]	N/A	High-power water pump Trailer	High		No provision in this system.	Uneven removal depth.	Close wall approach
EP/EH wet scabbling. Developmental	0.25/1.0	0.25 - 1.75	25 (46) (4)	110 (175) (4)	3.1 - 5.0 (5) (2.2 - 3.5) (6) [0.02 - 0.2]	Water 12 - (2) (6) gpm	No limits	3 - ph 45kW AC Forklift	High	10" from walls	Wet rubble + process water collected/ recirculated or flows to treatment plant	Locally nonuniform on concrete structure scale. 32" path width	No dust generated. No surface condition limitations. Single, wide path, deep scabbling capability.

(1) In two passes
(2) Multi-unit combination for large/small areas
(3) "Moose" unit for large areas
(4) ( ) - Projected for moderately upgraded unit
(5) For 0.25 to 0.6" depth
(6) With water treatment/recirculation
(7) At one of two demo sites

- Some of demonstrators did not bother to equip their units with devices for waste containment and removal. Because removal of contaminated concrete debris from the floor surface is a substantial part of the whole task, some of data overstate the processing rate and underestimate the processing cost.

- No measurements or even rough estimates were made of the dust content in the surrounding air, and of the amount of fine debris remaining over the surface of scabbled concrete at the FIU. Therefore, no conclusive judgment can be made about degree of decontamination, cross-contamination etc. This is especially true for dry processing; meanwhile, pre-wetting of concrete, at least for blasting techniques, is not feasible.

- Some of processing cost estimates not only ignore waste containment/removal expenses, but barely exceed direct labor cost; not only waste management, and support services are ignored, but also costs related to equipment amortization, energy consumption, maintenance and spare parts and consumables. Using the same limited approach for the A-EP unit demonstrated at FIU a 45 ft^2/hr scabbling rate (instead of 25 ft^2/hr in our more complete evaluation) and scabbling cost of about 1.3 \$/ft^2 (instead of 3.1 \$/ft^2).

- Surrogate floors prepared for FIU demonstration trials are made of limestone-based concrete which is not typical for DOE facilities. While this concrete has adequate compression strength, other properties are not representative of industrial concrete: limestone is softer than granite, and the debris contains more calcium, and is much finer. These peculiarities may affect relative performance of the technologies in comparison: soft aggregate benefits use of grinding and shot blasting but not techniques where aggregate remains basically intact (high pressure water and EP scabbling); high calcium content makes it difficult to reuse the process water (for EP scabbling).

- None of the "commercial" scabbling techniques did achieve the targeted depth of removal (see Table 9.9). It does not mean that these targets can not be reached but it would require some equipment modification and/or more traverses. Even if the depth of target is achieved, the scabbling rate will be lower while processing cost - higher.

9.5 COMMERCIALIZATION OF EP/EH TECHNOLOGY FOR CONCRETE DECONTAMINATION

9.5.1 Introduction

It is obvious that quite diverse concrete decontamination technologies have their strong and weak features. Accordingly, they could find separate niches in various D&D areas.
The following specific factors should be taken into account to obtain maximum benefits from the EP/EH technology:

- Scabbling depth: Moderate to deep; single pass desirable
- Scabbling area: Large, no obstacles
- Floor surface: Regular or irregular (with local defects)
- Surface condition: Painted or unpainted, dry or wet
- Concrete: Lower lime content
- Contaminants: Low water solubility
- Utilities: Sufficient electric and water supply only
- Processing rate: Should not be main factor
- Dust generation: None
- Cross-contamination: Undesirable
- Waste management: Presence of water processor would benefit scabbling rate, avoid water recirculation/treatment cost
- Remote Operation: Operators not in contact with radioactive dust or rubble.
- Other (multi-uses): prospects for removal of organic contaminants from concrete debris, decontamination of concrete tanks, concrete blocks, demolition of concrete structures treatment of materials other than concrete (e.g. asbestos)

The EH scabbling technique is relatively sophisticated in a sense that it integrates mechanical, flow and high voltage/high current electric components in a nontraditional fashion. Only recently (last 10-15 years), due to progress in technology (especially for military applications), the pulsed power components and systems reached reliability and lifetime sufficient for commercial applications.[5] Without this development it would not be possible to develop a practical and competitive EH scabbling device.Continuing development in the electric pulse power area should emphasize positive features of the EP/EH processing.

To evaluate techno-economical prospects and markets for application of EP/EH concrete decontamination techniques, we have two sources of information at our disposal.

A. Based on the performance data obtained from laboratory experiments and from the field trials at Fernald and FIU sites with 4 to 30 kW EH and EP scabbling units, and from estimates made for upgraded 30 to 60 kW industrial system, we are able to project the main characteristics of EHS equipment and process: processing (scabbling) rate, quality of decontamination, volume of generated waste, capital and operating cost of the EP/EH equipment.

B. By using information from DOE/METC (especially data and summaries from a 1995 report, DOE/ORO/2034, "Contaminated Concrete: Occurrence and Emerging Technologies for DOE Decontamination, 1995" [12] FIU/HCET 1997 Report "Analysis of Potential Concrete Floor Surface Removal Technologies" [9] and reports/publications and contacts with some DOE sites and contractors, we obtain an understanding of current and future decontamination needs, requirements, and capabilities of commercially available and emerging concrete decontamination technologies.

Both sets of information are limited by substantial uncertainties. While the projected EP/EH data and predictions should be correct within $\pm$ 30% of the assumed values, the information on performance of other decontamination/scabbling techniques is less certain because either the techniques were not tested under real conditions, or processing parameters were not comparable, or the base for operating cost (especially labor cost) was not reported. Latitude in the DOE market size (i.e. the scale of the D&D effort, the timing and availability of funds, etc.) also contribute to the uncertainty of the estimates.

9.5.2 Concrete Decontamination Needs

Concrete contaminated by various organic and inorganic chemicals and radionuclides can be found at many industrial and utility, civic and military, currently operating and abandoned (decommissioned) sites. Among them, sites of the DOE complex are of most importance, both because of surface areas of concrete and by the character of the contamination. These sites are also better defined and localized than others. The most frequently reported radiological contaminants are ^{238}U and ^{137}Cs, followed by Co, Sr and tritium. Nonradiological contaminants include oils, PCB, and heavy metals, especially mercury.

The total (DOE) area of contaminated concrete is estimated to be about 8×10^8 ft^2 or 18×10^3 acres. Shallow penetration is characteristic for broader areas, especially in epoxy paint pre-coating; deep penetration is typical for uncoated concrete and concrete with local defects (cracks, etc.) and around joints.

In estimating the concrete decontamination needs, we have assumed that 2×10^8 ft^2 of concrete will be assigned for treatment and:

A. "Shallow" decontamination can be performed by rapid and relatively inexpensive surface wash and soft blasting techniques. We assume that 80% of the total concrete areas (mostly floors) can be decontaminated by these methods.

B. The remaining 20% of the concrete areas require deeper treatment by more energetic action, which will inevitably be slower and more costly. Appropriate scabbling techniques include EP/EH, which allows one-pass removal of up to a 1" thick concrete layer. This technology will compete with mechanical scabbling and other methods (listed in Tables 9.6 to 9.9) which are also capable of deep scabbling (while usually requiring multipass operation). Among these techniques, centrifugal shot blasting and microwave scabbling developed in Japan appear to be most competitive. For market projection we further assume that on the basis of technical merits, capital/operation costs, volume of waste produced, quality of decontamination, environmental and many other considerations, about 40% of deep scabbling will be performed by EP/EH technique.

C. The main part of the DOE D&D program will be completed in 10 years (1998 to 2007).

These assumptions are summarized in **Table 9.10** with some examples of concrete D&D needs shown in **Table 9.11**. In both figures, dollar amounts that are likely to be appropriated for concrete D&D are also provided.

Table 9.10

Concrete decontamination at DOE. Tasks scales and projected

Total surface area considered	8.10^8 sq. ft. ↓		DoE Projected Cost
Assigned for treatment	2.10^8 ↓		5 B$ ↓
For deep scabbling	4.10^7 ↓		1 B$ ↓
For EHS in 10 years	$1.4.10^7$ ↓		300 M$ ↓
EHS total per year, av. per 1 unit, per year	 $1.4.10^6$ $1.4.10^5$		 30 M$ 3 M$
EHS units operating, av. total built (10 years)	 20 10		
Operating cost "available" from DOE			20 $/sq. ft.

Table 9.11

Examples of concrete D$D DOE sites, needs and costs

INEL (Idaho):	1M ft^3 rubble - 100 M$ - 10 years; at 100$/$ft^3$
LBL (Lawrence Berkeley):	500 Kft^3 - 10 M$
Los Alamos	200 Kft^3 - 5 M$ - 3 years
Mount Plant	160 Kft^2
Oak Ridge K-25 plant:	20 Mft^2, mostly 1/16" deep; total cost 8 B$ or 400$/$ft^2$ (disposal cost at $ 1,000/drum, 2$/$ft^2$)
Oak Ridge Y-12 plant:	150 Kft^2 (includes mercury)
Paducah Plant:	260 Kft^2 accepted for D&D; plus 10 Mft^2 20 years (470 M$ cost estimate) +15 years

9.5.3 Marketing Data and Assumptions

For the purpose of estimating the demand for EH/EP units, we considered an EP-B scabbling unit characterized in **Tables 9.1 and 9.2** as an industrial grade entry in a commercial D&D market. With this unit capable of 70,000 ft^2 processed per year and a market size/share 1,400,000 ft^2 per year (see Table 9.10), 20 units would be needed to complete the DOE concrete decontamination program in 10 years.

With an average lifetime of five years for each unit, a total of 40 units (average 4 units per year) would have to be built and operated through the segment of the DOE, D&D program assigned for EP scabbling. At a 175 K$ production (direct) cost, 35 K$ of other costs and 240 K$ sale price per unit, revenue generated and profit would be 960 K$ and 120 K$ per year respectively, and 19 M$ and 2.4 M$ for the whole DOE D&D program.

It is recognized that both revenues and profit could double if maintenance of the operating equipment and supply of (short lifetime) parts is included in the program.

9.5.4 Commercialization Potential and Strategy

In reviewing the process cost projections and the market analysis, it is evident that the predominant process cost items are site preparation, health and safety compliance, liability insurance and labor. The cost of the equipment, approximately $250 x 10^3 per unit, and the number of units, projected to be 40 over the 10 year DOE program would be relatively small. It follows, therefore, that the major revenues and profits from the development of the process would flow to the company providing the labor and service. Thus, the prime incentive for development of the EH/EP scabbling process is to engineering contractors that provide decontamination services and not companies that manufacture the EH/EP units.

Textron Corp. is primarily a manufacturing organization rather than a decontamination service contractor. Thus, it was deemed advisable to transfer the EH/EP technology to a company where the technology would compliment existing capabilities and where the incentive for added revenues would justify further investment.

On this basis, Textron initiated a concerted effort to transfer the technology to an engineering, contracting company active in commercial D&D. Textron sought to protect the technology by requesting a waiver from the government for patent rights. Letters were sent to the companies listed in **Table 9.12** indicating Textron's willingness to transfer the technology. Later a short video was made describing the elements of electrohydraulic scabbling, a review of the device development and the demonstrations at Fernald and Florida International University. These videos were sent to companies that indicated initial interest in the process.

Table 9.12

List of commercial D and D contractors contacted regarding technology transfer

Bartlett Services Inc.	(1) (2)
Roy F. Weston Inc.	(1) (2)
B and W Nuclear Environmental Services Inc.	(1) (2)
BNFL, Inc.	(1)
Camp Dresser and McKee International Technology	
Westinghouse Idaho Nuclear Co. Inc.	(1)
SEG, Inc. (GTS Duratech)	(1)
MIRAGE, INC.	(1)
Stone and Webster Engineering Co.	
MSE/MTC	(1)
(1) Follow-up Video sent (2) Served on Project Advisory Panel	

In addition to the Commercial Contractors listed in Table 9.12. Textron also sent letters and videos to the Global Environmental Technology Enterprise (GETE) and Downbreaker, a business planning firm, both contracted by DOE-EM as part of the Commercialization Assistance Program (CAP). Videos were also sent Advisory Panel Members at DOE sites, that is, Oak Ridge, Fernald, Rocky Flats and Savannah River.

After a series of follow-up communications with representatives of these companies, there appears to be minimal interest in additional private investment in the further development of the EH/EP scabbling process. The consensus is that that there are adequate scabbling techniques available, and although the EH/EP offers desirable features, the incetive for private investment will not exist until

(i) a market for the clean-up of nuclear power plants develops, or

(ii) the budget for the clean-up of DOE sites is more “concrete”.

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