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Hydraulic Impact End Effector Final Test Report

Automation and Robotics Section
ER/WM-AT Program

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Contents

Executive Summary

One tool being developed for dislodging and fragmenting the hard salt cake waste in the single-shell nuclear waste tanks at the Hanford Reservation near Richland, Washington, is the hydraulic impact end effector (HIEE). This tool operates by discharging 11-in.^{3} slugs of water at ultrahigh pressures. The HIEE was designed, built, and initially tested in 1992. Work in 1993 included advanced development of the HIEE to further investigate its fragmentation abilities and to determine more effective operating procedures. These tests showed that more fragmentation can be achieved by increasing the charge pressure of 40 kpsi to 55 kpsi and by the use of different operating procedures.

The size of the material and the impact energy of the water slug fired from the HIEE are believed to be major factors in material fragmentation. The material's ability to fracture also appears to depend on the distance a fracture or crack line must travel to a free surface. Thus, larger material is more difficult to fracture than smaller material. Discharge pressures of 40 kpsi resulted in little penetration or fracturing of the material. At 55 kpsi, however, the size and depth of the fractures increased. Nozzle geometry had a significant effect on fragment size and quantity. Fragmentation was about an order of magnitude greater when the HIEE was discharged into drilled holes rather than onto the material surface. Since surface shots tend to create craters, a multi-shot procedure, coupled with an advanced nozzle design, was used to drill (crater) deep holes into large material. With this procedure, a 600-lb block was reduced to smaller pieces without the use of any additional equipment.

Through this advanced development program, the HIEE has demonstrated that it can quickly fragment salt cake material into small, easily removable fragments. The HIEE's material fragmentation ability can be substantially increased through the use of different nozzle geometries and operating procedures.

History

The environmental restoration and final disposal of the radioactive contents of the underground storage tanks at the Hanford site will require the removal and treatment of the tank contents. These contents are in the form of various residues from nuclear separation operations conducted at the Hanford site since 1943 and span the continuum of two-phase constituency from liquids to crystalline solids. Radioactivities associated with these residues are (and will remain) far above levels suitable for direct manned operations.

Attachment 1 is a summary by the Westinghouse Hanford Company (WHC) of detailed studies of this problem conducted since the 1970s. A number of viable concepts and tools for breakup have been identified and evaluated with surrogate materials. The tools, which include various hydraulic fracturing and slurrying techniques, were all able to dislodge and transport the anticipated waste forms. Further study of short-term and interim storage technologies will be required.

Various dislodging and transport concepts have been developed and have been evaluated at Hanford for their ability to meet established "essential" and "wanted" criteria. These evaluations have led to the identification of a series of concepts for dislodging end effectors operating on the end of a robotic boom and coupled to an airlift transport system for further engineering study and evaluation. This equipment is specified in Attachment 2. Attachment 3 describes the development of this report.

This work was a follow-on to the WHC study that defined the following subsystems for further engineering design:

- **Waste Dislodging System**
    - Soft waste dislodging equipment
    - Hard waste dislodging equipment

  - Rubble-forming equipment
  - Post-rubble forming equipment
  - Gleaning equipment

- **Hardware Handling System**
  - Large cutter end effector
  - Small cutter end effector
  - Gripper end effector
  - Lifting lanyard

- **Conveyance System**
  - Waste conveyance system
  - In-tank hardware conveyance system

Westinghouse Hanford Company has overall responsibility for specification of the design function guidelines and specifications. Lawrence Livermore National Laboratory (LLNL) and Sandia National Laboratories provided engineering and design support to design subsystem elements that met the performance and function guidelines and specifications. Following two planning meetings with the UST-ID, Sandia National Laboratories was assigned the work scope related to the Hardware Handling System because of their experience and ongoing work in the area. Lawrence Livermore National Laboratory was assigned responsibility for the hard waste dislodging equipment of the Waste Dislodging System. The soft waste dislodging equipment was assigned to the Westinghouse Hanford Corporation. This work was begun in FY 1992 and provided for support to WHC effort to develop waste retrieval technologies needed for the national Underground Storage Tank Integrated Demonstration (UST-ID). In a multiyear effort, this task was to perform development, demonstration, testing, and evaluation resulting in waste dislodging system elements to be used in the UST-ID.

TTP SF-221205, *UST Waste Dislodging and Conveyance Technology Development*, provided two major thrust areas to accomplish these goals. The first step was to identify, select, develop, and test candidate waste dislodging concepts. The second step was to identify, select, develop, and test candidate simulating materials and conglomerate models with which to validate performance of the waste dislodging system. The first milestone, completed at the end of February 1992, involved review of the WHC criteria and specifications and familiarization with UST operating conditions and constraints. The development of a Market Survey, creation of the Exceptional Procurement Action, providing a Sole Source Justification, and the formulation of a Hydraulic Impact End Effector System Specification (MEL92-001809-00) were all completed in support of the design review (Attachment 4) held in March 1992 before procurement of the HYDREX unit from QUEST Inc. The contract with QUEST was placed and design reviews (with participants from LLNL and WHC) were held. Testing was completed at QUEST to demonstrate the practicality of using ultrahigh-pressure (UHP) technology for removal of adherent waste and to determine the removal rates, fragmentation sizes, dilution levels, cycle rates, dead weight loads, and reaction forces to be expected. Attachment 5 gives the results of this testing. This equipment was shipped to WHC in August 1992 and operated successfully in the Robotics Technology Demonstration Program (RTDP) Demonstration carried out at the UST Testbed.

Efforts in FY 1993 were initially directed along two fronts. The first was to better understand the performance of the hard waste dislodging system as it applied to removal of material from large masses of salt. The second was to investigate the use of alternative fluids as the hydraulic fracturing medium of the end effector. The use of UHP water adds water to the waste tank. Efforts have already been made to minimize water use by operating at the highest possible pressure and by timing the control valves to reduce water loss during venting and charging. The elimination of water altogether through the use of a fluid that vaporizes at ambient temperature was regarded as a very beneficial possibility. With this approach, rapid vaporization of the high-pressure fluid after it exits the end effector converts it to a gas, making it suitable for treatment by an air filtration system. Candidate fluids were to be evaluated for potential use and their expected impact on system components evaluated. QUEST has experience with using various fluids in the UHP system and was well positioned to provide alternatives to water. This work was also to include LLNL concepts for reducing water volumes introduced into the tanks by using materials that gel after discharge.

Several changes in the UST-ID focus in FY 1993 resulted in a rescoping of the UHP development program. The first was a renewed interest in confined sluicing, relaxing the emphasis on "dry" techniques. The second was the selection of a sludge tank for the first target remediation, pushing the need for a salt-fracturing tool past the year 2000. Therefore, upon agreement and at the direction of the UST-ID, the alternative UHP fluid system effort was terminated, and QUEST was instructed to discontinue work in this area.

Fiscal Year 1992 Completion Efforts

• Formally reviewed WHC specifications and environmental requirements	February 1992
• Completed and reviewed design concept for a rubble-forming tool	March 1992
• Placed contract for design of HIEE	April 1992
• Provided complete design review package	May 1992
• Fabricated and assembled HIEE	June 1992
• Completed in-house testing of HIEE at QUEST	July 1992
• Shipped HIEE to WHC	August 1992
• Successfully demonstrated HIEE in RTDP Demonstration	October 1992

Fiscal Year 1993 Effort

The HIEE was successfully demonstrated in FY 1992 as a tool capable of fracturing hard salt cake. Previous testing evaluated the feasibility of water-blast removal of adherent waste but did not fully optimize the process. Work in FY 1993 was focused on performance testing to evaluate the effect of nozzle geometry and firing pattern on the tool's removal rate.

Task Milestone Summary

Performance Testing Program

• Modifications of tool completed	May 1993
• Performance testing on tool completed	June 1993
• Test results transferred to other groups (key milestone)	June 1993
• Test reports completed	September 1993

Objectives

Performance Testing Program Objectives

As reported in the FY 1992 test report (Attachment 5), fracturing was significantly increased by increasing the pressure from 40 to 55 kpsi, which increased the shock energy per unit volume of the hydraulic impact. Tests will be conducted on approved waste simulants to quantify tool improvement at 55 kpsi. The tests (Attachment 6) would be a subset of those previously made to determine the tool's concept and will include such attributes as standoff distance and interface loads (i.e., loads at the interface between end effector and robot arm). The primary effort will be in correlating the volume and size of fragments to the dilution of tank contents by water from the HIEE. Existing specifications or requirements, such as those contained in the WHC Functions and Requirements document, will be used to determine the ideal size and distribution targets. As information from other projects (such as the ongoing conveyance system development) becomes available, targets will be changed and additional testing will be done as required. The geometry of the tool outlet will be evaluated to direct the energy more efficiently for spalling action. Various outlet configurations (e.g., wedge- or slot-shaped) will be tested for their effect on fracture patterns. Shock energy can be increased by increasing the internal volume of the end effector. This approach may be effective if combined with containment of the fluid flow. The containment serves to resist fluid outflow and thus increases pressure within the hole. The addition of a seal between the tool outlet and the water surface will be evaluated and tested. Multiple shots on the surface may produce more small fragments. If a single shot does not remove much material, the crater that is created may be a weak point for the surrounding shots. Fractures may also propagate from shot to shot. Thus each shot should remove (fragment) the material between it and the surrounding craters.

Technical Approach

Performance Testing Program Technical Approach

Changes required to operate the tool 55 kpsi will be completed at QUEST. The redesigned tool outlet will be tested after modifications by QUEST. These tests will be similar those carried out in FY 1993. LLNL will provide a testbed for full performance testing of the 40-kpsi tool; LLNL will test tools with improved outlet designs, provided by QUEST, for removal rate and fragmentation size and distribution. The major difference between these tests and those performed earlier will be that the density, strength, and particle size of the simulant materials will be characterized by Pacific Northwest Laboratory (PNL) to ensure that all hard-waste dislodging tasks are using simulants of the same strength. A more detailed analysis of the fragment distribution will be made to provide data, as required, to the tasks working on waste conveyance. Test results will be documented, and recommendations for required future work will be made.

Milestones

Performance Testing Program Milestones

The four FY 1993 milestones involve enhancements of the HIEE to provide test data on fragment size and distribution. This information will be provided in a timely manner to the conveyance, simulant development, and long-reach manipulator groups and to other working groups as necessary.

- Tests will be conducted on approved waste simulants to quantify tool performance improvement at 55 kpsi. A performance comparison will be completed and documented in a test results report.
- The geometry of the tool outlet will be evaluated to direct the energy more efficiently for spalling action. Configurations will be evaluated and their performance quantified. The effect of nozzle outlet configuration will be documented in a test results report.
- Containment of fluid flow (by addition of a seal between the tool outlet and the waste surface) will be evaluated and tested for improvement of shock energy. Results will be documented in a test report.

Funding Basis

The performance testing part of the task was performed at LLNL using existing equipment after modifications at QUEST. It is estimated that this part of the task is approximately $50K at QUEST and $190K at LLNL. The alternative UHP fluid system part of the task was to have been performed at QUEST and was estimated at approximately $60K. After the FY 1993 change in scope, funds allocated for UHP alternative-fluid studies were recovered and redirected to cover increased expenses incurred because of equipment failures, delayed completion of testing, and decommissioning of the test facility required by project termination. These costs approximate the $300K funding level for FY 1993.

Testing

Specific Tests

- Tests were conducted at 40 and 55 kpsi to determine the effect of increasing the HIEE's charge pressure. Four impacts were made at each pressure on 1-ft^3 (50-lb) samples with a standoff distance of 2 in. between nozzle tip and material. (This distance was found in FY 1992 tests to be roughly optimal within a fairly broad range of standoff distances that gave good fragmentation.)
- Three outlet geometries approved by LLNL were tested at 55 kpsi to determine the effect of outlet geometry on material removal (particularly fragment size), amount removed, and removal pattern. Four impacts were made with each geometry; again, tests were made on 1-ft^3 samples with a standoff distance of 2 in.
- Tests were conducted at 55 kpsi with HIEE discharges into sealed and unsealed blind holes in 2000-lb samples to determine the effect of containing the discharge fluid within the material. For these tests, which again consisted of four shots each, the nozzle tip was placed at the bottom of a hole drilled to a depth equal to the nozzle length. A seal between the outer diameter of the nozzle and the wall of the hole was designed, manufactured, and emplaced for the sealed-hole tests.
- Tests were performed to evaluate the effects of impacting an area that has multiple free faces near one another. A successive impact pattern was designed with a view to propagating multiple free face areas. The test of the pattern approved by LLNL consisted of at least 12 55-kpsi impacts on an 8000-lb sample at a standoff distance of 2 in. Sample weights were recorded before and after the entire shot series to determine the net effect of the multiple impacts.
- A test was performed to evaluate the effect of fragmentation pattern on rubble size. A successive impact pattern was designed with a view to minimizing rubble size. The test consisted of at least twelve impacts based on an LLNL-approved pattern. Impacts were made at a charge pressure of 55 kpsi and a standoff distance of 2 in. The test were conducted on a 2000-lb sample.

Data Recorded

Data recorded included the following:

1. Weight of sample before test.
2. Weight of sample after test.
3. Size and weight of fragments over 2 in. in any dimension.
4. Charge pressure.
5. Comments on problems encountered and/or suggestions for improvements in end effector design or operating procedure.

6. Videotape recording of discharge impact.
7. Photographs of test area before and after test.

Data were recorded on a preprinted data sheet (Attachment 7).

Safety

All testing was conducted in a manner that ensured the safety of operating personnel and observers. The test area was isolated and appropriate warning signs were posted.

Results and Accomplishments

LLNL Accomplishments

The hydraulic impact end effector (HIEE) was installed in Room 1102 of Bldg. 169, which has an on-grade slab floor. The pump set was installed in Room 1200 of Bldg. 169. Before operation of the system, an Operational Safety Procedure (OSP), an Engineering Safety Note (ESN), and an Engineering Note (EN) were written and approved. These three publications are described below.

The OSP (No. 169.08, Attachment 8) was written because the use of the HIEE system was not authorized by existing procedures and could present hazards not completely addressed by the LLNL *Health and Safety Manual*. The OSP authorizes the use of the HIEE system for experiments to determine the effectiveness of the equipment to break up simulated salt cake. Potential hazards associated with the operation of the HIEE addressed in the OSP included high-pressure, electrical, noise, lifting, and chemical hazards. High-pressure controls used to reduce the risk to personnel and the environment to an acceptable level included requiring a ESN, retesting of high-pressure hoses, implementation of the "Lock and Tag" procedure during maintenance operations, administrative control of access to the HIEE experimental area, door interlocks to disable the HIEE, a debris barrier to protect personnel, and enforcement of a two-person rule. All work with electrical equipment must comply with the provisions of the LLNL *Health and Safety Manual* (Chapter 23, "Electricity," and Supplement 26.13, "General Lock and Tag Procedures") and the Engineering *Electrical Safety Policy*. All participants were trained in control of noise hazards by Industrial Hygiene Team 6 before startup. Hearing protection (ear muffs and ear plugs) was worn at all times during firing. Personnel access to the mechanical room was restricted. Noise placards were posted at all entrances to noise-hazard areas. A strobe light outside the entrance to experimental area was activated during tests. Lifting devices were rated for the loads to be lifted and were inspected and load-tested in accordance with applicable portions of the *Health and Safety Manual*. The powdered materials from which sample blocks were formed (described in more detail below) were mixed outdoors. Employees worked up-wind from the materials, minimized the creation of dust, and wore chemical goggles and butyl rubber gloves during mixing. All effluents (water and salt cake) were contained to prevent entry into a storm drain or sanitary sewer. All spills were wiped up and the cleanup materials disposed of with the process effluent. Disposal procedures were determined by the Environmental Analyst, and the materials were handled as hazardous waste according to policies and practices outlined in the LLNL Environmental Protection Department's *Guidelines for Waste Accumulation Areas* (UCAR 10192/Rev. 1) and the *Preparation Guide for Generators of Hazardous Chemicals and Radioactive Waste at LLNL* (March 1987). All authorized operators completed required safety courses including fire extinguishers, noise, pressure safety, and the lock and tag procedure.

The ESN (ENE93-906, Attachment 9) was written to document the HIEE system and to address safety concerns dealing with a high-energy system. The *Health and Safety Manual* requires that safety notes be prepared for all equipment with liquid pressures greater than 1500 psi. Failure to properly support the HIEE during testing could create local life safety hazards, so the test stand is in seismic hazard category II

(Sec. 5.2, *Mechanical Engineering Design Safety Standards Manual*). The test stand is fully described in Engineering Note ENE93-079, described below. The ESN (Attachment 9) describes hazard mitigations such as testing the high-pressure hoses at 150% of the maximum allowable working pressure (MAWP) in the LLNL High Pressure Laboratory, incorporating a shrapnel barrier, and wrapping rigging straps around the cross-member of the test stand and under the HIEE whenever the strain bar (described below) is in place.

The EN (ENE93-079, Attachment 10) was written to document the design of the test stand that supports the HIEE. Calculations were made to prove the adequacy of the test stand. All components met or exceeded LLNL safety standards except the strain bar, a thin-walled cylindrical tube used to measure reaction loads; this tube, which supported the HIEE during impact load tests, had a safety factor of 1.1 under operating loads. To add support for the HIEE in case of a catastrophic failure of the tube, Willer brand rigging straps are wrapped around the cross member and under the HIEE.

The test area met the requirements of the OSP, the ESN, and the EN. Test samples were made from Western AG-Minerals Company's K-MAG. Attachment 11 is the MSDS for this material, a potassium magnesium sulfate composition suggested by M. Elmore of Pacific Northwest Laboratory (PNL) as a surrogate material for testing. In a cement mixer, 86 parts (by weight) of K-MAG were mixed with 14 parts of water, and the mixture was poured into target and sample molds. Targets of 1 ft^3 and samples approximately 2 and 4 in. in diameter and 8 in. long were initially cast. These were air-dried for at least a week before testing was begun.

The testing apparatus and targets were ready before the instrumentation was completed, so testing proceeded with the solid HIEE attachment to evaluate the effect of excavation patterns on material removal rates. The first pattern tested was an "X" shape, starting in the lower right of the restrained 1-ft^3 simulant target sample and continuing upward and across to the upper left corner. Spacing between shots was approximately 2 in. Twelve shots were made at 40 kpsi with a 2-in. standoff. The only material removed was at the corners, where small chunks were dislodged; otherwise the firing of the tool resulted only in the drilling of a hole about an inch deep. The second series was a duplicate of the first "X" series; fourteen shots were fired, and no appreciable spalling occurred. The third test evaluated a spiral pattern; 19 shots were made starting at the center of the target. There was some spalling, but only when the shot was near a free surface, such as a corner. These test results are shown in the photographs of Attachment 12.

A test firing of the HIEE was made to determine the possible effect on surrounding concrete in the UST tanks of an inadvertent HIEE discharge directly onto the steel wall of the tank. A 1-ft^3 waste simulant sample, nearly filling a cubical steel box with no top, was used as the target. The outside of the steel casing was struck normally, with the tool lying in the plane of the sample surface; no fracturing or change to the surface resulted.

Using a three-way transducer (Attachment 13) similar to that used by QUEST in earlier testing, LLNL testing verified the reaction loads of the HIEE firing. To calibrate the transducer, known weights were applied in orientations to provide bending, torsion, and tensile loading of the transducer. A computer program was set up to record the responses from the strain gages. The test fixture was mounted horizontally for the bending and torsion measurements and vertically for the tensile measurements.

Testing was terminated because filters in the water supply line became plugged. While new filters were being procured, the instrumented portion of the testing proceeded. Only one firing was made with the new filters before trouble with one of the two UHP pumps again halted testing. The pump tripped out at pressures above 15 kpsi. Numerous trials were made trying to get the pump to attain a higher pressure with no success. A trial run was made using the remaining functioning pump, but it could not supply enough water volume to force the poppet closed during initial pressurization. Because of the limited remaining time and money and the good correlation between LLNL tests and those at QUEST, it was decided to terminate testing at LLNL rather than to incur additional repair costs.

There was initial confusion as to exactly what size material samples for simulant confirmation testing at PNL should be provided. Because it was stated that exact dimensions must be adhered to for material testing at PNL and because the existing material test samples were only slightly larger, there was not time to produce additional test target and samples, it was decided to test the existing material samples for shear and compression strength at LLNL. These tests indicated that the compressive strengths of the materials (Attachment 14) were in the 3000 psi range based upon material test samples that were three months old with no attention given to their storage conditions. Shear strengths (Attachment 15) of similar material test samples were about 400 to 600 psi. Both the compression and shear strengths are lower than measured values provided by PNL for K-MAG salt cake simulant.

QUEST Accomplishments

In June 1993, QUEST prepared 24 1-ft^3 test samples and one 2000-lb sample. The hydraulic impactor to be used at QUEST, which was designed to operate at 55 kpsi but had not been used for several months, was torn down and inspected for use. A spacer to make the volume of the QUEST impactor equal to that of the LLNL impactor was designed and manufactured. This spacer was required to ensure that baseline testing of the QUEST impactor at 40 kpsi would be equivalent to that of the LLNL impactor, which was designed to operate at 40 kpsi. Worn components of the QUEST impactor were replaced and the impactor was reassembled. QUEST produced a test plan (Attachment 16), which was approved by LLNL.

In July 1993, QUEST completed preparation of a second 2000-lb test sample and of a single 8000-lb sample. The design of a straight nozzle, a converging nozzle, and a diverging nozzle (Attachment 17) were begun. The straight nozzle is shorter than the nozzle previously used in an attempt to reduce resistance and increase water slug energy. The converging nozzle is designed to increase the slug's specific energy by accelerating it through the tapered section. The diverging nozzle may improve fragmentation by spreading the blast over a larger area, and should provide some control of the direction of fracture. The baseline pressure comparison tests between 40 and 55 kpsi were begun.

In August 1993, QUEST completed the 40-kpsi baseline tests, the 55-kpsi standard nozzle tests, and the alternative design nozzle tests, and began design and manufacture of the nozzle-to-hole seal. Data sheets for this testing (Attachment 18) show that the converging nozzle produced more suitably small fragments and larger spalled areas than the other nozzles tested. The three-hole nozzle fragmented the salt cake well, splitting two of the test samples completely in half.

In September 1993, QUEST completed the drilled-hole tests. Discharge into unsealed holes gave the best results (see Attachment 18). In all three discharges into sealed holes, the simulant block fractured into large chunks, rather than into small fragments. Five discharges into unsealed holes produced smaller fragments than those produced by the sealed hole tests and produced additional, smaller fragments. The excavation pattern test portion of the HIEE test procedure determined the effect of multiple shots on the surface of an 8000-lb sample. On the previous surface tests, the shots produced a small crater in the sample. Also, on many of the samples tested, fragments from 1 to 12 in. were created. The excavation test used a multi-shot pattern to increase small fragment development. In the pattern chosen (SK3006, Attachment 19), the excavation follows an involute curve. This spiral pattern was laid out and discharges were conducted in 28 locations at a 2-in. standoff distance. This produced little fragmentation; instead, it bored into the block to a depth of about 1.5 in. The same pattern was then again laid out and holes 1 in. deep were drilled into the target. Discharges were then made into the holes resulting in spalling of the surface and some fragmentation. However, after 14 discharges, the QUEST unit quit discharging. QUEST completed repairs on the unit and resumed testing of the patterns. They completed their testing and provided a final report, QUEST Technical Report No. 601 (Attachment 20), in November. Video tapes of the QUEST testing are included as Attachment 21.

Conclusions and Recommendations

The key results from these tests are:

- Increasing the charge pressure from 40 to 55 kpsi increases the material removed per shot. The number and size of the fragments increased with increasing pressure, as did the size of the craters on samples that did not fracture.
- There is little danger of fracturing the surrounding concrete tank lining when discharging the HIEE to dislodge hard cake wastes.

- The alternative nozzle designs used were much more effective at dislodging larger amounts of material than the original nozzle design. The diverging nozzle increased the impact area on the test samples, thus creating larger craters and greater fragmenting ability. The three-hole, in-line nozzle tended to cleave the samples in half and create narrow, deep craters. The converging nozzle showed the most promising results: the craters were deeper, the spalled-off areas were larger, and the samples fractured more easily.
- Inserting the nozzle into holes bored in the samples caused a large amount of fracturing. In many cases, the fragments tended to be quite large dependent upon the location of the free edges of the sample. The deeper the hole, the larger the fragments produced. Shallow holes tend to shatter the simulant rather than fracturing it.
- The use of a spiral pattern with the insertion of the nozzle into holes was to be a very successful technique for removing large quantities of small-sized material. Without the holes, insufficient fracturing occurred, preventing the pattern from providing any net benefit.
- The use of multiple shots in the same area was shown to successfully fragment large-sized samples. HIEE is a drilling tool. When the hole gets to a certain depth, the material fractures in half. This was observed with the rubble destruction tests. With this procedure, very large samples can be systematically broken down into small-sized rubble. This method can also eliminate the need for drilling holes to fracture large materials.

The HIEE can quickly fragment large-scale salt cake simulant materials into small, easily removable fragments. The HIEE's fragmentation ability can be substantially increased through the use of different nozzle geometries and firing patterns.

The following recommendations are made for future testing:

- Further work needs to be done in nozzle design. These tests show that nozzle geometry has a major effect in material fragmentation. Additional nozzle geometries should be tested to find an optimal configuration, or a set of nozzles should be tested for a particular application. Depending upon the desired result (e.g., fracturing large monoliths, further size reduction of independent chunks, drilling holes, or producing smaller fragments), possible nozzle designs include a four-hole, square-array nozzle, a converging nozzle with a smaller outlet, or a nozzle with a wider row of holes.
- Further investigation into multiple shots for hole drilling to fracture the simulant, as opposed to predrilling the holes, should be conducted. This should be done using very large samples. Samples under 600 lb can be fractured easily with this method.

Attachments

Attachment number	Title/Description
1	Retrieval Technology Study Summary
2	WHC-SD-WM-FRD-004
3	Support Documentation for FRD-004
4	Design Review
5	QUEST Report No. 355
6	Specific Tests to Improve Tool
7	Sample Data Sheets
8	OSP
9	ENE93-906
10	ENE93-079
11	MSDS
12	LLNL Test Photographs
13	Three-Way Transducer
14	Compression Strengths of Samples
15	Shear Strengths of Samples
16	QUEST Test Plan
17	Three Nozzle Designs
18	Base Line Data
19	QUEST Excavation Pattern, SK3006
20	QUEST Final Report No. 601
21	Video Tape (provided separately)

ATTACHMENT 1

Review of Previous and Current Work

Contents

1. Introduction

Management of the radioactive waste in the underground storage tanks has included both long term and interim programs. The long term program studies, defines, and develops alternatives for the ultimate disposition of the tanks. Final closure of the tanks farms is expected to require at least some retrieval of the waste.

Single-shell tank waste was retrieved during the strontium and cesium recovery program in the 1960's. Waste has also been retrieved as part of the interim stabilization program, which reduces the liquid content of tanks. This program was started after the strontium and cesium recovery program and has produced a less fluid, harder waste. All tanks are expected to be interim stabilized before large scale retrieval begins.

Several methods for retrieving SST waste have been proposed and studied in the past. Some of the more pertinent studies related to SST waste retrieval are summarized below.

2. Vitro-R-375

Vitro, 1975, *Evaluation and Adaption of Standard Mechanical, Hydraulic and Pneumatic Devices for Saltcake and Sludge Retrieval at Hanford*, Vitro–R–375, Vitro Engineering, Richland, Washington.

This study presents the results of feature tests of commercially available equipment for mechanical, hydraulic and pneumatic retrieval on simulated SST waste. Recommendations for the design features of a follow-on system for in-tank testing are also included.

A Gradall 660 hydraulically actuated boom-mounted excavator was selected for testing as the mechanical system. The field tests performed, using simulated wastes, showed the system capable of breaking up and loading concrete, soft sludge, jelly-type saltcake, and diatomaceous earth reacted with caustic liquid.

The hydraulic system tested consisted of a 10,000 psi water jet operating at 4-5 gallons per minute. The water jets successfully broke up and emulsified hard salt cake and reacted clay-caustic simulants.

The pneumatic system consisted of a commercially available high volume vacuum unit that picked up simulants and transported them 60 feet vertically. The simulants successfully transported were the emulsified products produced by the water jets as well as sludges and saltcake.

Recommendations for future work included development of a large central arm attached to a Gradall excavator for positioning pumps, tools and jets within the SST.

3. ARH-LD-144

Wallskog, H. A., 1976, *Program of the Hanford High-Level Waste Retrieval Task*, ARH–LD–144, Atlantic Richfield Hanford Company, Richland, Washington.

This report is a narrative description of the project to mechanically mine the wastes from the SSTs. The report also discusses the features of a mechanical retrieval system including an articulated arm, retrieval tools, conveyance system, above ground support facilities and a television viewing system. The requirements for a full scale test facility are also presented. The majority of the data presented in this report is still valid and will be useful in development of a SST waste retrieval system. This study is the first of four leading to the completion of the design of a prototype mechanical waste retrieval system.

4. ARH-C-20

Prototype Waste Retrieval System, Conceptual Design - Final Report, ARH-C-20, PaR Systems Corp., St. Paul, Minnesota, May 1977.

This is the second study in the series leading to the design of a prototype waste retrieval system. This is essentially a conceptual design report prepared by Programmed and Remote Systems Corporation (PaR) of St. Paul, Minnesota. This is the conceptual design of the system that has been referred to as the "Wallskog" design.

5. RHO-C-43

Final Report Prototype Waste Retrieval System Engineering Design, RHO-C-43, Nuclear Systems Associates, Inc., Brea, CA, Feb. 1980.

This 20 volume document is the final design data for the prototype SST waste retrieval system. A series of drawings (SK-2-6000 through SK-2-6054) were also developed by the design vendor, Nuclear Systems Associates of Brea, CA. The design developed by this effort consists of a large above ground structure that straddles a single shell tank and rests on a 3 tracked vehicles. The structure houses a waste preparation area and includes a tower for raising a large robotic arm into. The retrieval tools are operated on the robotic arm through a 42" diameter opening in the center of the SST.

6. RHO-ST-33

Strickler, J. K., H. A. Wallskog, and J. R. Wetch, 1980, *The System for Retrieval of Solidified Hanford High-Level Defense Wastes*, RHO–ST–33, Rockwell Hanford Operations, Richland, Washington.

This is the fourth and last document in the series leading to the design of a prototype waste retrieval system. This report is a description of a retrieval system design and a presentation of waste and SST characteristics, summary of design criteria and a discussion of the relative merits of sluicing and mechanical retrieval systems. This study contains much data that is as valid today as it was in 1980.

7. ARH-CD-935 and ARH-CD-273

Arnold, N.M., 1977, Scumbuster Pump Test Series Analysis, ARH-CD-935, Atlantic Richfield Hanford Company, Richland, Washington.

Arnold, N. M., 1978, *Fabrication and Testing of an Experimental Slurry Elevator for Use Within Single-Shell Hanford Waste Tanks*, ARH-CD-273, Atlantic Richfield Hanford Company, Richland, Washington.

Additional studies concerning tank waste retrieval were done between 1977 and 1981. These studies dealt mainly with retrieval systems other than mechanical retrieval. Studies ARH-CD-935 and ARH-CD-273 described the fabrication and testing of a hydraulic system to remove tank waste once it had been recovered mechanically. After being placed in the slurry elevator, the waste's solids would be reduced and the slurry batch homogenized. The slurry would then be pumped to the surface by a pump for high solids content liquids.

8. RHO-CD-1533

Janicek, G.P., 1981, *Equipment Development Study for Hydraulic Recovery of Single-Shell Tank Sludges*, RHO–CD–1533, Rockwell Hanford Operations, Richland, Washington.

The RHO-CD-1533 study reconsidered hydraulic recovery. The management program at the time called for as much in situ disposal as possible. Fewer tanks would require retrieval, and a less sophisticated system could be used. The waste would be retrieved for 1) consolidation of waste, 2) recovery of high heat sludges for thermal considerations, or 3) to recover high transuranic (TRU) or high risk wastes that cannot be disposed of in-situ.

Two hydraulic methods developed were "confined" and "limited" sluicing. Confined sluicing consisted of a bell shaped sluicing module manipulated within the waste tank by a four segment articulated arm. High pressure water jets in the sluicing module slurried the waste beneath the module and a self contained vacuum system or pump removed the slurried waste. The sluice module is similar to commercial scarifiers used to remove paving from bridge decks.

The limited sluicing concept placed water jets at the periphery of the tank to move the waste to the center of the tank and to form a slurry. The slurried waste would then be pumped out of the tank by a pump installed in a center riser. The theory behind limited sluicing was that moving the waste toward a pool in the center of the tank by a water jet would reduce the potential for leakage from the tank.

9. WHC-EP-0352

Krieg, S. A., W. W. Jenkins, K. J. Leist, K. G. Squires, and J. F. Thompson, 1990, *Single-Shell Tank Waste Retrieval Study*, WHC–EP–0352, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0352 (June 1990) was an extensive effort in reviewing and documenting waste retrieval methods. This study reviewed waste retrieval technologies related to pumping, sluicing, air transport, and mechanical mining. Three pumps, a pneumatic system and a mechanical system were recommended for testing and evaluation.

Two basic methods were considered: sluicing and mechanical retrieval. The study determined that sluicing would require little development for retrieval but would require some development for precluding further tank leakage during sluicing operations.

Mechanical retrieval concepts center on the devices used for maneuvering the retrieval equipment. With proper end effectors, the maneuvering system can remotely cut up in-tank hardware, remove debris and waste, recover solid waste, clean tank walls, and load waste into conveying systems for transport out of the tank.

Maneuvering systems considered were articulated arms, telescoping arms, a link arm, and self propelled vehicles. Deployment methods for the arms varied from the standard installment through a 42 inch riser, to larger diameter holes with a turret-mounted arm, to support systems within the tank. Self-propelled vehicles were not recommended because of the uneven surfaces and inconsistency of the waste. Support systems within the tank were not recommended because of load restrictions on the tank liner.

10. WHC-SD-ER-DA-001

Croskrey, N.R., Jaquish, W.R., Jenkins, W.W., Krieg, S.A. and Leist, K.J., 1991, Retrieval Equipment Concept Selection Decision Analysis, Westinghouse Hanford Co., Richland, WA.

This document is a decision analysis performed to identify the more practical concepts for retrieving waste from a SST. Eleven alternatives were identified as viable concepts for the analysis. The analysis concluded that the most desirable retrieval methods were: (1) A large mechanical arm operating through the smallest practical size opening in the center of the tank; and (2) A crane mounted manipulator arm operating through a 48-foot diameter hole in the center of the tank.

11. TRAC-0247

Klem, M.J., *Peer Review of Single-Shell Tank Waste Retrieval Concepts*, July 1991, Westinghouse Hanford Co., Richland, WA.

This memo documents the peer review results from a multi-laboratory peer review of three SST retrieval concepts. Peer Review Team members were from Pacific Northwest Laboratory, Sandia National Laboratory, Oak Ridge National Laboratory, Idaho Nuclear Co. and Westinghouse Hanford Co. The three concepts reviewed were: (1) Hydraulic sluicing; (2) A mechanical arm operating through an opening in the center of the tank; and (3) A bridge mounted manipulator arm operating through a 48 foot diameter hole in the top of the tank.

The team recommended that the mechanical arm operating through an opening in the center of the tank was the best way to proceed. They also recommended that an air conveyance system be developed for removing waste from the tank.

ATTACHMENT 2

WHC-SD-WM-FRD-004
REV C

FUNCTIONS AND REQUIREMENTS
IN-TANK PROCESSING EQUIPMENT

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Richland, Washington

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FUNCTIONS AND REQUIREMENTS
IN-TANK PROCESSING EQUIPMENT

1.0 INTRODUCTION

1.1 SUMMARY

Over the course of the last 40 years, high-level radioactive liquid wastes, resulting from the production of plutonium for national defense, have been stored underground in single-shell tanks (SSTs) at the Hanford Site near Richland, Washington. Interim stabilization activities have removed much of the liquid from the tanks, leaving waste deposits in the form of sludge and hard cake. Each SST is of carbon steel lined, reinforced concrete construction with capacities ranging from approximately 500,000 gallons to one million gallons; some are nearly empty, some are about 90% full. Hanford Federal Facility Agreement and Consent Order, an agreement among the Washington State Department of Ecology, The U.S. Environmental Protection Agency, and the U.S. Department of Energy (DOE), calls for demonstrating the capability of removing waste from one of these tanks. A demonstration tank will be selected from one of the 149 SSTs at Hanford. The task of removing the waste will require the development of several interdependent systems and subsystems. It is not the intent of this document to define each of these various systems, but instead to stay within the limitations of the scope specified below.

1.2 SCOPE

The purpose of this document is to establish functions and requirements for the design of the In-Tank Processing Equipment (IPE) only. The In-Tank Processing Equipment encompasses that equipment which interacts directly upon the waste and/or the In-Tank Hardware (ITH) located inside the Single-Shell Tank (SST), in order to accomplish removal of the waste and certain ITH from the SST. It should be noted that all requirements are based on the assumption that a mechanical system of waste retrieval will be chosen after the selection process is complete. Should an alternative method of waste retrieval be chosen instead, the contents of this document may no longer be valid.

Not addressed by this document are the operations support facility, the in-tank maneuvering arm and control systems that are required to move the IPE end effectors about inside the tank, and the various process and transportation systems for ultimate waste disposal after it has been retrieved from the tank; these systems will be defined by other documentation.

The IPE is divided into three basic sub-systems; i.e., 1) Waste Dislodging System, 2) ITH Handling System, and 3) Conveyance System. The Functions and Requirements applicable to the design and operation of each of these sub-systems are provided in the following sections of this document.

1.3 DEFINITIONS

The following acronyms and definitions are applicable to this document.

IHS	ITH Handling System (IHS). That equipment used specifically to effect the severing and/or manipulation of ITH within the tank.
IPE	In-Tank Processing System (IPE). The overall system of equipment directly used to dislodge and convey waste and ITH from inside the SST, not including the in-tank maneuvering system. All equipment defined in this document is in one of the IPE subsystems.
ITH	In-Tank Hardware (ITH). The SST being processed may contain various items of scrap metal, tools, or other articles that have been tossed into the SST as radioactive "scrap". In addition, there are various structures that comprise a portion of the SST itself, that may require removal in support of waste retrieval operations. All such scrap and structures are considered to be ITH and are to be regarded and processed as solid waste after its removal from the SST.
OSF	Operations Support Facility (OSF). The OSF is a large containment structure located over, and sealed to, the opening(s) in the SST. It provides structural support and confinement for the IPE. The OSF may also permit operation and maintenance activities on the many of the IPE components.
SST	Single Shell Tank (SST). Those tanks at Hanford, of single shell construction, which are to be subject to waste retrieval operations. Unless otherwise indicated, the usage of the word "tank" in this document refers to the SST.
Waste	In this document the term "waste" refers only to those chemical compounds stored in the SST, which were the result of past processing of nuclear materials, and does not include the various ITH also found within the tank.
WDS	Waste Dislodging System (WDS). That equipment used to dislodge waste from the SST and/or transfer it to the Waste Conveyance System.

2.0 FUNCTION DESCRIPTION, IN-TANK PROCESSING EQUIPMENT

This section provides a general description of the functions to be accomplished by each of the three basic subsystems of the IPE (i.e. the Waste Dislodging System, the ITH Handling System and the Conveyance System). The actual configuration of the hardware to accomplish these functions is not yet defined. Likewise, selection of the method used to deploy the various end effectors in the tank has not yet been finalized at this time, and is a separate task beyond the scope of this document.

However, the various end effectors will be deployed inside the tank by some type of maneuvering arm, and will require service lines, electrical cables, etc. to be attached to them. The methodology of attaching/detaching the end effectors to the maneuvering arm, and the routing and attachment of the services to them is not yet determined. As the deployment method becomes more clearly identified, this document will be updated to comply. It is anticipated that the method of end effector attachment/detachment and service routing will not have significant impact on any development work done up to that time, and can readily be incorporated into the final designs.

2.1 FUNCTION DESCRIPTION, WASTE DISLODGING SYSTEM

The Waste Dislodging System (WDS) encompasses that equipment which interacts directly upon the waste in the SST to effectively loosen it and/or process it such that it can be removed from the tank by the Waste Conveyance System (see Section 2.3.1). In this section the term "waste" refers to only those chemical compounds stored in the SST, which were the result of past processing of nuclear materials, and does not include the various In-Tank Hardware (ITH) described in Section 2.2. Waste may be in the form of either hard waste (e.g., dried salt cake, dried sludge, etc.) or soft waste (e.g., soft salt cake, moist sludge, liquids, etc.)

The WDS equipment is divided into five basic groups; i.e., 1) Soft Waste Dislodging Equipment, 2) Hard Waste Dislodging Equipment, 3) Hard Waste Rubblizing Equipment, 4) Post-Rubblizing Equipment, and 5) In-Tank Cleaning Equipment. A general description of each of these five groups of WDS equipment is provided in the following sub-paragraphs.

2.1.1 Function Description, Soft Waste Dislodging Equipment

Large quantities of the waste found in the tanks is soft waste in the form of soft cake, sludge and/or liquids, as described in Section 3.0. The end effector required to dislodge this material is attached to the end of the In-Tank Maneuvering Arm while the arm is positioned at the end effector storage/changeout station.

The In-Tank Maneuvering Arm positions the end effector into its operating position over the soft waste. The end effector then agitates the soft waste, captures the portions so loosened up, and transfers it into the Waste Conveyance System (see Section 2.3.1). Agitation of the soft waste may be by high pressure liquid, high pressure gas or mechanical means; or any combination thereof. The soft waste exits the tank through the Waste Conveyance System.

2.1.2 Function Description, Hard Waste Dislodging Equipment

Much of the waste found in the tanks is in the form of hard cake, as described in Section 3.0. The end effector required to remove this hard cake is attached to the end of the In-Tank Maneuvering Arm while the arm is positioned at the end effector storage/changeout station.

The In-Tank Maneuvering Arm positions the end effector into its operating position over the surface of the hard cake. The end effector then breaks up the hard cake into fragments, captures the fragments, and transfers them into the Waste Conveyance System (see Section 2.3.1). Fragmentation and transfer of the hard cake may be by high pressure liquid, high pressure gas or mechanical means; or any combination thereof. The fragments of hard cake exit the tank through the Waste Conveyance System.

2.1.3 Function Description, Rubblizing Equipment

The Rubblizing end effector is closely related to the Hard Waste Dislodging Equipment, insofar as it operates upon hard cake. However, unlike the Hard Waste Dislodging Equipment, the Rubblizing end effector does not transfer waste to the Waste Conveyance System. Instead, the purpose of this end effector is only to break up monolithic, or large pieces of hard cake into smaller fragments that can be more readily handled by the Post-Rubblizing Equipment (see Section 2.1.4).

The end effector required to breakup this hard cake is attached to the end of the In-Tank Maneuvering Arm while the arm is positioned at the end effector storage/changeout station. The In-Tank Maneuvering Arm positions the end effector into its operating position over the surface of the hard cake. The end effector then breaks up the hard cake into fragments. Fragmentation of the hard cake may be by high pressure liquid, high pressure gas or mechanical means; or any combination thereof. The fragments of hard cake remain in the tank awaiting further processing by the Post-Rubblizing Equipment.

2.1.4 Function Description, Post-Rubblizing Equipment

After the hard cake in the tank has been broken up by the Rubblizing Equipment (see Section 2.1.3) many of the fragments are too large to pass through the Conveyance System without further processing. Such further processing is provided by the Post-Rubblizing end effector.

The Post-Rubblizing end effector, required to further process this hard cake, is attached to the end of the In-Tank Maneuvering Arm while the arm is positioned at the end effector storage/changeout station. The In-Tank Maneuvering Arm positions the end effector into its operating position over the rubblized surface of the hard cake. The end effector then breaks up the larger pieces of hard cake into smaller fragments, and transfers them into the Waste Conveyance System (see Section 2.3.1). Fragmentation of the hard cake may be by high pressure liquid, high pressure gas or mechanical means; or any combination thereof. The fragments of hard cake are transferred out of the tank by the Conveyance System.

2.1.5 Function Description, Cleaning Equipment

After the bulk of the waste and other material have been removed from the tank, residual waste adhering to the tank walls and certain large ITH will have to be removed.

The Cleaning end effector required to remove this residual waste is attached to the end of the In-Tank Maneuvering Arm while the arm is positioned in the end effector storage/changeout station. The In-Tank Maneuvering Arm positions the end effector into its operating position next to the tank wall or ITH, where it then proceeds to remove the residual waste and transfers it into the Waste Conveyance System (see Section 2.3.1). Removal of the residual waste may be by high pressure liquid, high pressure gas, steam or mechanical means; or any combination thereof. Removal may also be accomplished by solids entrained in high pressure liquid or high pressure gas. The residual waste so removed, is transferred out of the tank by the Conveyance System.

2.2 FUNCTION DESCRIPTION, ITH HANDLING SYSTEM

The ITH Handling System (IHS) consists of that equipment used to detach, disassemble, cut-up, or perform other processes involved with removing the In-Tank Hardware (ITH) from the interior of the tank. The ITH consists of all materials inside the tank, other than those chemical compounds which were the result of past processing of nuclear materials (see Section 2.1 for chemical waste removal). Some ITH is hardware, which for various reasons, was disposed of inside the tank. Other ITH includes hardware inside the tank which is part of the tank system itself (e.g., risers, instrumentation, etc.).

It is likely that the need for more IHS equipment will arise as the program proceeds, consequently each item of equipment is described separately in the following sub-paragraphs to facilitate the future addition of new equipment as the need arises.

2.2.1 Function Description, Large Cutter End Effector

Some of the ITH to be removed from the interior of the tank is too large or awkward to be removed intact, or may be attached to part of the tank structure, thereby necessitating that a cutting operation be performed to enable their removal.

It is known that some of the ITH is of sufficient size and construction as to defy cutting with more conventional mechanical cutting techniques; these items of ITH will be cut using the Large Cutter end effector. The Large Cutter end effector may employ technologies utilizing high pressure abrasive water jets, slow mechanical abrasion, or machine/milling operations. To preclude damage to the cutter caused by shifting of the ITH as severing progresses, the Large Cutter incorporates an ITH restraint/support Mechanism that may be used when required.

The Large Cutter end effector will be attached to the end of the In-Tank Maneuvering Arm while the arm is positioned in the end effector storage/changeout station.

After having been cut up by the cutter end effector the pieces of ITH will be removed from the tank via the ITH Conveyance System (see Section 2.3.2).

2.2.2 Function Description, Small Cutter End Effector

ITH of smaller cross-section, for which more conventional shearing operations may be used, are accomplished using the Small Cutter end effector. The Small Cutter end effector may employ shears which are powered by either hydraulics, pneumatics or electric.

The Small Cutter end effector will be attached to the end of the In-Tank Maneuvering Arm while the arm is positioned in the end effector storage/changeout station.

After having been cut up by the cutter end effector the pieces of ITH will be removed from the tank via the ITH Conveyance System (see Section 2.3.2).

2.2.3 Function Description, Gripper End Effector

The Gripper End Effector is a small, teleoperated gripping mechanism which can be attached to the In-Tank Maneuvering Arm while in the end effector storage/changeout station. While its primary purpose is to pick up the smaller items of ITH from the waste and deposit them into containers, and to attach lifting lanyards to larger items of ITH, the gripper has sufficient usefulness as to have general application to the many handling tasks that are certain to be identified as the program proceeds. Various non-powered tools (e.g., small cutting shears, pry-bars, etc.) and powered tools (e.g., drill, impact wrench, air chisel, etc.) are mounted in a tool rack on the In-Tank Maneuvering Arm. These tools may be accessed by the gripper to assist in freeing the ITH and/or working it as required for ease of handling.

2.2.4 Function Description, Lifting Lanyard

Large ITH will have to be picked up and moved about inside the tank to facilitate cleaning operations. This may be accomplished by attaching one end of the Lifting Lanyard to the ITH using the Gripper end effector (see Section 2.2.3) and the other end to a lift point on the In-Tank Maneuvering Arm. The lanyard will have means of clamping onto the ITH. The clamp may be operated by pneumatics, electrical or mechanical means, but must remain positively engaged after removal of all power. Whether, or not, some large ITH may have to be removed from the tank has yet to be determined.

2.3 FUNCTION DESCRIPTION, CONVEYANCE SYSTEM

The purpose of the Conveyance System is to receive material from the various end effectors, or other means, and transport the material to an above-ground holding receptacle, until it can be further processed. The Conveyance System is divided into two subsystems; 1) The Waste Conveyance System, and 2) the ITH Conveyance System. In this section the term "waste" refers to only those chemical compounds stored in the SST, which were the result of past processing of nuclear materials. ITH is as described in Section 2.2 of this document.

A general description of the Waste Conveyance System and the ITH Conveyance System are provided in the following sub-paragraphs.

2.3.1 Function Description, Waste Conveyance System

The Waste Conveyance System includes a long, tubular structure which extends from the WDS end effector on the arm (inside the tank) to the Waste Transport System, located above ground in the Operations Support Facility (OSF). High velocity air from an air moving device located in the OSF causes the waste, received from the end effector, to be swept along and deposited in the Waste Transport System. The Waste Transport System is not a part of the Waste Conveyance System and is not addressed in this document.

The Waste Conveyance System is intended to handle waste having a consistency ranging from that of water to that of dry chunks of hard cake of 4 in. maximum dimension, including any combination in between (e.g., sludge, solids suspended in water, etc.). The conveyance system includes a discrimination mechanism located at its inlet, adjacent to the outlet of the end effector. This discriminator prevents any material of an unacceptable size and configuration (e.g., steel tapes, wires, bent sheet metal, etc.) from entering the tubular structure, to minimize the potential for flow blockage. In normal operation, the discriminator will be self-clearing of any trapped material, without having to remove the unit from the SST. However, should such self-clearing mechanisms fail, the discriminator shall be designed to be easily cleared out using remote techniques in the Operations Support Facility.

It is desired that full flow be maintained through the conveyance system at all times, to prevent the settling of material with consequent restart difficulties. Therefore, self-opening air bleeds are provided at various locations along the length of the conveyance system. Water injection may also be needed at various points along the length of the conveyance system, as well as at its inlet, to assist in keeping the sludge waste materials entrained in the air flow. Redundant air moving devices, with automatic backup power supplies assure that air flow is maintained. The exhaust from the air moving device will pass through an air drying system. Exhaust ducting is designed such that the exhaust may be routed back into the tank, or outside through a

HEPA filtration system. The exhaust will have instrumentation to monitor air flow, moisture, radiation and (TBD).

2.3.2 Function Description, ITH Conveyance System

Much of the ITH, even that which has been reduced in size by the cutter end effectors, is of unpredictable shape and may be made of steel, cloth, or other hard to convey materials. Such inconsistent material would likely result in frequent jam-ups in a tubular air-conveyance system, such as the Waste Conveyance System. Therefore, a separate conveyance system is provided to transport the ITH from the interior of the tank to a holding hopper, located above ground in the Operations Support Facility (OSF).

The ITH Conveyance System consists of a receiving container, a mechanical lifting system, and a Shielded ITH Holding Hopper, and is intended to handle only that ITH which does not exceed (TBD) inches length in any direction. Inside the tank, the ITH Conveyance System is loaded with ITH by the Gripper end effector (see Section 2.2.3). The ITH Conveyance System then lifts the ITH, by mechanical means, into the OSF where it is deposited in the Shielded ITH Holding Hopper prior to being transferred to a transportation canister.

3.0 DESIGN REQUIREMENTS, IN-TANK PROCESSING EQUIPMENT

This section provides the basic design requirements for the In-Tank Processing Equipment. Other design requirements applicable only to specific equipment are specified in the respective subparagraphs of this section. Unless otherwise specified, the following general requirements apply to the design of all In-Tank Processing Equipment:

Environmental:

- Atmosphere inside tank:

  Air, monitored to assure that explosive concentrations of hydrogen, methane or other combustible gases do not exceed 20-25% of the Lower Explosive Limit.

  Water content: 35% minimum, 100% maximum relative humidity.

  Temperature: 65°F minimum, 200°F maximum.

  Pressure: -9 in. w.g. minimum, 0 in. w.g. maximum relative to external atmosphere.

- Radiation level: 270 R/hr above surface of the waste, 540 R/hr beneath surface of the waste.

- Waste compounds to be removed from the tanks:

Waste temperatures may range from 65°F to 300°F. Some of the tanks contain waste in the form of a saltcake, which consists primarily of sodium nitrate. Damp saltcake appears to be a jelly form. Dried saltcake is a hard, abrasive, brittle material and even exists in large single crystals. Dried saltcake is expected to be similar in physical characteristics to the hard salt-blocks used in the cattle industry. The saltcake in the tanks will vary from wet, to dry, to damp and may contain pockets of liquids. The porosity of the saltcake is expected to vary from 10% to 50%.

Some of the tanks contain waste in the form of a sludge, which consists primarily of heavy metal, iron, and aluminum precipitates. Sludges vary greatly in their physical properties and may contain pockets of liquid. The viscosity of thicker sludges is expected to approach 1.7M cP and may exhibit shear strengths of up to 100,000 dynes/cm^2. Some sludges have dried (to some degree) and have formed a cracked pattern similar to the bottom of a dried up pond. Some descriptive analogous terms applied to the sludge are: varying in consistency from cream of wheat to peanut butter; sandy with hard chunks of material; dried up mud or clay; thick, sticky, dark brown paste which sticks to everything.

Certain of the tanks contain ferrocyanides and may require special handling. Such special handling for these few tanks is (TBD).

The tanks may contain any combination of hard cake or sludges. The waste surface may be very uneven, with large irregular formations of hard cake having sludge around, under and on top of it, in varying amounts. Free liquid, with the consistency of water, may also be present in the form of puddles, or layered underneath.

Certain tanks are known to contain high level sources of radiation in the form of ^{60}Co capsules. At least one tank contains spent fuel elements. Special handling will be required for these tanks.

Much of the waste materials are very abrasive, with the potential to impose significant wear on removal equipment.

pH of waste may be as high as 12.

<u>Design/Analysis</u>:

- Design life: six months based upon 320 hrs/month.
- That portion of the equipment mounted on the end of the In-Tank Maneuvering Arm shall not impose loads on the interface plate in excess of those specified in section 3.6.1.2 of this document.
- That portion of the equipment, mounted on the end of the in-tank maneuvering arm shall be capable of passing through a pipe of 42 inches I.D. while attached to the arm.
- Allowable operating stresses in non-pressurized, load carrying members shall not exceed AISC allowables reduced by a factor of 2.
- Although explosive concentrations of gases are not present, all equipment exposed to the in-tank atmosphere, directly or indirectly, shall be designed to minimize its potential as an ignition source, where practical.
- Because of its saturated state, precipitation or crystallization of solids, from the liquid wastes may occur as the waste temperature drops below that of its normal surroundings. Such potential for transformation of material within the equipment should be considered in design and operation.
- Cutting operations shall be performed minimizing vaporization of materials.
- Certain IPE end effectors may utilize water to accomplish their function. Provision shall be made to promptly remove water added to the tank due to the waste retrieval process. If the end effector requires the use of new water (i.e. water not already inside the tank), the volumetric ratio of the effluent (new water plus waste) to waste removed shall not exceed 5:1 as a maximum limit.

- Those portions of the equipment which are subject to being removed or replaced remotely for preventative maintenance or repair, shall incorporate typical hot cell type fasteners and features to facilitate the task.

Operational:

- The IPE shall not preclude the ability to perform those tasks necessary to assure safe conditions within the SST. These tasks are defined in WHC-EP-0407, Action Plan for Response to Abnormal Conditions in Hanford Site Radioactive Waste Tanks Containing Ferrocyanide, and WHC-EP-0436, Action Plan for Response to Abnormal Conditions in Hanford Site Radioactive Waste Tanks Containing Flammable Gases.
- The equipment shall be capable of being removed and attached to the end of the In-Tank Maneuvering Arm while the arm is in the end effector storage/changeout station. To the maximum extent practical, attachment/removal operations shall be accomplished by automatic, remote means, with operator intervention only to correct off-normal conditions.
- The end effectors shall be designed to facilitate the removal of loosely adhering waste from their outer surfaces and inner mechanisms, by being flushed with low pressure water.
- Provisions shall be made in the end effector storage/changeout station for staging the end effectors such that they do not interfere with other work when not in use, and can be readily retrieved or restaged using manipulators, and/or bridge crane.
- The equipment shall present the operator with the choice of being operated in a fully automatic, autonomous mode with little, or no, operator intervention, or in a manual mode with full real-time operator control.
- The control system shall provide an automatic collision avoidance system to prevent collision between the WDS equipment and tank internal structures, whether operated in the automatic mode or manual mode.
- Control system interlocks shall be provided as required, to assure that noncompatible commands can not be inadvertently carried out by the equipment that could result in injury to personnel or equipment damage.
- Sensors and controls shall be provided as required, to alert the operator to any critical out-of tolerance process parameters (e.g., flow rates, pressures, voltages, etc.) that may indicate impending failure of equipment to accomplish its task.

- All operations, and power to the equipment, shall be ceased in the event that explosive concentrations of vapors reaches or surpasses the 25% Lower Explosive Limit mark.

Materials:

- Certified materials, where used for fabricated components, do not require documentation of physical and chemical analysis or traceability.
- The use of flammable or hazardous materials shall be minimized to As Low As Reasonably Achievable.
- Hydraulic fluids shall be nonflammable, inorganic, and consistent with a high radiation environment. Consider use of water with water soluble additives.
- All materials, including lubricants and seals, must be compatible with the environmental conditions specified in this document.

3.1 DESIGN REQUIREMENTS, WDS EQUIPMENT

3.1.1 Design Requirements, Soft Waste Dislodging Equipment

The following special design requirements apply to the Soft Waste Dislodging Equipment in addition to the general requirements specified in Section 3.0:

- Process soft cake, sludge and/or liquids at an average steady state rate of 20 gal/minute, as a goal. Must be capable of dislodging any waste form having an ultimate shear strength of 0 to 100,000 dynes/cm^2.
- Shall not become easily clogged or jammed by small ITH (e.g. tape, wires, etc.). If clogged or jammed, shall be designed to facilitate removal of such ITH by remote means.
- The inlet portion, in contact with the soft waste, should be as small as practical to provide ease of mobility between and around large objects.
- Agitation of the soft waste may be by high pressure liquid, high pressure gas or mechanical means; or any combination thereof.
- Dislodged waste and solid or liquid cleaning media shall be passed on to the Waste Conveyance System (see Section 2.3.1).

- Interfaces with the interface plate on the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1 of this document.

- Interfaces with the Waste Conveyance System to enable the material exiting this equipment to be removed from the tank.

3.1.2 Design Requirements, Hard Waste Dislodging Equipment

The following special design requirements apply to the Hard Waste Dislodging Equipment in addition to the general requirements specified in Section 3.0:

- Process hard waste at an average steady state rate of 6 gal/minute. Must be capable of dislodging any waste form having an ultimate shear strength ranging from 100,000 dynes/cm^2 up to that of the hardest waste.

- Shall not become easily clogged or jammed by small ITH (e.g., tape, wires, etc.). If clogged or jammed, shall be designed to facilitate removal of such ITH by remote means in the OSF.

- Waste dislodging may be accomplished by high pressure liquid, high pressure gas, or mechanical means; or any combination thereof. Dislodged waste and solid or liquid materials shall be passed on to the Waste Conveyance System (see Section 2.3.1).

- The ability of this equipment to process hard waste shall not be impacted by the presence of small amounts of soft cake, sludge and liquids that may be present.

- Shall be able to accommodate hard waste of any size or shape, including monoliths, at its inlet.

- Interfaces with the interface plate of the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1 of this document.

- Interfaces with the Waste Conveyance System to enable the material exiting this equipment to be removed from the tank.

- The size of the pieces of hard waste, or other materials, exiting this equipment shall not exceed a dimension of 2 in. measured in any direction.

3.1.3 Design requirements, Rubblizing Equipment

The following special design requirements apply to the Rubblizing Equipment in addition to the general requirements specified in Section 3.0:

- Breakup hard waste at an average rate of 12 gal/minute.

- The ability of this equipment to breakup hard waste shall not be impacted by the presence of small amounts of soft cake, sludge and liquids that may be present.
- Shall not become easily clogged or jammed by small ITH (e.g., tape, wires, etc.). If clogged or jammed, shall be designed to facilitate removal of such ITH by remote means in the OSF.
- Waste breakup may be accomplished by high pressure liquid, high pressure gas, or mechanical means; or any combination thereof. The resulting waste fragments are not passed on to the Waste Conveyance System, but remain inside the tank.
- Interfaces with the interface plate of the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1 of this document.
- Shall be able to breakup hard waste of any size or shape, including monoliths.
- The size of the pieces of hard waste remaining after being processed by this equipment shall not exceed a dimension of 14 in. measured in any direction.

3.1.4 Design Requirements, Post-Rubblizing Equipment

The following special design requirements apply to the Post-Rubblizing Equipment in addition to the general requirements specified in Section 3.0:

- Process hard waste at an average rate of 12 gal/minute.
- Processing of the hard waste may be by high pressure liquid, high pressure gas or mechanical means; or any combination thereof.
- The ability of this equipment to process hard waste shall not be impacted by the presence of soft cake, sludge and liquids that may be present.
- Interfaces with the interface plate of the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1. of this document.
- Interfaces with the Waste Conveyance System to enable the material exiting this equipment to be removed from the tank.
- Shall be able to accommodate pieces of hard waste, having a dimension of up to 14 in. in any direction, at its inlet.
- The size of the pieces of hard waste, or other materials, exiting this equipment shall not exceed a dimension of 2 in. measured in any direction.

- Must not become easily clogged or jammed by small ITH (e.g. tape, wires, etc.). If clogged or jammed, must be designed to facilitate removal of such ITH by remote means in the OSF.

3.1.5 Design Requirements, Cleaning Equipment

The following special design requirements apply to the Cleaning Equipment in addition to the general requirements specified in Section 3.0:

- This equipment shall be able to remove residual amounts of saltcake, sludge or liquids that may adhere to surfaces and crevices of ITH or the interior tank walls after the bulk of the waste has been removed. The final cleanliness level of the ITH after removal of residual waste is to be (TBD).
- Capable of removing waste from surfaces at the rate of 2 ft^2 per minute as a goal.
- The removed waste and solid or liquid cleaning media shall be passed on to the Waste Conveyance System (see Section 2.3.1).
- Removal of the residual waste may be by high pressure liquid, high pressure gas, steam or mechanical means; or any combination thereof. Removal may also be accomplished by solids entrained in high pressure liquid or high pressure gas.
- The process must not degrade the structural integrity of the tank walls.
- Interfaces with the interface plate of the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1. of this document.
- Interfaces with the Waste Conveyance System to enable the material exiting this equipment to be removed from the tank.

3.2 DESIGN REQUIREMENTS, IHS EQUIPMENT

3.2.1 Design Requirements, Large Cutter End Effector

The following special design requirements apply to the Large Cutter End Effector in addition to the general requirements specified in Section 3.0:

- Typical material to be cut by the Large Cutter End Effector are as listed below:
    - Steel or stainless steel tubing or pipe having diameters ranging from 4 to 42 in. diameter, with wall thicknesses up to 2 in.

  - Railroad rail segments
  - Rocks and concrete
  - Steel pipe of 18 in. diameter x 1.5 in. wall, with twelve or more solid fixed rods inside ranging from 1 to 3 in. in diameter.

- The large cutting equipment must include provisions to assure that the object being severed can not shift position or fall in such a way as to cause damage to the cutting equipment or tank structure.

- Cutting of large ITH may be by high pressure liquid, high pressure gas, or mechanical means; or any combination thereof. Cutting may also be accomplished by solids entrained in high pressure liquid or high pressure gas.

- The ITH being cut may be in any orientation and may, or may not, be rigidly secured in place. If securing of the ITH is necessary for cutting, then means shall be included in the design of the cutter.

- The surface of ITH may be covered with waste residuals. Such residuals shall not impede the effectiveness of the cutter.

- The ability to cut ITH in a single pass is highly desirable, however, more passes are permissible.

- The minimum cutting rate of the large ITH is (TBD) inches/minute.

- Interfaces with the interface plate of the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1. of this document.

3.2.2 Design Requirements, Small Cutter End Effector

The following special design requirements apply to the Small Cutter End Effector in addition to the general requirements specified in section 3.0:

- Typical material to be cut by the Small Cutter end effector are as follows:

  - Miscellaneous steel piping and tubing ranging from .25 to 12.75 in. diameter, wall thickness up to .406 in.
  - Fiberglass tubes ranging from 4 to 6 in. diameter, wall thickness up to .13 in.
  - Solid iron bars up to .75 in. diameter.
  - Steel strips such as flexible steel measuring tapes.

- Cutting shall be accomplished in a single pass, by means of mechanical shearing or punching action, powered by hydraulics, pneumatics or electric. The blade closing speed shall be variable by the operator.

- The ITH being cut may be in any orientation and may, or may not, be rigidly secured in place. If securing of the ITH is necessary for cutting, then means shall be included in the design of the cutter.

- The surface of ITH may be covered with waste residuals. Such residuals shall not impede the effectiveness of the cutter.

- The ability to cut ITH in a single pass is highly desirable.

- Interfaces with the interface plate of the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1. of this document.

3.2.3 Design Requirements, Gripper End Effector

The following special design requirements apply to the Gripper end effector in addition to the general requirements specified in Section 3.0:

- The gripper shall be of a proportional master/slave configuration and shall be capable of being controlled real-time by the operator.

- Dead weight of the gripper should not exceed 15 lbs as a goal.

- The combined weight of the gripper and the load it is lifting shall not exceed the loads allowed to be imposed on the interface plate specified in section 3.6.1.2 of this document.

- The gripper shall include a wrist. The wrist shall be capable of full 360° multi-turn rotation, and capable of exerting a torque of (TBD) in-lbs. Torques in excess of that allowed to be imposed on the interface plate (see section 3.6.2) must be reacted out on the work, instead of the interface plate.

- Gripper jaws shall remain parallel as they open and close, shall be capable of opening to a minimum of 8 in., and exert a closing force of (TBD) lbs.

- The gripper shall feature remotely replaceable contact pads for increased versatility (e.g., round pads to grip pipes, flat pads to grip flats, etc.).

- May be powered by hydraulics, pneumatics or electric; or any combination thereof.

- Various nonpowered tools shall be provided on the In-Tank Maneuvering Arm, which are accessible by the gripper. Such tools shall include: pry bars, shears capable of cutting steel measuring tapes and wire, and other tools (TBD).
- Various air-powered tools shall be provided on the In-Tank Maneuvering Arm, which are accessible by the gripper. Such tools are (TBD) but may include an impact wrench, drill, power chisel, etc.
- Interfaces with the interface plate of the In-Tank Maneuvering Arm for services, support and mobility, see section 3.6.1. of this document.

3.2.4 Design Requirements, Lifting Lanyard

The following special design requirements apply to the Lifting Lanyard in addition to the general requirements specified in Section 3.0:

- Capable of being remotely engaged to ITH of the following description:
    - Cylindrical shapes of 4 to 42 in. diameter x 80 in. long.
    - Flat shapes of 20 in. wide x .25 to 4 in. thick x 80 in. long.
    - Any irregular shape fitting within a 42 in. diameter spherical envelope.
- Design, inspect and test the lanyard in accordance with WHC-CM-6-4, Hanford Hoisting and Rigging Manual, for a non-critical, class 2 lift. Load Capacity shall be 2000 lbs.
- The clamping end of the lanyard may be engaged with the large ITH using pneumatic or mechanical means, but must remain positively engaged after removal of all power. The lanyard may be positioned on the ITH by the Gripper end effector (see Section 2.2.3).
- The free end of the lanyard, shall be capable of being remotely attached to the In-Tank Maneuvering Arm using the Gripper end effector.
- The length of lanyard, remaining after having been attached to the ITH and the maneuvering arm, shall not preclude using the arm to lift up and move the ITH.

3.3 DESIGN REQUIREMENTS, CONVEYANCE SYSTEM

3.3.1 Design Requirements, Waste Conveyance System

The following special design requirements apply to the Waste Conveyance System equipment in addition to the general requirements specified in Section 3.0:

- As a goal the system shall be capable of transporting soft waste continuously, at a minimum average rate of 20 gal/minute, for a distance of 60 ft vertical and 40 ft horizontal. Similarly, the rate for hard waste shall be 12 gal/minute.
- The waste to be conveyed may consist of dry solids, having a maximum dimension of 4 in. in any one direction; soft cake or sludge, as defined in Section 3.0; liquids, the consistency of water; or any combination thereof.
- Some SSTs are known to contain high level sources of radiation (e.g. ^{60}Co slugs, spent fuel elements, etc.), which shall normally be removed by the ITH Conveyance System (see section 3.3.2). Provision shall be made to assure protection of personnel should such material be inadvertantly carried out of the tank by the Waste Conveyance System.
- The inlet of the Waste Conveyance System will interface with one of the WDS end effectors described in Section 2.1., at the interface plate, described in section 3.6.1.1. The outlet of the Waste Conveyance System will interface with the Waste Transport System (not addressed by this document) in preparation for transport.
- Provisions shall be made to assure that the waste remains entrained in the air flow at all times once it has entered into the duct. This may be accomplished by self-opening air bleeds and injected water at strategic locations along the duct.
- Redundant air moving devices and automatic backup power supplies shall be provided to assure that air flow is maintained at all times.
- Exhaust ducting from the air moving device may be routed back into the tank or routed outside through a HEPA filtration system, as the particular operation may dictate based upon tank contents. This filtration system shall conform to Hanford Standard (TBD).
- Exhaust from the air moving device shall pass through an air drying system to remove entrained liquids, before exiting. The exhaust will also be monitored for radiation. Exhaust emission requirements are (TBD).

- A discriminating mechanism will be incorporated into the inlet end of the system, which will permit material of a size less than 4 inches (measured in any direction) to pass through. The discriminator will prevent materials of unacceptable size and shape (steel tapes, wires, bent sheet metal, plastic bags, etc.) from entering, in order to minimize potential for flow blockage.

- The discriminating mechanism shall be designed to be self-clearing of entrapped flow obstructions, without having to remove the unit from the SST.

- The design of all flow paths, including the discriminator, must provide for easy removal of flow obstructions, using remote techniques.

- For non-seismic Category 1 over seismic Category 1 hardware allowable stresses during DBE shall not exceed 1.3 x allowable AISC working stresses for primary load bearing parts.

3.3.2 Design Requirements, ITH Conveyance System

The following special design requirements apply to the ITH Conveyance System equipment in addition to the general requirements specified in Section 3.0:

- The inlet of the system shall consist of containers capable of being loaded inside the SST using the Gripper end effector (see Section 2.2.3).

- The system will include a shielded waste holding bin located above ground in the OSF. This holding bin shall be of sufficient size and capabilities as to enable continuous ITH removal operations while bin is being emptied.

- The system will include equipment capable of transporting the canisters and ITH from the tank into the shielded waste holding bin. The working capacity of this equipment shall be a minimum of (TBD) lbs.

- The system shall accommodate ITH having a maximum dimension not to exceed an external space envelope of (TBD) x (TBD) x (TBD), and not exceeding (TBD) lbs.

- Some SSTs are known to contain high level sources of radiation (e.g. ^{60}Co slugs, spent fuel elements, etc.), which shall be removed by the ITH Conveyance System. Provision shall be made to assure protection of personnel when such material is removed from the tank by the ITH Conveyance System.

- The rate of transferral of ITH, from inlet to holding bin, shall not be less than (TBD) lbs/hr as a goal.

- For non-seismic Category 1 over seismic Category 1 hardware allowable stresses during DBE shall not exceed 1.3 x allowable AISC working stresses for primary load bearing parts.

3.4 DRAWINGS AND SPECIFICATIONS

3.4.1 Drawings

(To be added as they become available).

3.4.2 Specifications

American Institute of Steel Construction (AISC), Manual of Steel Construction, Latest edition

3.5 APPLICABLE DOCUMENTS

3.5.1 Nongovernment Documents

WHC-CM-1-3, MRP5.43, Impact Levels

WHC-CM-1-3, MRP5.46, Safety Class of Systems, Components and Structures

WHC-CM-6-1, EP-1.7, Engineering Document Approval and Release Requirements

WHC-CM-6-4, Hanford Hoisting and Rigging Manual

WHC-CM-4-2, Quality Assurance Manual

WHC-CM-4-3, Industrial Safety Manual

WHC-CM-4-46, Section 2.0, Nonreactor Facility Safety Analysis Manual

WHC-EP-0407, Action Plan for Response to Abnormal Conditions in Hanford Site Radioactive Waste Tanks Containing Ferrocyanide

WHC-EP-0436, Action Plan for Response to Abnormal Conditions in Hanford Site Radioactive Waste Tanks containing Flammable Gases

3.5.2 Government Documents

Hanford Federal Facility Agreement and Consent Order, Washington State Department of Ecology, U.S. Environmental Protection Agency, and the U.S. Department of Energy, Olympia, Washington

3.6 SYSTEM INTERFACES

3.6.1 SYSTEM INTERFACES WITH MANEUVERING SYSTEM

The maneuvering system interface plate is one of the primary points of interface between the various IPE end effectors and the maneuvering system. See drawing H-2-(TBD), End Effector/Maneuvering System Interface Details, in appendix of this document (To be added later). The physical interfaces between the end effectors and this service plate are as specified in the following subparagraphs of this section.

(Note: The interfaces specified in this section assume that service lines are routed along the maneuvering arm. The decision has not yet been made whether lines will be so routed, or tethered through a separate opening)

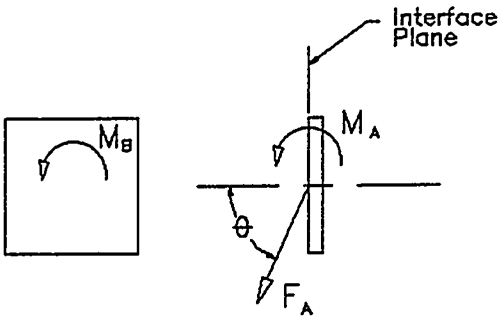
3.6.1.1 Service Connections

That equipment on the end of the In-Tank Maneuvering Arm shall be constrained to being powered and controlled by those services available at the maneuvering system interface plate. It is a goal to have no more than the following services available at this interface plate, however services may be added or increased on a case basis, contingent upon WHC written approval.

- Two hydraulic connectors (one sending, one receiving); working capacity 45 gpm @ 2000 psig. Note: Only one set of two 5000 psig hydraulic lines shall be routed along the maneuvering arm, The other connectors specified below will be supplied by hydraulic lines branched from these and isolated by valving at the arm side of the interface plate.
- Two hydraulic connectors (one sending, one receiving); working capacity 2 gpm @ 5000 psig. See note above.
- One pneumatic connector; 200 SCFM @ 200 psig
- One 8 inch diameter vacuum connector (Waste Conveyance System); 1,620 SCFM @ 18 in. Hg.
- One high pressure water connector; 6 gpm @ 55 ksi
- One low pressure water connector; 8 gpm @ 80 psig
- One abrasive supply connector; .50 inch I.D., rated 200 psig
- One three conductor ac power supply connect; 125 vac, 60 Hz, 25 amp
- One dc power supply and instrumentation connector with 16 contacts; 5 amps each

3.6.1.2 Mechanical Loads

The load diagram below shows the worst case loads that the end effectors are allowed to impose upon the maneuvering system interface plate during normal operation.



Load vector F_A may lie in any plane perpendicular to the interface plane shown. Angle θ may vary from 0° to 90°

Moment M_A may also be in any plane perpendicular to the interface plane

Moment M_B is in the interface plane

The interface plane may vary from vertical (as shown) to horizontal

<u>Load Values</u>:

The table below provides maximum allowable values of the above loads for the different loading conditions defined as follows:

<u>Dead Weight</u>, is the gravitational weight of the end effector, used to determine the inertial effects of the end effector upon the interface plate due to being moved about by the maneuvering system with an acceleration of no more than ±1/4 g in any direction.

<u>Operating Loads</u>, are the loads imposed upon the interface plate by the end effector during its normal operation. Operating loads consist of dead weight loads combined with reaction loads caused by the end effector operating upon the waste. The end effector and interface plate must continue to function normally during, and after, being subjected to operating loads.

<u>Faulted Loads</u>, are the loads imposed upon the interface plate by the end effector during a (TBD) seismic event. The Faulted Loads consist of operating loads combined with those loads resulting from a seismic event of (TBD) g's. The end effector and interface plate need not remain functional after a faulted event, although they must remain structurally attached to each other and to the maneuvering system.

LOADS	DEAD WEIGHT	OPERATING	FAULTED
F_A (lbs)	± 800	± 1,000 *	(TBD)
M_A (in-lbs)	± 9,600	± 12,000 *	(TBD)
M_B (in-lbs)	± 4,000	± 5,000	(TBD)

* Up to 40% of these maximum allowable loads may be applied cyclically at a maximum rate of 60 cycles/minute.

3.6.1.3 Positioning Capabilities

This portion of the interface requirements defines the limits of motion that may be imparted to the end effectors by the maneuvering system through the interface plate. Should any end effector require motions beyond these limitations, they shall be provided by the end effector itself.

Degrees of freedom:

The motion imparted to the end effector through the interface plate by the maneuvering system consists of two elements: 1) Proximity positioning, and 2) Working motions. Proximity positioning is accomplished by the primary drive of the maneuvering system, to position the end effector in the selected zone of the SST at which its task is to be performed. The secondary drive of the manevering system then imparts working motions to the interface plate, which are then transferred to the end effector to enable it to accomplish its task. The proximity positioning has no significance to the design of the end effectors, and is therefor not addressed in this document. The working motions imparted by the maneuvering system through the interface plate, are defined as follows:

Six degrees of freedom are provided by the maneuvering system at the interface plate, relative to a normal vertical position of the plate.

1) Axial translation of ±72 inches, in a direction normal to plane of interface plate, at velocities of .5 to 20 in/sec, ±1/4 g maximum.

2) Lateral translation of ±72 inches, horizontal and parallel to plane of interface plate, at velocities of .5 to 20 in/sec, ±1/4 g maximum.

3) Lateral translation of ±36 inches, vertical and parallel to plane of interface plate, at velocities of .5 to 20 in/sec, ±1/4 g maximum.

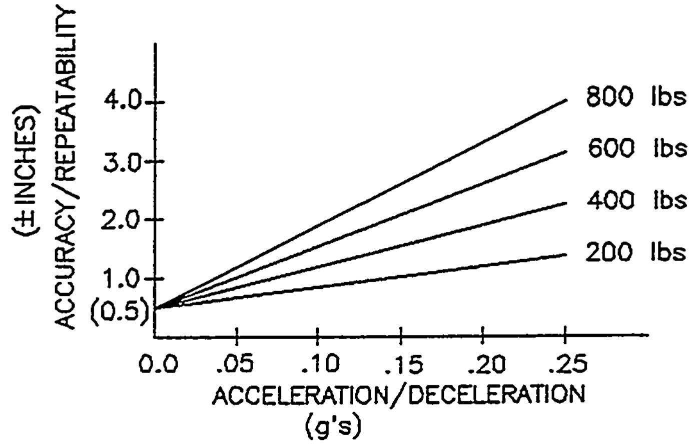
4) Pitch angulation of ±90° in a vertical plane, at angular speeds of .05 to .5 rad/sec, maximum angular acceleration of ±6 rad/sec^2.

5) Yaw angulation of ±90° in a horizontal plane, at angular speeds of .05 to .5 rad/sec, maximum angular acceleration of ±6 rad/sec^2.

6) Roll angulation of ±90° about axis normal to plane of interface plate, at angular speeds of .05 to .5 rad/sec, maximum angular acceleration of ±20 rad/sec^2.

Positional Accuracy and Repeatability:

The accuracy and repeatability with which the end effector may be positioned by the maneuvering system is a function of the dead weight of the end effector and the accelerations (or decelerations) imparted to it. Accuracy and repeatability are absolute values defined relative to the earth. The relationship of positional accuracy and repeatability to these accelerations is shown in the diagram below, for end effectors of various dead weights.



3.6.2 SYSTEM INTERFACES, WASTE DISLODGING SYSTEM

Physical and functional interfaces applicable to the Waste Dislodging Equipment are provided in the following subparagraphs.

3.6.2.1 Interfaces, Soft waste Dislodging Equipment

Physical and functional interfaces of the Soft Waste Dislodging equipment with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
Waste Conveyance System	Attaches to inlet of Waste Conveyance System duct	Attached by automated, remote means
	Transfers waste to Waste Conveyance System	20 Gal/minute
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Hydraulic System (TBD) Pneumatic System (TBD) HVAC System Process Water System (TBD)	(TBD)
SST	Must fit through opening into SST while mounted on In-Tank Maneuvering Arm	Opening size (TBD)

3.6.2.2 Interfaces, Hard Waste Dislodging Equipment

Physical and functional interfaces of the Hard Waste Dislodging equipment with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
Waste Conveyance System	Attaches to inlet of Waste Conveyance System duct	Attached by automated, remote means
	Transfers waste to Waste Conveyance System	12 Gal/minute
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Hydraulic System (TBD) Pneumatic System (TBD) HVAC System Process Water System (TBD)	(TBD)
SST	Must fit through opening of SST while mounted on In-Tank Maneuvering Arm	Opening size (TBD)

3.6.2.3 Interfaces, Hard Waste Rubblizing Equipment

Physical and functional interfaces of the Hard Waste Rubblizing equipment with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Hydraulic System (TBD) Pneumatic System (TBD) HVAC System Process Water System (TBD)	(TBD)
SST	Must fit through opening of SST while mounted on end of In-Tank Maneuvering Arm	Opening size (TBD)

3.6.2.4 Interfaces, Post-Rubblizing Equipment

Physical and functional interfaces of the Post-Rubblizing equipment with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
Waste Conveyance System	Attaches to inlet of Waste Conveyance System duct	Attached by automated, remote means
	Transfers waste to Waste Conveyance System	12 Gal/minute
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Hydraulic System (TBD) Pneumatic System (TBD) HVAC System Process Water System (TBD)	(TBD)
SST	Must fit through opening of SST while mounted on In-Tank Maneuvering Arm	Opening size (TBD)

3.6.2.5 Interfaces, Cleaning Equipment

Physical and functional interfaces of the Cleaning equipment with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
Waste Conveyance System	Attaches to inlet of Waste Conveyance System duct	Attached by automated, remote means
	Transfers waste to Waste Conveyance System	(TBD) Gal/minute
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Hydraulic System (TBD) Pneumatic System (TBD) HVAC System Process Water System (TBD)	(TBD)
SST	Must fit through opening of SST while mounted on In-Tank Maneuvering Arm	Opening size (TBD)

3.6.3 SYSTEM INTERFACES, ITH HANDLING SYSTEM

Physical and functional interfaces applicable to the ITH Handling System equipment are provided in the following subparagraphs.

3.6.3.1 Interfaces, Large Cutter End Effector

Physical and functional interfaces of the Large Cutter end effector with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
ITH Conveyance System	Pieces of ITH will be loaded into the ITH Conveyance	Cut ITH into pieces of size (TBD)
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Hydraulic System (TBD) Pneumatic System (TBD) HVAC System Process Water System (TBD)	(TBD)
SST	Must fit through opening of SST while mounted on end of In-Tank Maneuvering Arm	Opening size (TBD)

3.6.3.1 Interfaces, Small Cutter End Effector

Physical and functional interfaces of the Small Cutter end effector with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
ITH Conveyance System	Pieces of ITH will be loaded into the ITH Conveyance	Cut ITH into pieces of size (TBD)
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations support facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System (TBD) Hydraulic System (TBD) Pneumatic System (TBD) HVAC System	(TBD)
SST	Must fit through opening of SST while mounted on end of In-Tank Maneuvering Arm	Opening size (TBD)

3.6.3.2 Interfaces, Gripper End Effector

Physical and functional interfaces of the Gripper end effector with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
ITH Conveyance System	Used to load Pieces of ITH into the ITH Conveyance System	Load ITH pieces of size (TBD)
Lifting Lanyard	Lanyard is attached to In-Tank Maneuvering Arm by Gripper end effector	Design for ease of remote handling
In-Tank Maneuvering Arm	Attaches to interface plate of In-Tank Maneuvering Arm, including service connections	Attached by automated, remote means
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System (TBD) Hydraulic System (TBD) Pneumatic System (TBD) HVAC System	(TBD)
SST	Must fit through opening of SST while mounted on end of In-Tank Maneuvering Arm	Opening size (TBD)

3.6.3.3 Interfaces, Lifting Lanyard

Physical and functional interfaces of the Lifting Lanyard with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
In-Tank Maneuvering Arm	Lanyard is attached to end of In-Tank Maneuvering Arm, including service connections, for moving large ITH within the tank	Attached by remote means Working load 2000 lbs
Operations Support Facility	End effectors are staged, and attached to the In-Tank Maneuvering Arm while in the End effector storage/changeout station	Remote operation capabilities
Gripper end effector	Lanyard is attached to end of In-Tank Maneuvering Arm by Gripper end effector	Design for ease of remote handling
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System (TBD) Hydraulic System (TBD) Pneumatic System (TBD) HVAC System	(TBD)
SST	Must fit through opening of SST while mounted on end of In-Tank Maneuvering Arm	Opening size (TBD)

3.6.4 SYSTEM INTERFACES, CONVEYANCE SYSTEM

Physical and functional interfaces applicable to the Conveyance System equipment are provided in the following subparagraphs.

3.6.4.1 Interfaces, Waste Conveyance System

Physical and functional interfaces of the Waste Conveyance System equipment with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
End Effectors: • Soft Waste Dislodging • Hard Waste Dislodging • Post-Rubblizing • Cleaning	Receive waste from end effectors	Soft waste 20 gpm Hard waste 12 gpm
Operation Support Facilities (OSF)	Fans, power supplies and Shielded Waste Holding Hopper are located in the OSF	Radiologically controlled zone
Waste Transport System	Receive waste from the Waste Conveyance System	Maintain shielding and confinement during transfer. Maintain waste flow at all times
In-Tank Maneuvering Arm	Installed on In-Tank Maneuvering Arm	Able to install/remove by remote means
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Pneumatic System HVAC System Process Water System (TBD)	(TBD)
SST	Portions must fit through opening of SST while mounted on In-Tank Maneuvering Arm	Opening size (TBD)

3.6.4.2 Interfaces, ITH Conveyance System

Physical and functional interfaces of the ITH Conveyance System equipment with other systems and equipment are as tabulated below:

INTERFACE	DESCRIPTION OF INTERFACE	REQUIREMENT
Gripper end effector	Receive ITH from Gripper end effector	Max size and weight of ITH is (TBD)
Operation Support Facilities (OSF)	Drives, power supplies and Shielded Holding Bin are located in the OSF	Radiologically controlled zone
ITH Transport System	Receive ITH from the Shielded Holding Bin	Maintain shielding and confinement during transfer. Maintain work flow of (TBD) Gal/minute while awaiting transfer of ITH.
Control System	Sensors (TBD)	(TBD)
Facility Services	Electrical System Hydraulic System (TBD) Pneumatic System (TBD) HVAC System Process Water System (TBD)	(TBD)
SST	Portions must fit through opening of SST	Opening size and location (TBD)

3.7 OPERATION AND MAINTENANCE

This section includes only those special Operation and Maintenance provisions and requirements which require special design consideration. Standard Operating and Maintenance outlines will be prepared in a separate document at some future date and are not part of this document.

3.7.1 Special Operations

Flow should be maintained through the Waste Conveyance System at all times whenever waste is being transferred. Should flow of waste inadvertently stop, the entrained waste may settle in flow passages and greatly hinder the reinitiation of flow. In addition, the waste may "re-heal", or solidify, in the conveyance mechanism if allowed to remain there for a period of time.

Some of the SSTs may contain high level sources of radioactive material (^{60}Co slugs, experimental fuel, etc.) that may require special handling and shielding to effect their removal from the tank. The special handling and shielding is (TBD) at present.

Loosely adhering waste shall be flushed from the exterior surfaces and inner mechanisms of the end effectors prior to retracting them into the OSF for changeout or storage. Flushing may be accomplished with low pressure water spray.

The SST shall be monitored to assure that concentrations of explosive gases do not exceed 20-25% of the Lower Explosive Limit. All operations, and power to the equipment, shall be ceased in the event that explosive concentrations of vapors in the SST reaches or surpasses the 25% Lower Explosive Limit mark.

Those tanks containing ferrocyanides may be impact sensitive. Special precautions may need to be incorporated for handling waste that is impact sensitive or subject to exploding. These precautions are (TBD).

3.7.2 Special Maintenance

General:

Assemblies containing components subject to binding, wear or breakage, shall be designed such that the components can be replaced while the unit is in the Operations Support Facility. Such components include, but are not limited to motors, hydraulic or pneumatic cylinders, rollers, cutting blades, etc. Design features common to hot-cell equipment shall be incorporated in the fastening techniques securing these components in the assembly.

Waste Conveyance System:

Although the Waste Conveyance System is designed to assure full flow of waste at all times (see Section 7.1), it must also include features to facilitate the remote removal of that waste which may settle in the conveyance mechanism should flow be inadvertently stopped.

4.0 SAFETY, RELIABILITY AND QUALITY ASSURANCE

4.1 SAFETY

Historical data indicates that the presence of flammable concentrations of hydrogen or other combustible gases within most SSTs is highly unlikely. The tanks will be monitored for potentially explosive concentrations of these gases during waste retrieval operations, and corrective actions initiated as required in the event that the concentrations reach, or surpass, the 25% Lower Explosive Limit. Corrective actions will include efforts to reduce the concentrations in accordance with WHC-EP-0436, Action Plan for Response to Abnormal Conditions in Hanford Site Radioactive Waste Tanks Containing Flammable Gases. In addition, several of the SSTs may contain ferrocyanide in quantities sufficient to present a potential for exothermic or explosive reactions between ferrocyanide precipitates, and nitrate or nitrite compounds. These tanks will be monitored for temperature and flammable gases during waste retrieval operations, and corrective actions taken as required in accordance with WHC-EP-0407, Action Plan for Response to Abnormal Conditions in Hanford Site Radioactive Waste Tanks Containing Ferrocyanide.

Working within the constraints of the action plans discussed above, will create a safe atmosphere in which the waste retrieval operations may take place. Therefore, the Waste Dislodging System and ITH Handling System equipment are considered to be "Nonsafety Class 4" as defined in WHC-CM-1-3, MRP5.46, Safety Classification of Systems, Components and Structures. Those portions of the Waste Conveyance System and the ITH Conveyance System, which protect personnel from high level radiation sources (e.g. ^{60}Co capsules, elements, etc.) which may be conveyed from the tank, shall be defined as Safety Class 3 items.

The impact of flammable gas concentrations on readiness, exhausters, emergency equipment and emergency plans, etc. are beyond the scope of this document, insofar as this document only deals with specific in-tank retrieval equipment. Instead, these safety concerns shall be incorporated in a separate Functions and Requirements document (TBD) which primarily addresses the overall requirements of the waste retrieval project, including the confinement and all emergency and nonemergency facilities. Likewise, the Facility Hazard Classification, as determined in accordance with WHC-CM-4-46, Section 2.0, Nonreactor Facility Safety Analysis Manual, will be addressed by this other separate document (TBD) applicable to the overall facility and is not included in this document.

4.2 RELIABILITY

(TBD)

4.3 QUALITY ASSURANCE

- ANSI/ASME NQA-1, "Quality Assurance Program Requirements for Nuclear Facilities" shall be implemented in design documents as applicable.
- The impact level of the documentation associated with the IPE shall be determined in accordance with WHC-CM-6-1, EP-1.7.
- The actual QA requirements imposed on individual items will be specified on the documents that produce the part (i.e., drawings, specifications, or purchase orders), as applicable.

5.0 REFERENCES

The following references were influential to the system design, although not included in previous sections of this document:

- WHC-EP-0405 (DRAFT), Systems Engineering Study for the Closure of Single-Shell Tanks
- WHC-SP-0680, Single Shell Tank Waste Processing System Concept Review
- Memo, CSA:BVW:qv/5, "Design Criteria for Tools and Handling Equipment," B. V. Winkel to Distribution, dated April 13, 1977.
- Memo, DLB-23420-89-002, "Design Criteria for SP-100 In-Cell Handling Equipment," D. L. Becker to J. D. Potter, dated June 28, 1989.
- WHC-SD-WM-ER-128, Discovery Report SST Waste Retrieval New Technology for End Effector/Conveyance
- OSD-T-151-00013, Rev D-0, Operating Specifications for Single Shell Storage Tanks

6.0 TBD/HOLD REPORT

(to be added later)

ATTACHMENT 3

WASTE RETRIEVAL STRATEGY
SINGLE-SHELL TANKS

Purpose

The purpose of this paper is to provide a summary of the WHC engineering activities in support of development of a viable concept for a single-shell tank (SST) waste retrieval system. The summarized activities occurred between 1989 and 1991. The future activities that must be completed prior to design and fabrication of the retrieval system are also discussed.

Strategy

The program to provide a system to retrieve waste from the demonstration single-shell tank was initiated in 1989 in support of TPA milestone M-07-00 (October 1997) "Initiate full-scale demonstration of waste retrieval technology".

The strategy that has been developed and pursued for the past two years by WHC related to the development of the SST waste retrieval equipment includes:

- Develop background information
- Document functions and requirements
- Review past retrieval activities and studies
- Develop and evaluate numerous alternate retrieval concepts
- Select a "baseline" concept for development
- Conduct a peer review of baseline concept by a independent peer group
- Investigate alternatives to the baseline design that may be available from private industry, universities, national laboratories or the military sector
- Prepare an engineering study as a basis for the Functional Design Criteria (FDC)
- Prepare the FDC for the baseline design in support of project validation (WHC-CM-6-12)
- Obtain project validation
- Prepare Conceptual Design Report (WHC-CM-6-12)
- Negotiate contract with private vendors for design and fabrication of retrieval system

Concept Development

Preparation of the Single-Shell Tank Waste Retrieval Study (Ref 12) was the initial step in the program. This study was a comprehensive review of previous studies and past practices at Hanford. The study also evaluated existing technologies that may be applicable to the single-shell tank retrieval activities. Recommendations in this study included development of a robotic arm with eight interchangeable tools (end effectors) and an air conveyance system for transporting the waste out of the SST. Air jets, water jets and three different types of pumps were recommended for feature testing.

A parallel effort was undertaken by Quadrex Environmental Company, a private consulting firm, to perform an industry survey (Ref 13) to determine what equipment, techniques, or systems might be available in the private sector that could be applied to the SST retrieval program. Quadrex surveyed more than 100 private vendors, developed several retrieval concepts and numerous methods and tools to perform the retrieval operations. No new or unique retrieval concepts or tools were discovered by Quadrex, thereby supporting the completeness of the initial study.

Numerous mechanical retrieval concepts were then developed in a series of brainstorming sessions and by individual contributors. These concepts, in addition to the concepts from the initial study, were then combined into eleven concepts and evaluated by a team of engineers knowledgeable in the aspects of SST waste retrieval. Each alternative was evaluated against 37 "must meet" criteria and 28 "want" criteria. A weight factor was assigned to each "want" criteria and each alternative was then ranked as to how well it met the "want". A numerical score was then calculated for each alternative which was the product of the weight factor and the ranking. On this basis, five concepts were recommended for further development (Ref 7). All five of the recommended concepts fell into two general classifications; these were retrieval through a central opening with a remote arm and retrieval through a large opening in the top of the tank, up to 50 ft in diameter.

The two general retrieval concepts, retrieval through a central opening and retrieval through a large opening, along with a hydraulic retrieval concept were then developed in sufficient detail to allow determination of which concept should be the "baseline" concept. The concept development was accomplished by three separate design teams that developed a "preferred" alternative for each of the three basic concepts. This preferred alternative was developed based on Functions and Requirements written for SST waste retrieval. The three general retrieval concepts were evaluated against the Functions and Requirements, costs and environmental considerations. The concept of waste retrieval through an opening in the center of the tank with a robotic arm was determined as the preferable choice for the baseline concept.

A Department of Energy multi-contractor peer review committee was then convened to review the three concepts and the process by which the baseline concept was chosen. The committee included members from Idaho Nuclear Company, Oak Ridge National Laboratory, Sandia National Laboratory, Pacific Northwest Laboratory, and Westinghouse Hanford Company. The peer review was conducted as a two step process. First, the committee reviewed the concept development work performed by the three design teams and then resolved comments and concerns in a wrap-up meeting. The peer review committee agreed that retrieval with a arm operating through an opening in the center of the tank was the correct way to proceed and that this concept should become the baseline design (Ref 5,6).

At the time that the concepts were being developed for the peer review, it was recognized that there may be additional concepts available in the commercial robotics industry. Accordingly, an alternatives study (Ref 3) was undertaken to determine if additional methods or equipment were available for consideration in the retrieval activities. More than 60 contacts were made with private vendors, National Laboratories, Universities, and other government groups. This study identified several variations of the baseline concept that warrant further considerations. All practical variations use robotics (or teleoperation) and operate through a hole in the center of the tank.

Future Efforts

Future efforts consist of accomplishing the necessary activities to validate the retrieval project, including preparation of an engineering study, Functional Design Criteria (FDC), and Conceptual Design Report (CDR). These are required project stops leading to procurement of the retrieval system design and fabrication.

The next step is the preparation of a formal engineering study that will meet the criteria established in EP-5.1, Exhibit 1 of the Standard Engineering Practices manual WHC-CM-6-1. This study will include cost studies and trade-offs, schedules, concept development, evaluation of alternatives, and a recommendation for a preferred alternative. This study, along with the functional design criteria, will form the basis for project validation.

Preparation of functional design criteria (FDC) will follow completion of the engineering study. The FDC is the technical contract between the customer, the project engineer, and the architect engineer (AE). The FDC identifies the requirements that drive the design i.e., it emphasizes what is to be done over how it is to be accomplished. The FDC is prepared in accordance with the Projects Department Procedures, WHC-CM-6-12, P-05.

The conceptual design report (CDR) is the final major document required prior to entering into a contract with a private contractor for design and fabrication of the retrieval equipment. This document is prepared is concert with KEH and presents the actual conceptual design of the retrieval system. Cost estimates, schedules, and a detailed project description are included in this report. The CDR is prepared in accordance with the Projects Department Procedures, WHC-CM-6-12, P-06.

ATTACHMENT 4

PRELIMINARY DESIGN REVIEW

HYDRAULIC IMPACT END-EFFECTOR SYSTEM

MARCH 9, 1992 8:00

BUILDING 3726, ROOM 746

PRESENTER - PAUL DENSLEY

AGENDA

Introduction
Criteria
Options
Cost & Schedule

PARTICIPANTS

Guy Armantrout
Bill Brummond
Scott Couture
Mike De Micco
Mike Eberstein
Rino Fanchetti

Fritz Frick
Erna Grasz
Ann Heywood
Milt Hayward
Darrell Hogan
Buzz Pedrotti

DESIGN REVIEW

OBJECTIVE --	Procurement of the Hydraulic Impact End-Effector System for Westinghouse Hanford Company (WHC)
REQUIREMENTS --	Based upon WHC documents Performance Specification MEL92-001809-00
OPTIONS --	Review of WHC work
SELECTION --	Review of WHC work
COST & SCHEDULE --	Review of schedule requirements
SUMMARY --	Procure Hydraulic Impact End-Effector System

PURPOSE OF MEETING

- Review of present Hydraulic Impact End-Effector System and how it was selected.
- Approval to proceed with procurement.

Figure 2-2. Typical Configuration of a 20-ft Single-Shell Tank.

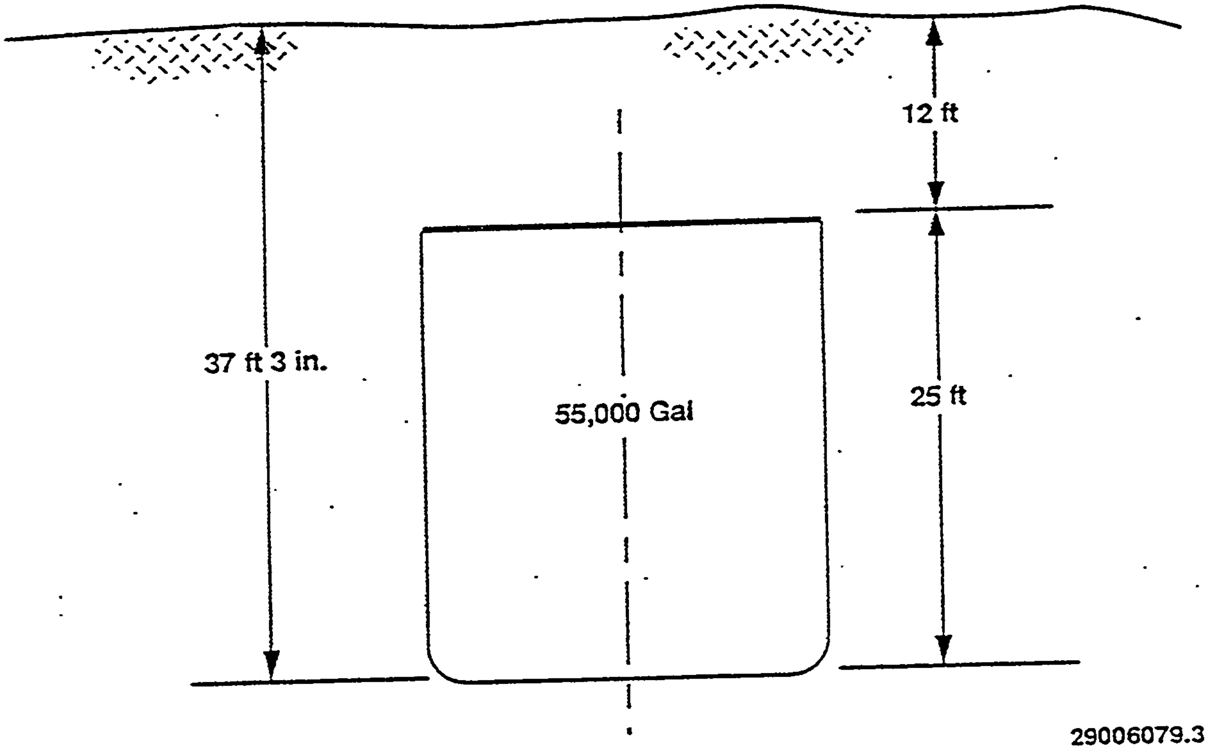
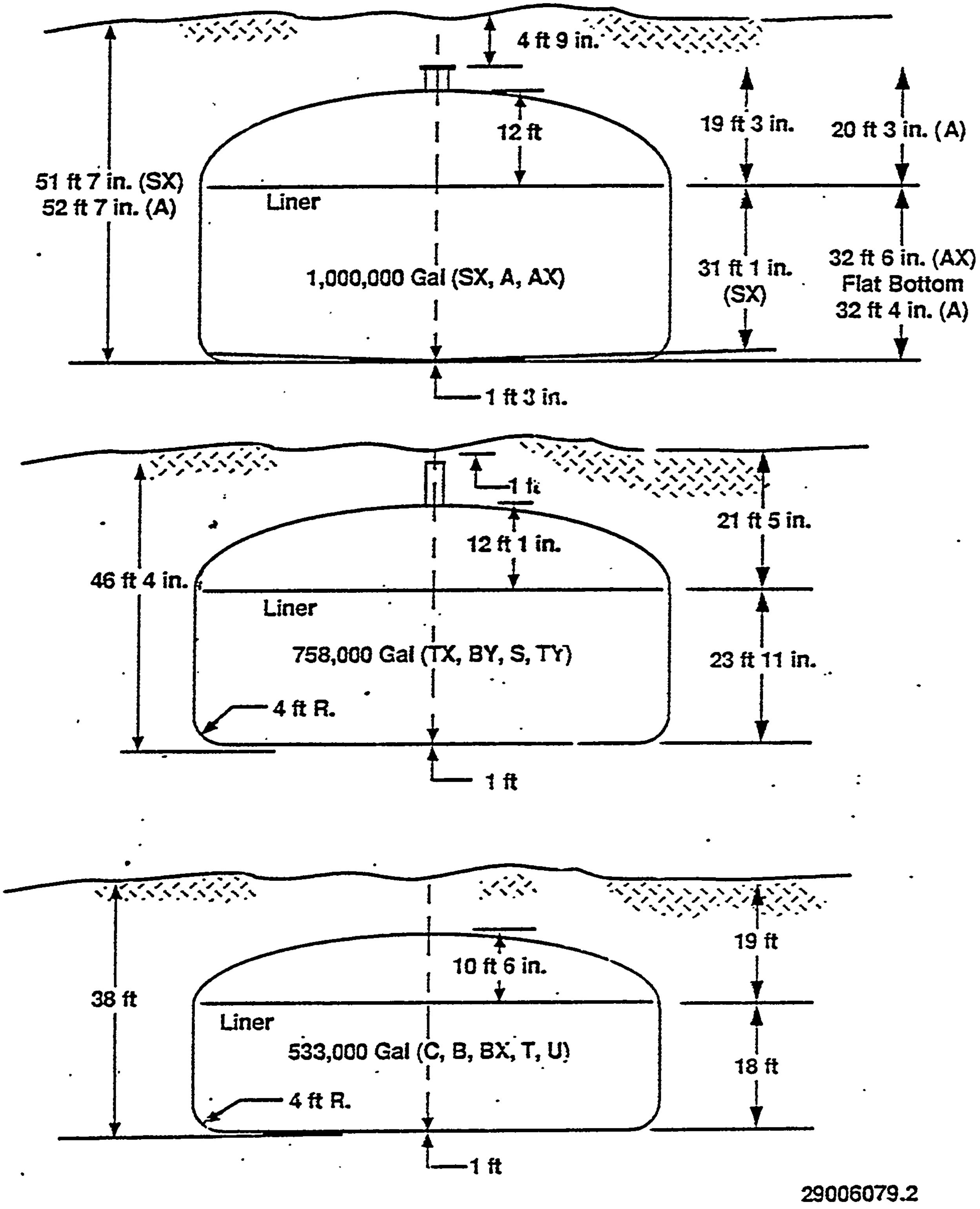


Figure 2-1. Typical Configuration of a 75-ft Single-Shell Tank.



DESIGN CRITERIA

COMPONENT:

- Hard saltcake fracturing/ rubble-forming end-effector system.

FUNCTION:

- Fragment or rubblize monoliths of hard saltcake from the WHC tanks.

REQUIREMENTS:

- Weight less than 200 pounds
- Remotely operated
- Low water usage
- Operate in all orientations
- Fragment/rubblize to less than 2" in any dimension
- Maintain integrity of steel liner
- Limit dust and high-speed fragments
- Limit reaction forces to the maneuvering arm
- Limit reaction forces to the tank structure
- Fit through a 42" diameter cylindrical hole, 12" deep when attached to maneuvering arm

FUNCTIONAL DESCRIPTIONS

HARD WASTE DISLODGING EQUIPMENT:

The In-Tank Maneuvering Arm positions the end-effector into its operating position over the surface of the hard cake. The end-effector then breaks up the hard cake into fragments, captures the fragments, and transfers them into the Waste Conveyance System. Fragmentation and transfer to the hard cake may be by high pressure liquid, high pressure gas or mechanical means; or any combination thereof. The fragments of hard cake exit the tank through the Waste Conveyance System.

RUBBLIZING EQUIPMENT:

The Rubblizing end-effector is closely related to the Hard Waste Dislodging Equipment. However, the Rubblizing end-effector does not transfer waste to the Waste Conveyance System. Instead, the purpose of this end-effector is only to break up monolithic, or large pieces of hard cake into smaller fragments that can be more readily handled by the Post-Rubblizing Equipment.

POST-RUBBLIZING EQUIPMENT:

After the hard cake in the tank has been broken up by the Rubblizing Equipment many fragments are too large to pass through the Waste Conveyance System without further processing. Such further processing is provided by the Post-Rubblizing end-effector.

GENERAL DESIGN REQUIREMENTS

ENVIRONMENTAL:

- Atmosphere inside the tank is air, monitored for explosive concentrations.
- Water content from 35% to 100% relative humidity.
- Temperature from 65°F to 200°F.
- Pressure from -9 in. w.g. to 0 in. w.g. relative to external atmosphere.
- Radiation level 5000 rads/hr, total exposure of 10^7 R gamma.
- Waste to be removed is hard, abrasive, brittle material with temperatures from 65°F to 300°F, porosity from 10% to 50%, and pH from 5 to 12. The surface is very uneven, with large irregular formations of hard saltcake having sludge or water around, under and on top of it in varying amounts.

GENERAL DESIGN REQUIREMENTS

DESIGN/ANALYSIS:

- Design life is two years based upon 8760 hrs/year.
- The end-effector shall not exceed a dead weight load of 200 pounds.
- The end-effector shall be able to pass through a 42" cylindrical opening, 12" deep while attached to the Maneuvering Arm.
- Provision shall be made to promptly remove water added to the tank due to the waste retrieval process.
- Portions of the equipment which are subject to being removed or replaced remotely for preventative maintenance or repair, shall incorporate typical hot cell type fasteners and features to facilitate the task.

GENERAL DESIGN REQUIREMENTS

OPERATIONAL:

- The equipment shall be capable of being removed and attached to the end of the In-Tank Maneuvering Arm while the arm is in the end-effector storage/changeout station. To the maximum extent practical, attachment/removal operations shall be accomplished by automatic, remote means, with operator intervention only to correct off-normal conditions.

- The equipment shall provide the operator with the choice of being operated in a fully automatic, autonomous mode with little, or no, operator intervention, or in a manual mode with full real-time operator control.

- Control system interlocks shall be provided as required to assure that commands can not be inadvertently carried out by the end-effector system that could result in injury to personnel or equipment damage.

- Sensors and controls shall be provided as required to alert the operator to any critical out of tolerance process parameters (flow rates, pressures, voltages, etc.) that may indicate impending failure of equipment.

GENERAL DESIGN REQUIREMENTS

MATERIALS:

- Certified materials, where used for fabricated components, do not require documentation of physical and chemical analysis or traceability.
- The use of flammable or hazardous materials shall be minimized to as low as reasonably achievable.
- Hydraulic fluids shall be nonflammable and compatible with a high radiation environment. Consider use of water with water soluble additives.
- All materials, including lubricants and seals, must be compatible with the environmental conditions present in the tank.

RUBBLIZIER DESIGN REQUIREMENTS

- Process hard waste at the rate of 30 gal/minute, as a goal.
- Shall not become easily clogged or jammed by small ITH (e.g., tape, wires, etc.). If clogged or jammed, shall be designed to facilitate removal of such ITH by remote means.
- The ability of this equipment to process hard waste shall not be impacted by the presence of small amounts of soft cake, sludge and liquids that may remain after soft waste removal operations.
- Shall be able to accommodate hard waste of any size or shape and in any orientation, including monoliths.
- Interfaces with the In-Tank Maneuvering Arm for support and mobility.
- Waste breakup may be accomplished by high pressure liquid, high pressure gas, or mechanical means; or any combination thereof. The resulting waste fragments are not passed on to the Waste Conveyance System, but remain inside the tank.
- The size of the pieces of hard waste remaining after being processed by this equipment shall not exceed a dimension of 12 inches measure in any direction.

EQUIPMENT OPTIONS

Air/water cutting/pulverizing

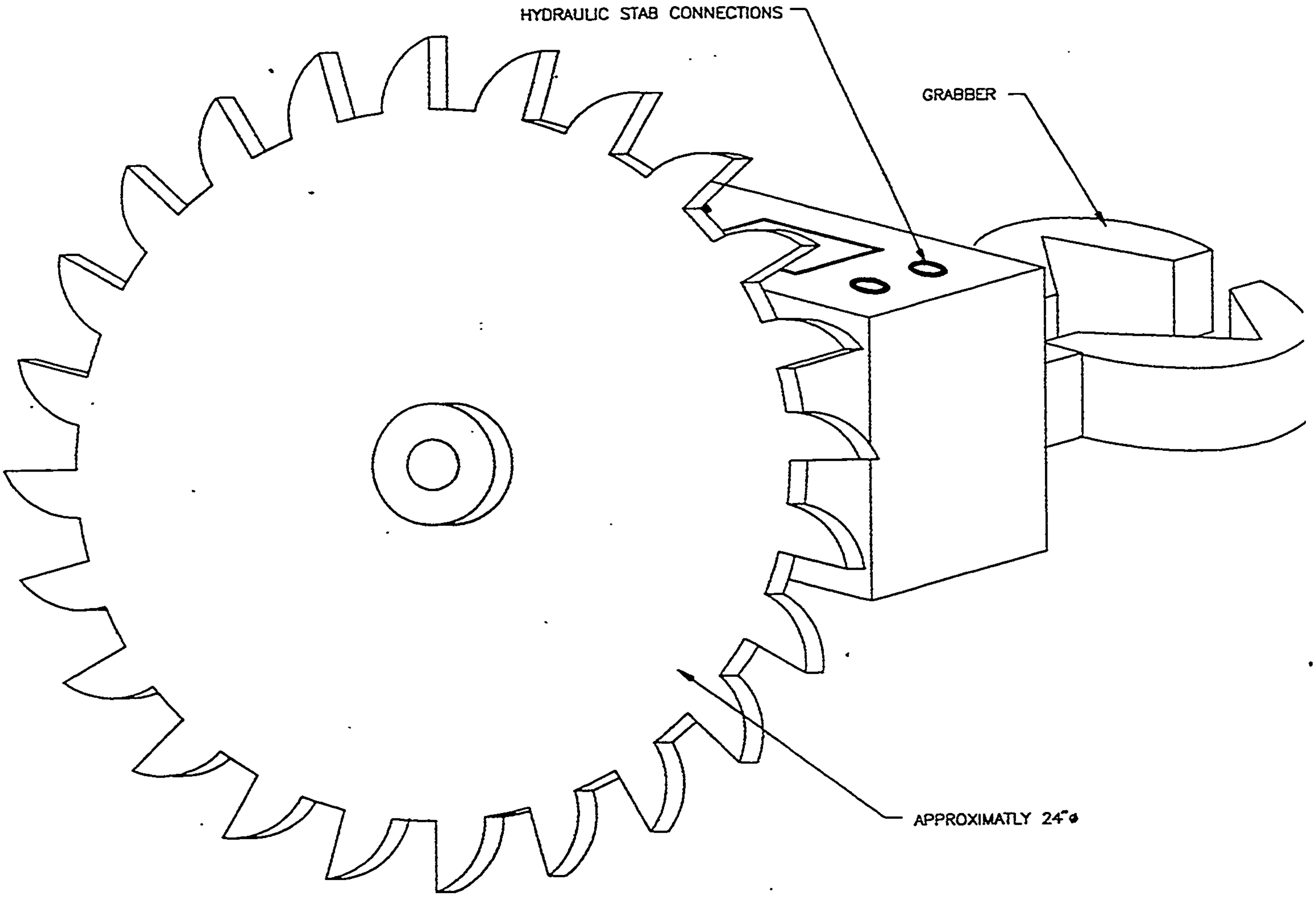
Scabbler

CO_2 pellet blasting

Water cannon

Cavitating water jet

Figure 5-38. Blade Grinder End-Effector.



FEATURES:

- HYDRAULICALLY DRIVEN
- INCORPORATES GRABBER
- REPLACEABLE REMOTELY

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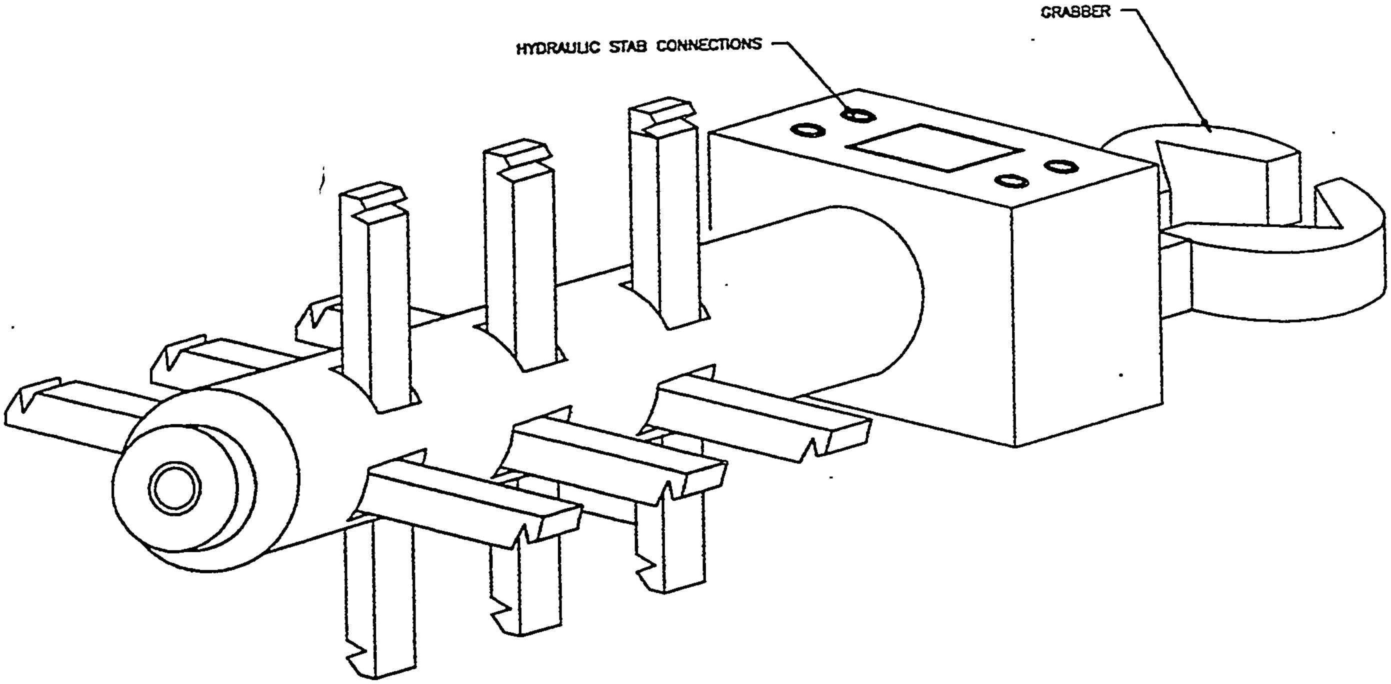
DATE: 8/27/91

Figure 5-37. Hammer Grinder End-Effector.



FEATURES:

- HYDRAULICALLY DRIVEN
- INCORPORATES GRABBER
- CANTILEVER SHAFT
- REPLACEABLE REMOTELY

CADFILE: ZELK0272
DATE: 8/27/91

WASTE DISLODGING SYSTEM OPTIONS

AIR AND WATER JETS (SCARIFIER):

High pressure air/water jet technology could be used to rubblize the hard saltcake waste. A scarifier type of end-effector utilizes ultra high pressure water (55 ksi) or high pressure air (1500 psi) jets. The idea of this end-effector as an inverted can with either UPH water/HP air jets that rotate inside of the enclosure and dislodge the waste. The integration of these two technologies into one end-effector looks like a good approach for cleaning the tank floors and walls.

Figure 5-35. Air/Water Jet End-Effector.

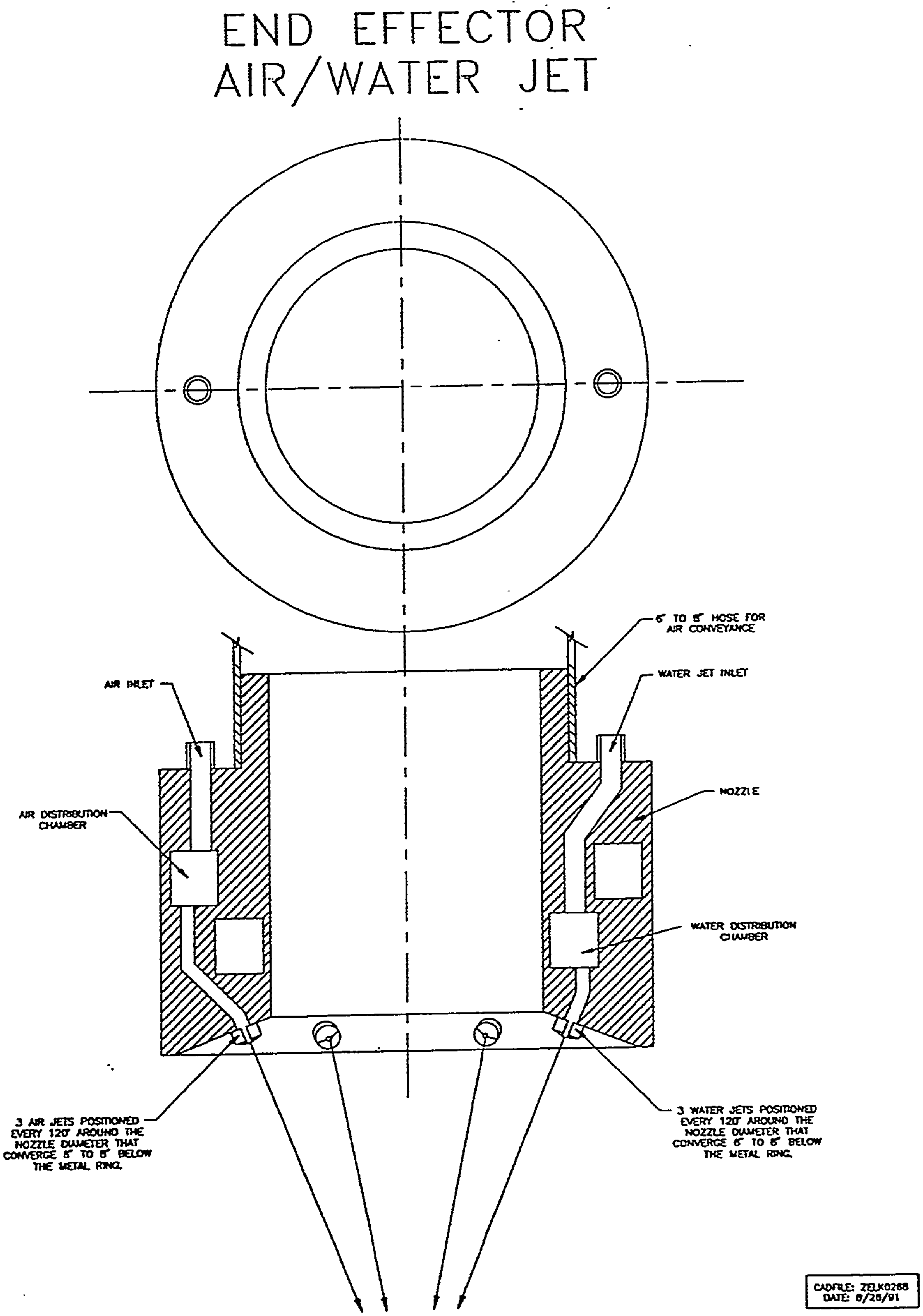
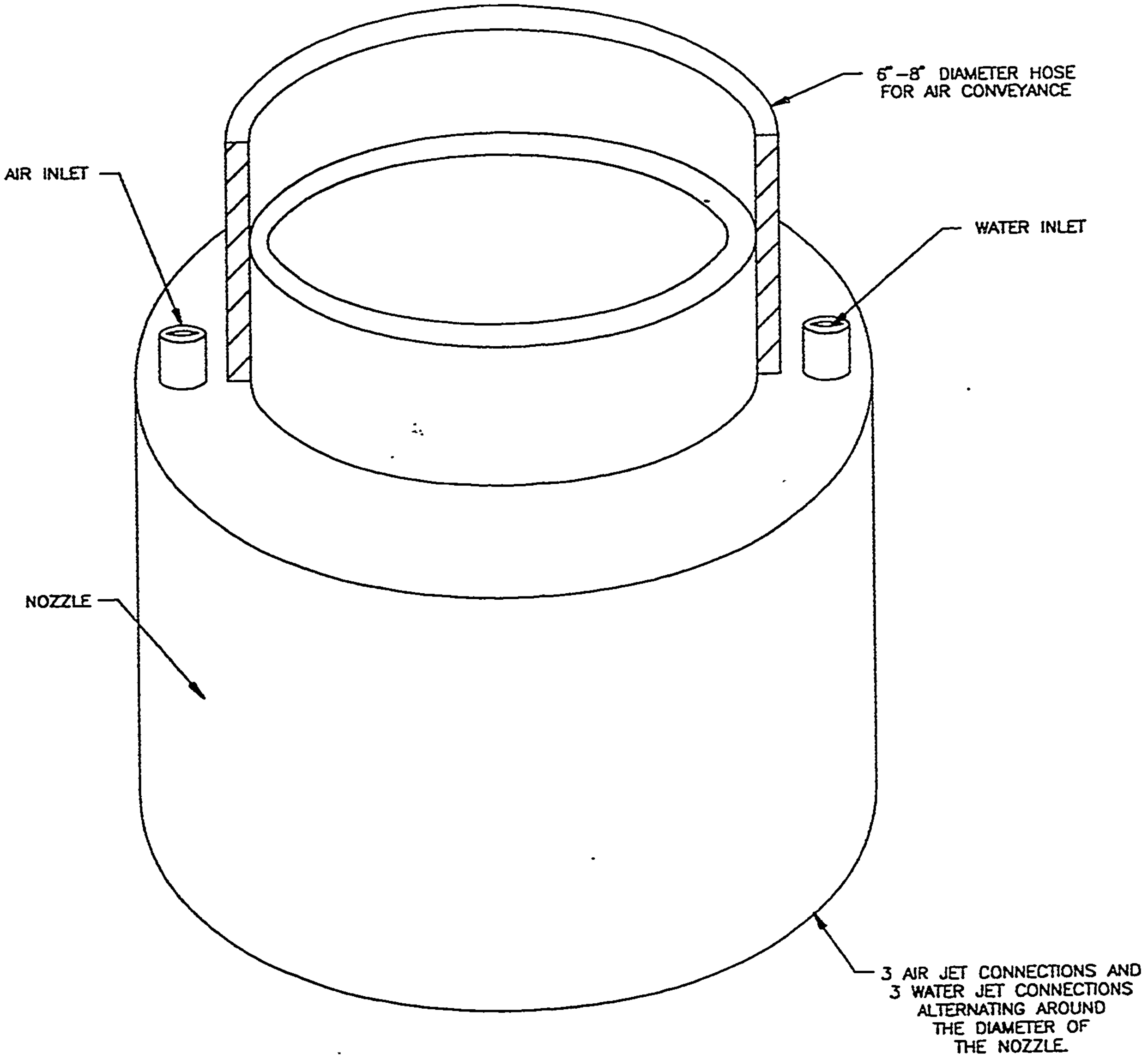


Figure 5-36. Air/Water Jet End-Effector.



METAL RING NOZZLE CONTAINS WATER JETS (PULSED) THAT CONVERGE 6" TO 8" BELOW THE METAL RING. (SEE TEST RESULTS IN REPORT VITRO-R-375, PAGE C9) AIR JETS (AIRKNIFE) AND LOW PRESSURE WATER INJECTION PORTS ARE ALSO SPACED AROUND THE METAL RING TO AID IN AIR CONVEYANCE.

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DATE: 8/26/91

WASTE DISLODGING SYSTEM OPTIONS

SCABBLER:

A scabbler is a large version of a needle scaler. The pneumatic needle scaler is an air driven piston to which the scaler needles are attached. As the piston cycles the scaler needles move up and down impacting the material applying a force which dislodges the material from the surface. This end-effector would be effective to break up hard saltcake and to clean the waste that is encrusted on the tank walls and floor.

WASTE DISLODGING SYSTEM OPTIONS

CO_2 PELLET IMPACT:

This technology is commercially available but would have to be developed as a down-sized custom unit suitable for use as an end-effector. CO_2 pellet blast delivers a high-velocity stream of solid CO_2 pellets to clean or strip a substrate. Upon impact these pellets sublime, i.e., change from a solid to a gas, and simply return to their natural state in the atmosphere, while the material removed falls from the cleaned surface. The potential use for this technology would be in the area of final clean up of the tank floor and the de-scaling of the waste on the walls of the tank. The other attractive possibility for this technology is decontaminating the other end-effectors and equipment in the tank prior to their removal for maintenance.

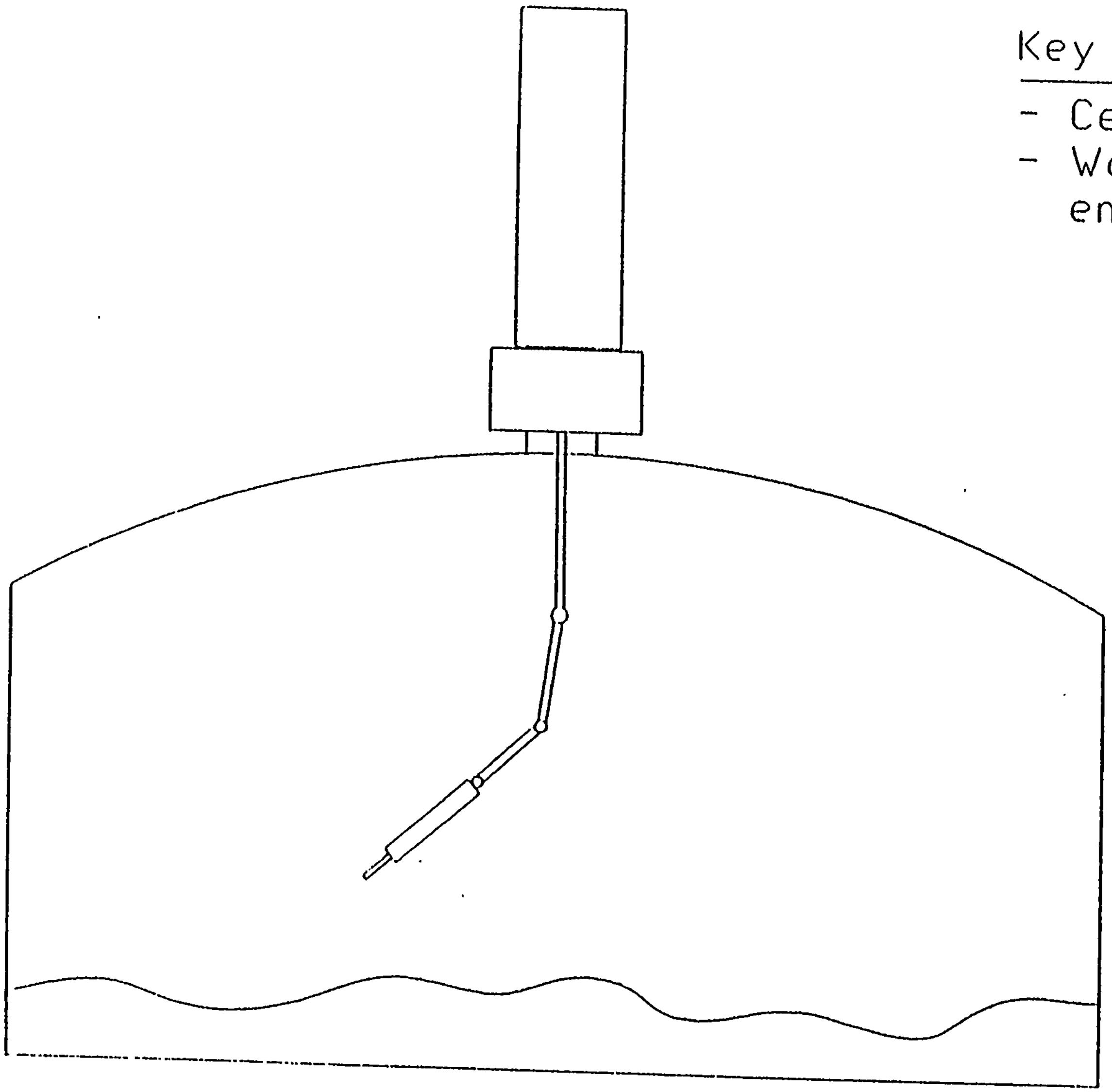
WASTE DISLODGING SYSTEM OPTIONS

HYDRAULIC IMPACT SYSTEMS:

Hydraulic impact equipment is widely utilized for rock fracturing in tunneling and mining operations. The most adaptable of this equipment for use in rubblizing hard saltcake waste is the HYDREX tool manufactured by Quest Integrated, Inc. of Kent, Washington. This tool can supply a means for rapid high-pressure pulse generation for hard salt cake fragmentation. The tool can deliver with a 0.5 gal charge of water approximately 30,000 ft-lbs of energy. The tool can be recharged and fired repeatedly (approximately five to ten seconds). Some early testing has already been done by Quest on simulated hard saltcake. These tests showed that the stand-off distances could be in the range of inches to feet. The results were very encouraging.

Key Features

- Center arm
- Water impact end effector



Center Arm With Water Impact End Effector

FIGURE 4

WASTE DISLODGING SYSTEM OPTIONS

CAVITATING WATER JET TECHNOLOGY:

This technology is similar to the Hydraulic Impact System, but utilizes the erosive action of a water jet, by stimulating the creation of cavitation in or around the jet. This technology has proven capable of maximizing the cleaning or cutting performance for a given input of hydraulic power. This technology uses <20 ksi water pressure to operate, as compared to hydraulic impact systems that use >50 ksi water pressure. With minimal water flow rates, this system will cut the salt cake material and remove it with an air conveyance system.

COST AND SCHEDULE

COST:

The estimated cost for the Hydraulic Impact End-Effector is $90 K. This includes the design, fabrication, testing and installation at the UST Testbed at Hanford, Washington.

SCHEDULE:

This end-effector is to be LLNL's part of the demonstration scheduled for the end of this fiscal year. The UST-ID is a program involving ORNL, WHC, WINCO, SNL, and PNL as well as LLNL in an effort to provide required equipment for the retrieval of waste from the tanks at Hanford. The Hydraulic Impact End-Effector is LLNL's major role in this upcoming demonstration. Failure to meet this milestone would seriously impact the labs credibility and chance for further development opportunities.

SUMMARY

PROCUREMENT OF THE HYDRAULIC IMPACT END-EFFECTOR SHOULD PROCEED.

ADDITIONAL OPTIONS FOR WASTE RETRIEVAL WILL BE EVALUATED.

Attachment 5

QUEST Technical Communication No. 355

HYDRAULIC IMPACT END EFFECTOR INSPECTION AND TEST RESULTS

D. O. Monserud and R. C. Lilley

July 1992

Prepared for
LAWRENCE LIVERMORE NATIONAL LABORATORIES
Under Purchase Order No. B199069

QUEST INTEGRATED, INC.
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1. Introduction

This document describes the results of the Inspection and Testing task for development of a Hydraulic Impact End Effector System. This system is being developed for Lawrence Livermore National Laboratories (LLNL) under P.O. No. B199069. The end effector is designed to dislodge and fragment adherent wastes from the single-shell tanks at the Hanford Reservation near Richland, Washington. The end effector accomplishes this task by the use of high-velocity, small-volume water blasts.

2. Purpose

The tests described in this report are for the purpose of demonstrating the practicality of utilizing ultrahigh-pressure (UHP) technology for adherent waste removal and to determine expected removal rates, fragmentation sizes, dilution levels, cycle rates, dead weight loads, and reaction forces. These tests do not fully optimize the adherent waste removal process but evaluate the feasibility of the waste removal by the water blast concept. The test items are described in Section 3.

3. Test Description

3.1 Test Items

1. **Charge Pressure Effects:** Effector discharges at charge pressures of 40,000 and 50,000 psi were examined to determine the charge pressure effect on wastage removal volumes and fragmentation.
2. **Standoff Distance Effects:** Effector discharges at standoff distances of 0, 4, 6, 12, 24, and 36 inches from the sample were tested to determine the effect of standoff distance on wastage removal volumes and fragmentation.
3. **Effector Angle:** Effector discharges at angles of 15, 30, 45 and 90 degrees to the sample material surface were tested to determine the effect of effector angle on wastage removal volumes and fragmentation.
4. **Dilution Level:** The water volume per end effector discharge was determined at various discharge pressures. These volumes, together with the results from test items 1 through 3 above, were used to determine material dilution levels.
5. **Cycle Rate:** The effector was repeatedly discharged at the maximum rate for recharge and reaction damping to determine minimum cycle rate.
6. **Interface Loads:** Loads at the effector mounting interface were recorded prior to and during effector discharge to determine maximum dead weight and reaction loads at the effector interface.

3.2 Test Facilities

The tests were conducted at the facilities of QUEST Integrated, Inc., located at 21414 68th Avenue South, Kent, Washington. All testing was performed in the waterjet laboratory utilizing equipment resident at QUEST.

3.3 Test Equipment

Tests were conducted utilizing the following equipment:

1. **UHP Power Unit:** A dual skid-mounted 20-HP pumpset is in the process of being purchased by LLNL for use in the Integrated Demonstration project (currently scheduled for September 23 and 24, 1992). Since the purchase of this pumpset was not completed in time, two QUEST laboratory pumpsets were provided for LLNL during the Inspection/Testing task. One is a 125-HP diesel-driven pump providing 3.5 gpm at 40,000 psi. The other is a 150-HP electric unit delivering 2.5 gpm at 55,000 psi.
2. **Hydraulic Impact End Effector:** The Hydraulic Impact End Effector was constructed under this contract and consists of a scaled-down version of existing technology. This effector has a theoretical discharge of 7 cubic inches at 40,000 psi. Figure 1 illustrates the Hydraulic Impact End Effector.
3. **UHP Transducer:** End effector charge pressures and rates were traced by a UHP transducer with an operating range of up to 60,000 psi. The transducer is a Precise Sensors model D451-60000-01-6-ISF-8P10-07 that was calibrated to NBS standards at its date of manufacture on 1/11/91.
4. **UHP Gauge:** The UHP power unit supply was monitored by the use of hydraulic gauges proportional to the UHP level.
5. **Load Cells and Strain Gauges:** Dead weights and reaction forces were monitored by strain gauges. Two full bridge assemblies were prepared, one on an aluminum bracket, the other on steel. The aluminum bracket cracked, which resulted in questionable gauge traces, so the steel bracket was used for all reaction tests.
6. **Recording Devices:** Static pressures and loading were recorded from transducer read-outs. Transient responses were recorded on a Nicolet model 4094 high-speed digital oscilloscope. A Measurements Group model 2310 signal conditioner was used to amplify the strain gauge waveform. The Nicolet was calibrated 1/15/92 by EIL Instruments Inc.

3.4 Test Samples

Five sample types for the end effector discharge tests were used. Most of the samples were fine-grained sulfer k-mag fertilizer blocks cast in approximately 1 foot cubes (Figure 2). These were prepared in a small concrete mixer with a ratio of 150 lb of fertilizer to 10.5 liters of water. The samples were cast in plastic-lined boxes and cured for a minimum of one week before being used in testing. This recipe was furnished by Mr. Monte Elmore of Pacific Northwest Laboratories as a representative test simulant for hard saltcake waste. The other four sample types were for comparative fracture tendency. One was a commercial salt lick block (Figure 3). The second was a 12-inch concrete cylinder (Figure 4). The third was an 8-cubic-foot block made of fine-grained mixed with medium-grained sulfur k-mag fertilizer. The fourth was 1 foot cubes (five total) of medium-grained sulfur k-mag fertilizer.

The fine-grained sulfur k-mag fertilizer was purchased from Western Agricultural Chemicals of Houston, Texas, and is described as "feed" grade. The particles are of crushed angular shape of approximately 1/16 inch minus in size. The medium-grained sulfur k-mag is also produced by Western Agricultural Chemicals under the label of Nu-Life fertilizer and is composed of round grains of approximately 1/16 to 1/8 inch in diameter.

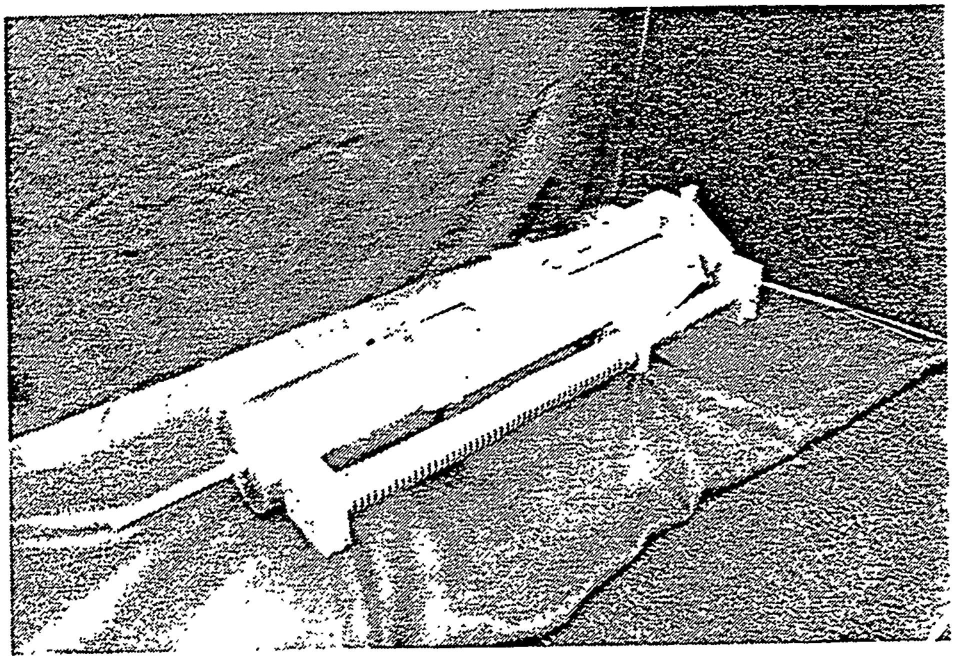

Figure 1

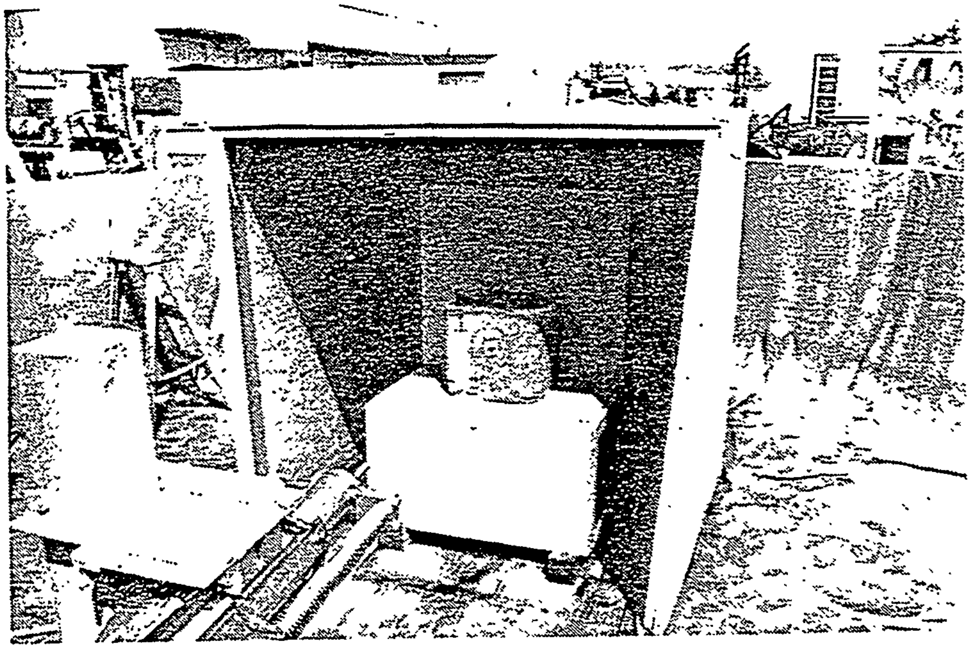

Figure 2

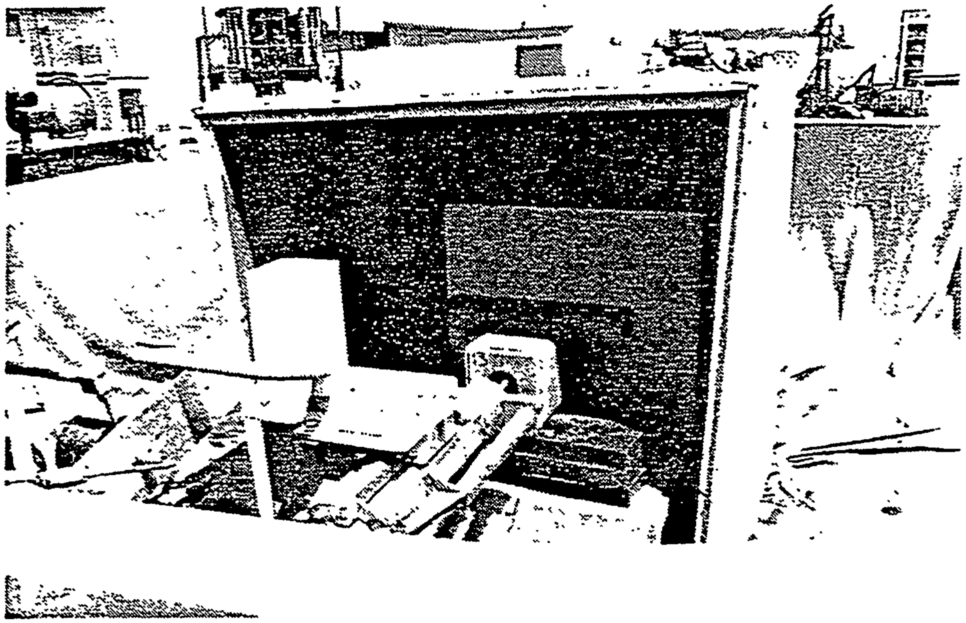

Figure 3

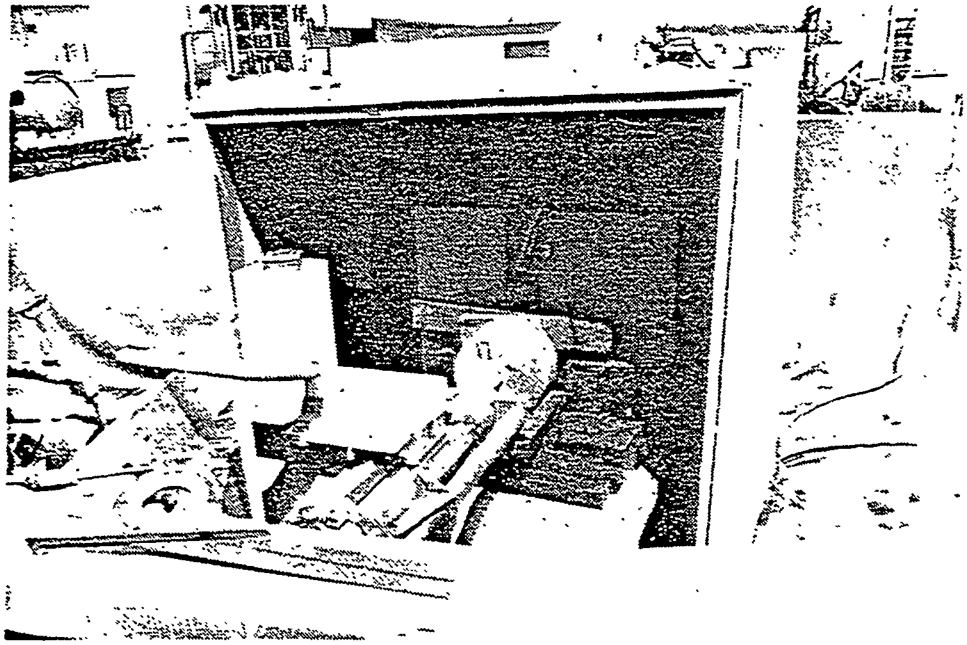

Figure 4

3.5 *Test Descriptions*

The tests were performed in QUEST's Waterjet Technology Laboratory. Two mounting frames were fabricated, one for the sample (Figure 5) and the second for the end effector (Figure 6). Rotation of a mounting bracket on the frame allowed for discharging in the horizontal, vertically upward, and vertically downward positions. A plastic swimming pool was used to provide containment of all fragmented sample material. Figure 6 illustrates the test area. The general procedure for each test was as follows:

1. Weigh sample and record weight.
2. Determine and mark the center of one sample face.
3. Place sample in test area. Position end effector with a proper standoff distance and angle from the sample while aiming at the marked center.
4. Charge end effector to charge pressure (one each of previously stated pressures in each position). Record charge pressure.
5. Discharge end effector.
6. Photographically record test area following discharge.
7. Weigh remaining sample and record weight.
8. Gather any fragments of over 2 inches in diameter. Measure and record dimensions and weight of fragments.

Specific tests for each test item were as follows:

1. **Charge Pressure Tests (Figure 7):** Charge pressure tests were conducted to test end effector charge pressures of 40,000 and 50,000 psi. Each charge pressure was performed in the horizontal position. This is a functional test to determine wastage removal volumes and fragmentation as a function of charge pressure.
2. **Standoff Distance Tests (Figure 8):** Tests were performed to evaluate the end effector performance standoff distances of -1.5 inches (1.5-inch penetration into a hole), 0, 3, 3.25, 4, 6, 12, 24, and 36 inches. Discharge at each distance was performed on the one-foot cube samples of fine-grained sulfur k-mag. All tests were conducted in a horizontal position at a charge pressure of 40,000 psi following the general procedure.
3. **Effector Angle Tests (Figure 9):** Effector angle tests were performed to evaluate the end effector performance at four angles of 0, 15, 30, and 45 degrees off of a perpendicular discharge direction. All tests were conducted in a horizontal position at a charge pressure of 40,000 psi following the general procedure.
4. **Dilution Level:** Tests were performed to evaluate the water volume discharged at various pressures from the end effector. The end effector was discharged into the closed chamber at pressures of 10,000, 20,000, 30,000, and 40,000 psi. The water volume in the chamber was collected and measured. The water volumes from these tests were used together with the results from the tests for items 1, 2, and 3 to analytically determine dilution levels.
5. **Cycle Rate Tests (Figure 10):** Tests were performed to evaluate the maximum operating cycle rate for the end effector. The charge pressure was monitored by a UHP transducer and recorded on a recording instrument. Reaction loads were monitored by strain gauges attached to the end

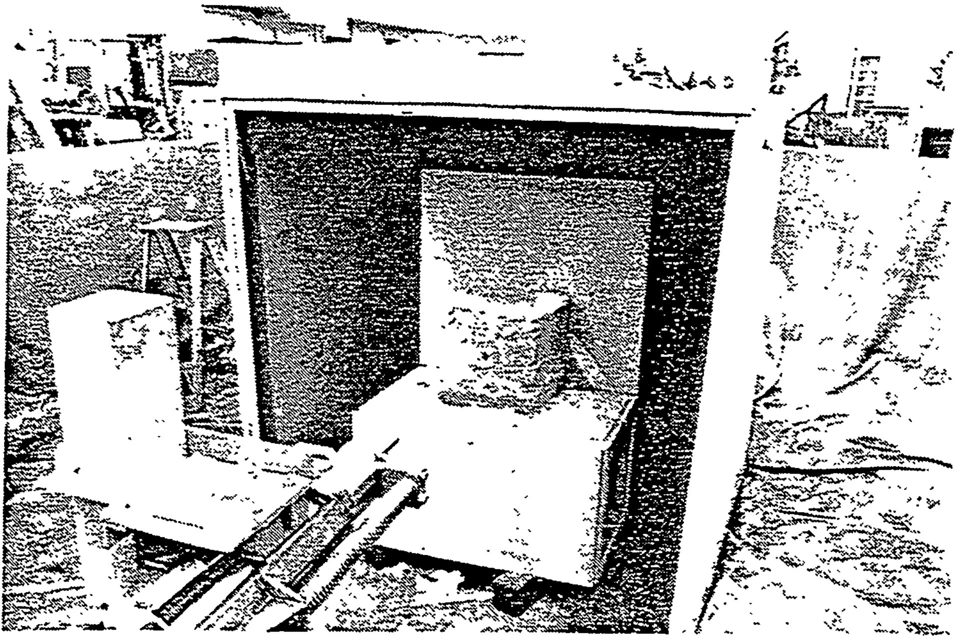

Figure 5

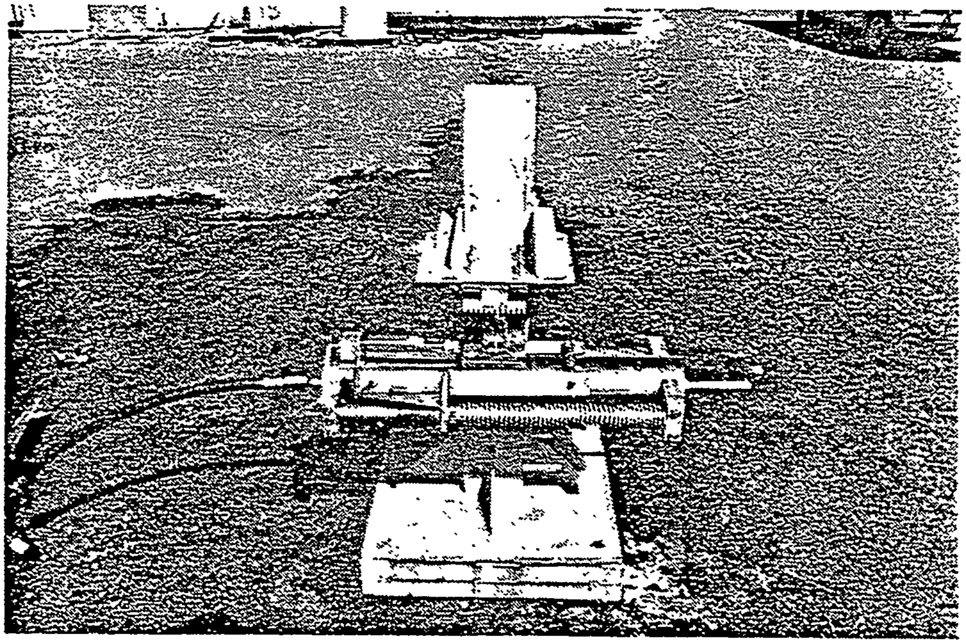

Figure 6

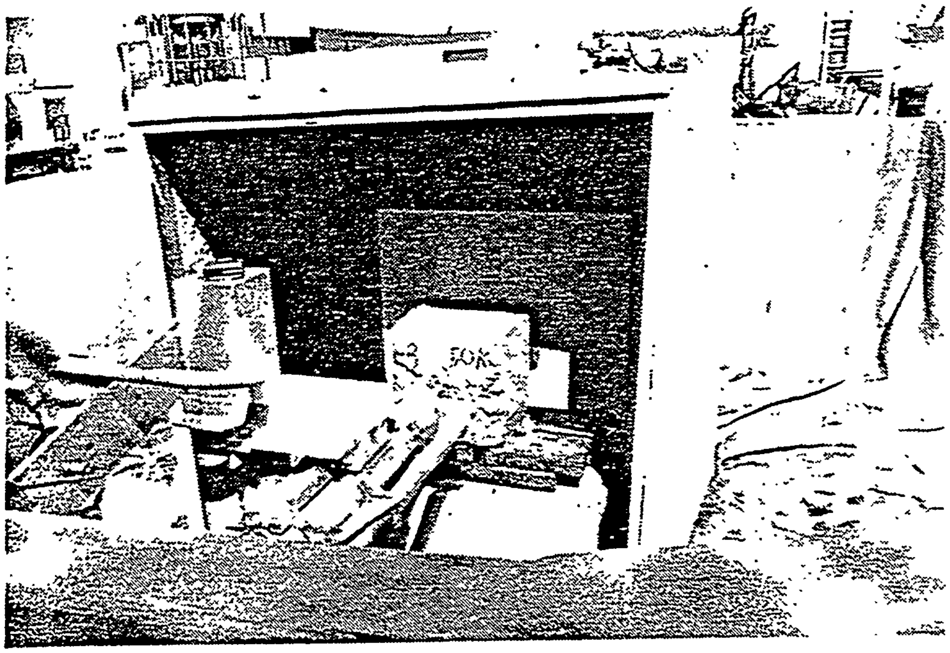

Figure 7

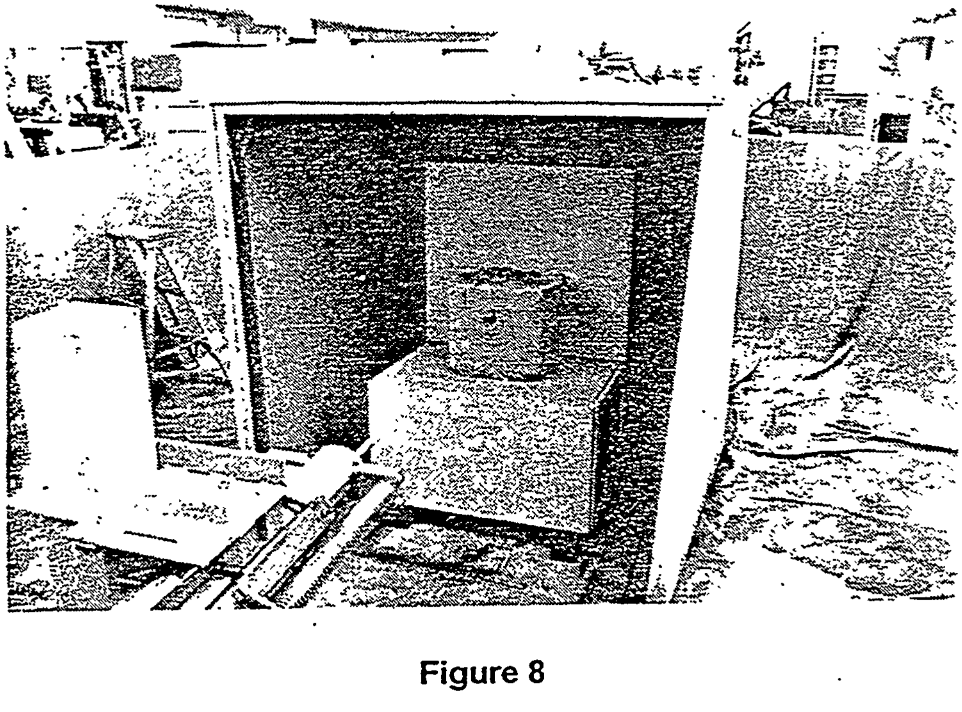

Figure 8

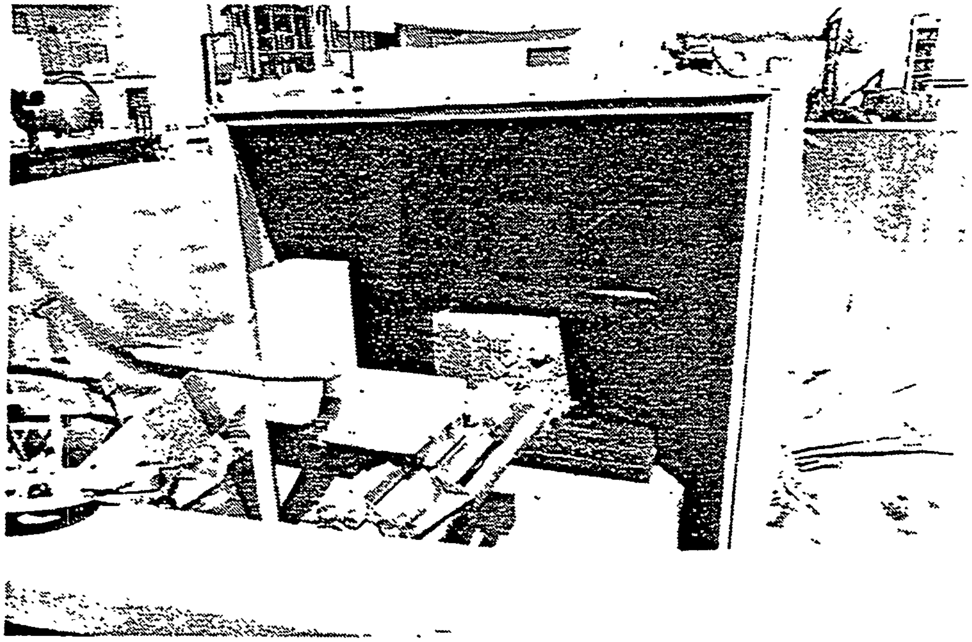

Figure 9

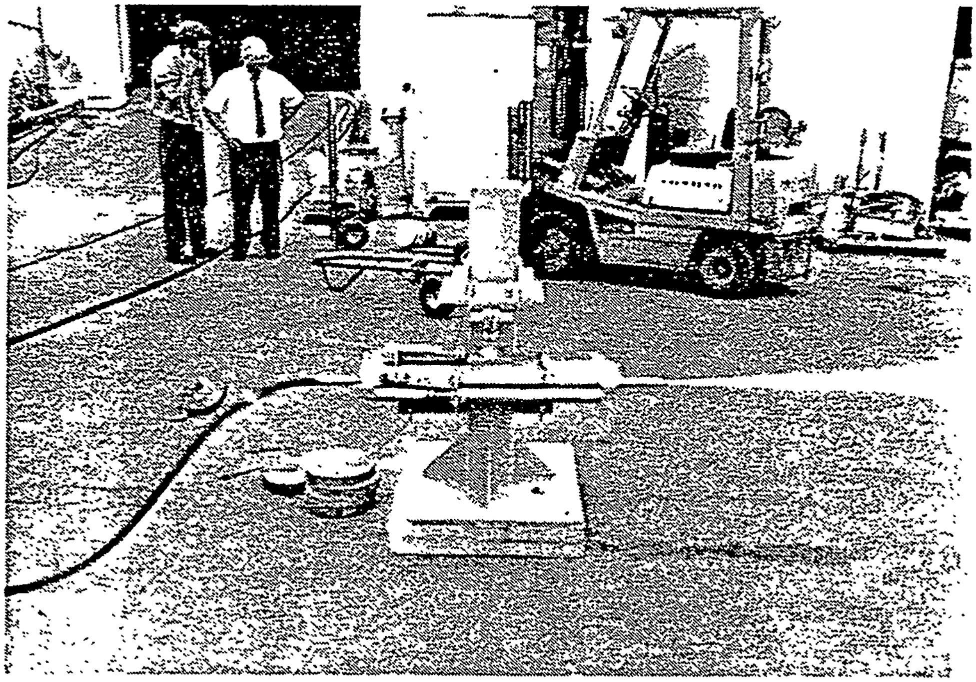

Figure 10

effector mounting (see description below of test for item 6). For the purpose of determining the cycle time, the following definition was used: When these loads fell to less than 5% of the maximum reaction load, the end effector was charged to charge pressure and then discharged. On this basis, the charge/discharge cycle was calculated for three test cases.

6. **Interface Load Tests (Figure 11):** Tests were performed to determine the interface loads that the end effector induced on its mounting structure. Strain gauges were attached to the end effector mounting to determine loads along axes normal, parallel, and perpendicular to the end effector centerline. The end effector was then charged and discharged in vertical upward, vertical downward, and horizontal positions. The vertical tests were conducted under tests for item 1, and the horizontal tests were conducted under tests for item 5.

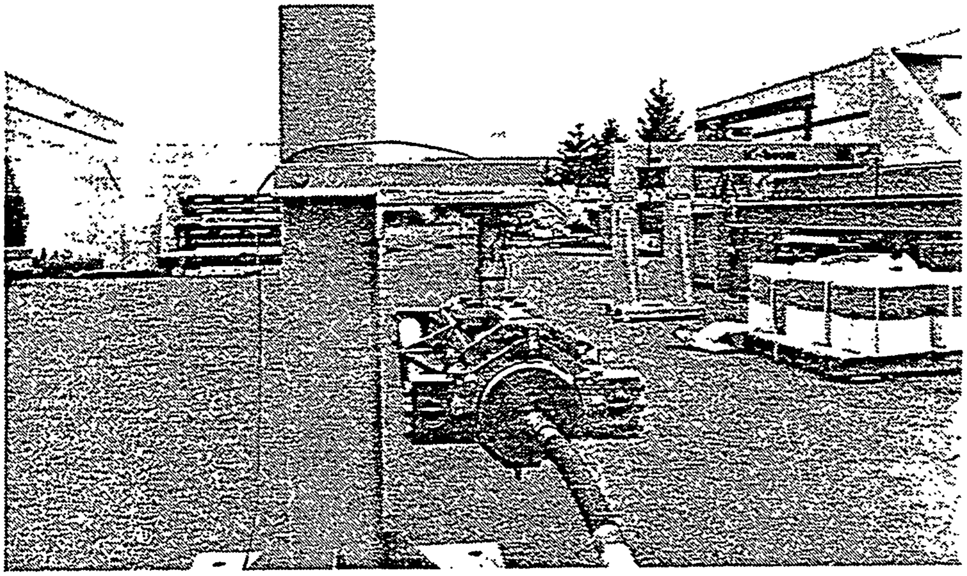

Figure 11

4. Test Results

4.1 Results of Specific Tests

1. **Charge Pressure Tests (Figure 7):** Initially, charge pressures less than 40,000 psi were tested on a trial sample with no appreciable effects, so the documented tests were all carried out at 40,000 and 52,000 psi. Table 1 lists test results at zero standoff and zero end effector angle (tests no. 11, 12, 13, 17, 18, 19, 20, and 21). In general, the 52,000-psi charge pressure was much more effective. All three 52,000-psi tests (no. 18, 19, and 21) broke the sample into several large pieces, while only one (test no. 13) out of the four 40,000-psi tests broke the sample into pieces. A concrete core sample 9-5/8 inches in diameter by 5 inches long fractured into three pieces after three shots at 40,000 psi. The compression strength of the concrete is unknown but appeared to be harder than the saltcake simulant. The reason that the concrete fractured appears to be due to its smaller size and because the concrete is probably more brittle than the saltcake simulant.

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Table 1. Impact Test Results

Test No.	Test Type	Charge Pressure (psi)	Effector Angle (degrees)	Standoff Distance (Inches)	Sample Weight (lb)	Weight Under 2" Ø (lb)	Weight Over 2" Ø (lb)	Comments
1	Standoff	40K	0	36	147	1-1/2	145-1/2	
2	Standoff	40K	0	24	149.5	1-1/2	148	
3	Standoff	40K	0	12	130	11.5	118-1/2	Broke into 5 pieces
4	Standoff	40K	0	6	148	2-2/3	145-1/4	
5	Standoff	40K	0	6	145-1/4	3-3/4	141-1/2	
6	Standoff	40K	0	4	148	1-1/4	146-3/4	Hole 4" x 2" x 2" deep
7	Cycles	40K	0	4	146-3/4			Tool not operating
8	Standoff	40K	0	6	145-1/4			Sample from #4
9	Standoff	40K	0	0				
10	Standoff	40K	0	12				
11	Standoff	40K	0	1-1/2 P*	145-1/2			Sample from #1 2-1/2"x 1-1/2 deep
12	Standoff	40K	0	1-1/2 P				
"	Standoff			1-1/2 P				Hole 3" deep
"	Standoff			3 P				
"	Standoff			3 P				Hole 4-1/2" deep
"	Standoff			4-1/2 P				
"	Standoff			4-1/2 P		13	132-1/2	Hole 8-1/2" deep

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* P = Penetration

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Table 1. Impact Test Results (Cont.)

Test No.	Test Type	Charge Pressure (psi)	Effector Angle (degrees)	Standoff Distance (inches)	Sample Weight (lb)	Weight Under 2" Ø (lb)	Weight Over 2" Ø (lb)	Comments
13	Standoff	40K	0	0	50	3/4	49-1/4	Salt Block Hole 2"Ø x 1-1/2"
"	Standoff	40K	0	0	49-1/4			
"	Standoff	40K	0	0		4-1/4	45	Block broke in half
14	Angle	40K	30	3	130.5			Spalling Did not Occur
15	Angle	40K	45	3-1/4				
16	Angle	40K	15	3		2	128.5	
17	Angle	40K	0	0				Cement Core 3 shots broke in 3 pieces
18	Standoff	52K	0	0	133.5	23.5	110	Broke in 5 pieces
19	Standoff	52K	0	0	143			Hole 3" Ø x 3/4" deep
"	Standoff	52K	0	0				Broke off 1/3
"	Standoff	52K	0	0		6	137	Broke into 6 pieces
20	Standoff	40K	0	0	143	1/4	142-3/4	No barrel used. 1-1/2 Ø x 1" deep
21	Standoff	50K		0	142-3/4		70	No barrel used. Shattered Sample

2. **Standoff Distance Tests (Figure 8):** At 40,000 psi and 12 inches or closer, the surface damage consisted of a small pocket 1 to 2 inches in diameter by 2 inches deep. Beyond 12 inches, there was little if any surface damage, so all additional tests were conducted at zero standoff. Table 1 lists the standoff test results at distances of -1.5 inch (1.5 inch penetration into a hole), 0, 3, 3.25, 4, 6, 12, 24 and 36 inches. The standoff range where the end effector is effective at waste removal and fragmentation is inconclusive from these test results. Performance improvements described in Section 5 of this report need to be addressed before standoff distance can be evaluated.

3. **Effector Angle Tests (Figure 9):** Effector angle tests were performed to evaluate the end effector performance at the four angles of 0, 15, 30, and 45 degrees, where 0 degrees is perpendicular to the sample surface. All tests were conducted in a horizontal position at a charge pressure of 40,000 psi following the general procedure. No spalling occurred at any angle, as shown in Table 1. These results are inconclusive because of the generally limited performance at the 40,000-psi charge pressure.

4. **Dilution Level:** Tests were performed to evaluate the water volume discharged at various pressures from the end effector. The end effector was discharged into a large capped tube at pressures of 10,000, 20,000, 30,000, and 40,000 psi. Table 2 lists the collected volume per discharge. The average water discharge volumes from these tests were used together with the results from tests for items 1, 2, and 3 to analytically determine dilution levels as shown in Table 3. The wide variance in dilution levels reflects differences in the removal rate at different test conditions. Tests no. 18 through 21 reflect the 52,000-psi results, which are the best to consider for minimal dilution.

5. **Cycle Rate Tests (Figure 10):** Tests were performed to evaluate the maximum operating cycle rate for the end effector. The charge pressure was monitored by a UHP transducer and recorded on a recording instrument. Reaction loads were monitored by strain gauges attached to the end effector mounting (see test description for item 6 in Section 3). For the purpose of determining the cycle time, the following definition was used: When these loads fell to less than 5% of the maximum reaction load and when the end effector had reached charge pressure, the effector could again be discharged. Figure 12 is a representative plot of typical discharge times verses reaction loads and charge pressures for four operating cycles. On this basis, the charge/discharge cycle was calculated for three test cases. Table 4 gives a summary of charge and discharge times.

6. **Interface Load Tests (Figure 11):** Tests were made to determine the reaction loading developed by the Hydraulic Impact End Effector at the mounting interface. To determine these loads, a strain-bar-type load cell was manufactured and installed between the end effector and the test mounting stand. Figure 13 illustrates the load cell. The load cell consisted of a 6-inch-long steel tube with 1/2-inch-thick mounting flanges on each end. Eight strain gauges were attached to the cylinder with four parallel to the cylinder's axis at 90-degree intervals about the circumference. Two of these gauges were employed to measure axial strain in the cylinder, and two were employed to measure strains due to bending moments induced by loads parallel to the end effector's axis. The other four gauges were mounted between the axial gauges at 45 degrees to the cylinder axis. These gauges were used to record torque moments about the cylinder axis. Power was supplied to the strain gauges, and output voltages were obtained for recording by a multifunction strain gauge amplifier. The output signals were recorded on a high-speed recording digital oscilloscope. The determination of these three items (axial load, bending moment, and torsional moment) provides for the calculation of reaction loads at the end effector mounting interface. These loads consist of the tensile load normal to the end effector axis, the transverse load along the end effector axis, and torsional moments about the mounting axis.

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Table 2. Discharge Volumes

Test No.	Charge Pressure (psi)	Charge Cycles	Discharge Volume (ml)
1	10K	10	1450
2	20K	9	1375
3	30K	10	1780
4	40K	10	2025

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Table 3. Dilution Levels

Impact Test No.	Salt Under 2" Ø (lb)	Water Weight (lb)	Dilution Level H_2O (lb)/salt (lb)
1	1.5	0.39	0.26
2	1.5	0.39	0.26
3	11.5	0.39	0.034
4	2.75	0.39	0.140
5	3.75	0.39	0.104
6	1.25	0.39	0.312
7			
8			
9			
10			
11-12	13	2.74	0.211
13			
14-16	2	1.17	0.585
17			
18	23.5	0.39	0.016
19	6	1.17	0.195
20-21	73	0.78	0.011

TYPICAL DISCHARGE CYCLES
TIME VS. REACTION LOAD AND CHARGE PRESSURE

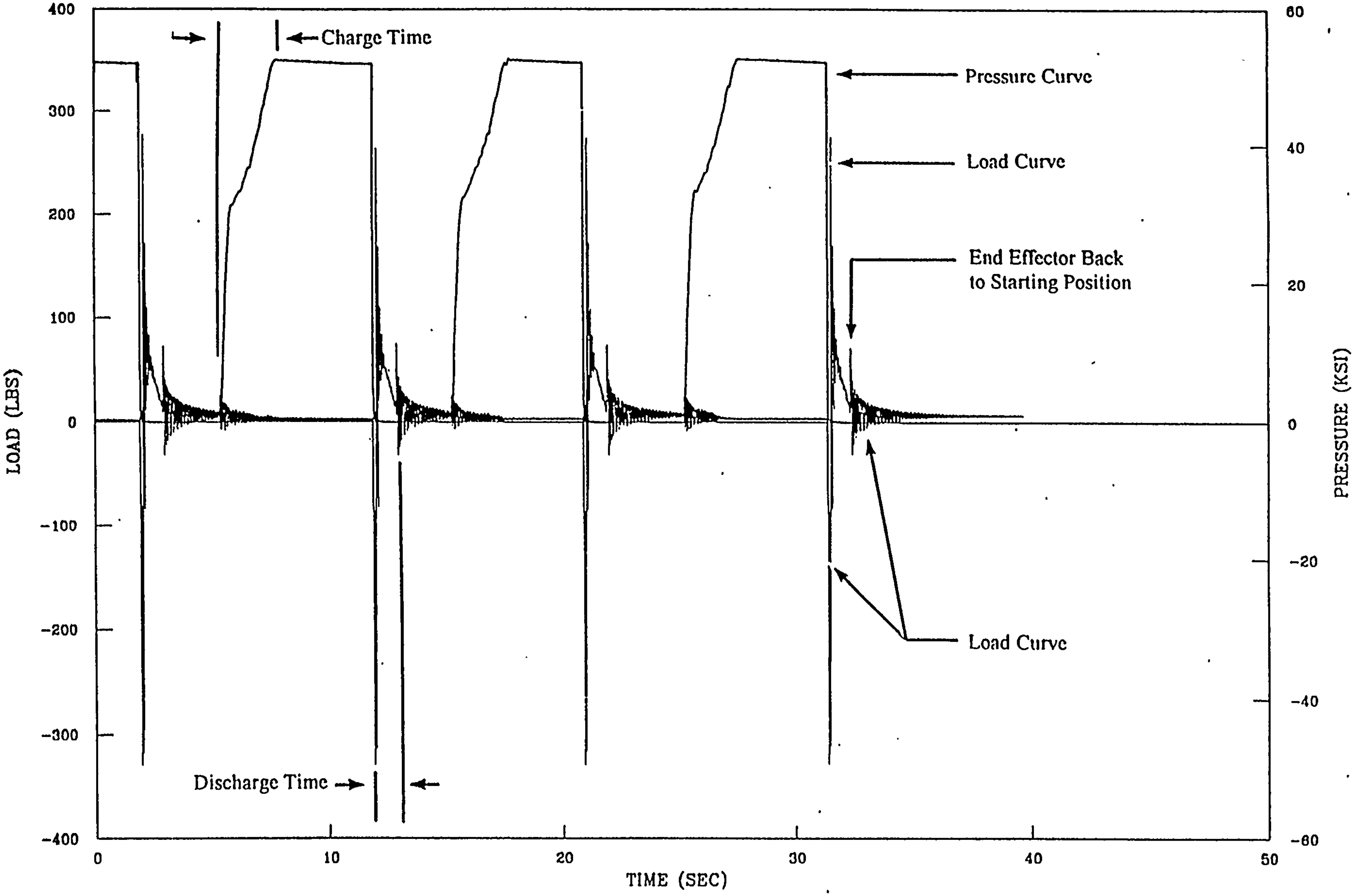

Figure 12

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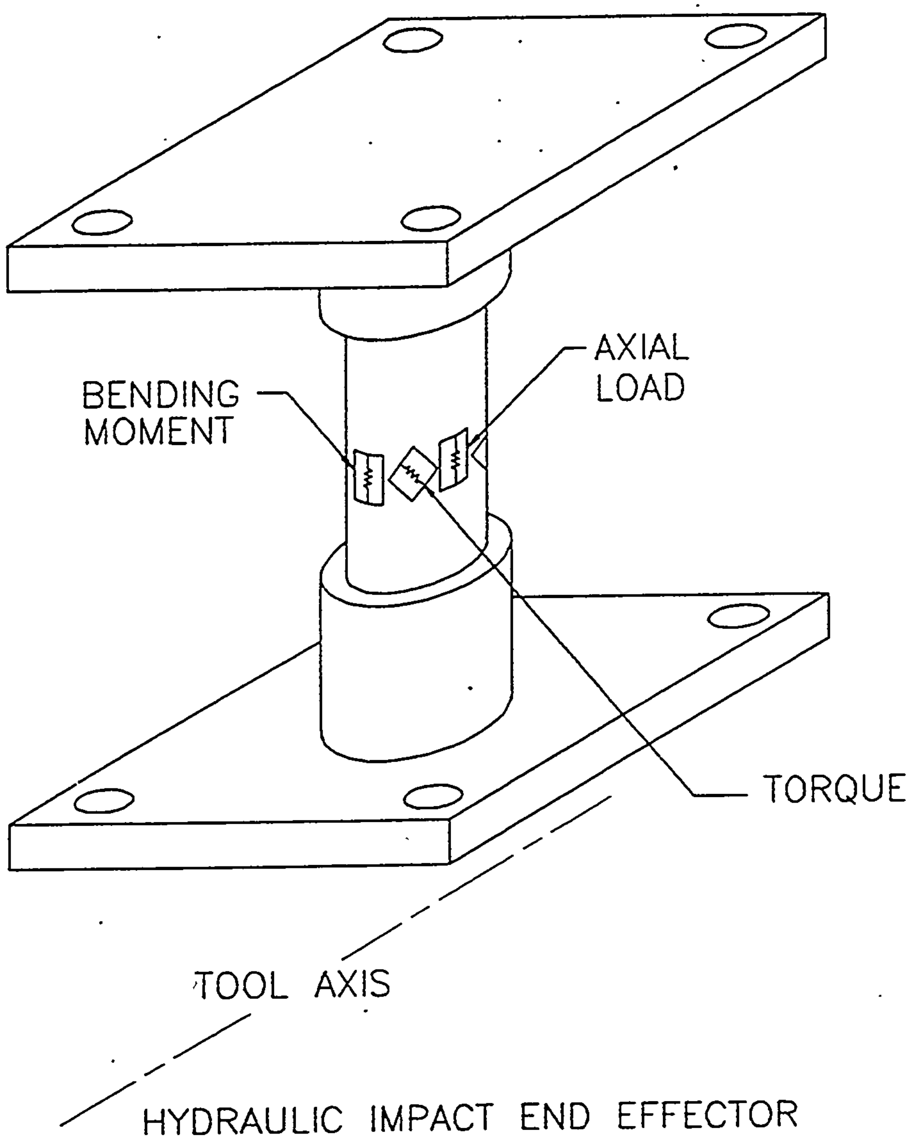
Table 4. Cycle Rate Tests

Test No.	Charge Pressure (psi)	Charge Time (sec)	Discharge Time (sec)
1	50K	2.415	1.010
2	50K	2.455	1.015
3	50K	2.330	0.990



HYDRAULIC IMPACT END EFFECTOR
STRAIN BAR MOUNT

Figure 13

To obtain accurate readings, the load cell was calibrated by known dead weights and a torque wrench. The axial load calibration was made mounting the load cell vertically on the test stand. The weights were then suspended from the end effector mounting and the strain gauge outputs recorded. Weights of 50, 100, 150, and 200 lb were used. The bending moment calibration was made by mounting the load cell horizontally to the test stand. The weights were then suspended from the end effector mounting developing a 7-inch moment arm. Strain gauge outputs for each load were recorded. Weights of 50, 100, 150, and 200 lb were used.

Test operations consisted of mounting the end effector and load cell to the test stand in the desired firing direction and connecting the strain gauges to the amplifier and oscilloscope. The end effector was then charged to the desired charge pressure and discharged. The resultant output from the strain gauges was recorded from end effector discharge until residual loads had dissipated. Figure 12 illustrates the output from typical discharge cycles. Mounting capabilities of the test stand allowed firing of the end effector in three directions: upward, downward, and horizontally. The end effector was discharged in each of these directions to obtain the torque and bending moments and axial load at various charge pressures. Discharges at charge pressures of 20,000, 30,000, 40,000, and 50,000 psi were recorded for bending moments, while 30,000, 40,000, and 50,000 psi were recorded for torsional and axial load.

Table 5 presents the recorded peak voltages and equivalent loads for discharges in each discharge direction at each charge pressure. These results indicate for downward discharges that the maximum axial and transverse loads occur at a 50,000-psi charge pressure with 97.5 and 438 lb, respectively, while the maximum torsional load occurs at a 40,000-psi charge pressure at 42.7 ft-lb. In a horizontal discharge direction, the maximum values for all three loads were obtained at a 50,000-psi charge pressure with values of 109 lb for the axial load, 358 lb for the transverse load, and 43.8 ft-lb for the torsional load. In the upward discharge direction, the maximum values for axial load and transverse load again occurred at a 50,000-psi charge pressure, while the maximum torsional load occurred at a 30,000-psi charge pressure with values of 20 lb, 343 lb, and 26.2 ft-lb, respectively.

4.2 Summary of Test Results

The test results are summarized in the following list:

- A 50,000-psi charge pressure was significantly more effective than a 40,000-psi or lower pressure on the sulfur k-mag simulant.
- Variations in standoff distance from 0 to 12 inches did not affect tool performance.
- Variations in incident angles did not affect tool performance.
- Repeated shots at the same target tended to drill a hole in the sample.
- Insertion of the tool outlet tube into the target hole may improve the fracture ability.
- Coarse-grained simulant was easier to fracture than fine-grained simulant.
- Splitting the outlet flow may increase spalling of material around the impact area.
- The concrete sample fractured to approximately the same degree as the fine-grained simulant samples.
- Cross drilling holes in large samples lead to large-scale fracture.

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Table 5. Interface Load Test Results

Pressure (psi)	Discharge Direction	Axial Strain Gauges (mV)	Bending Strain Gauges (mV)	Torque Strain Gauges (mV)	Axial Load (lb)	Transverse Load (lb)	Torsional Load (ft-lb)
20K	Down		856				
30K	Down	600	1084	1056	78	395	41.0
40K	Down	600	1032	1094	78	376	42.7
50K	Down	750	1204	973	97.5	438	37.9
20K	Up		834				
30K	Up	198	866	145	26	315	5.7
40K	Up	328	928	191	43	338	7.5
50K	Up	835	982	1122	109	358	43.8
20K	Horizontal		852				
30K	Horizontal	128	894	671	16	326	26.2
40K	Horizontal	149	992	567	19	332	22.1
50K	Horizontal	155	942	508	20	343	19.8

5. Conclusions and Recommendations

Two areas can be considered for additional development of the Hydraulic Impact End Effector tool. First, a performance testing program is recommended to improve the removal rate. Second, the development of an alternative UHP fluid system to eliminate the addition of water to the waste tank environment is recommended.

5.1 Improving End Effector Performance

The Hydraulic Impact End Effector tool is capable of fracturing saltcake simulant, but has two problems that impede the removal rate:

- The tool tends to drill a hole rather than spall saltcake simulant material.
- Removal rate is reduced when fracturing a large block of material.

Effective use of this end effector depends on improving the fracturing and removal capabilities. Fracturing was significantly enhanced by increasing the pressure from 40,000 to 50,000 psi. The increase in pressure increases the shock energy of the hydraulic impact. The energy per unit volume of the tool is increased at higher pressures. This is one of several approaches that can be considered for improving the removal rate.

The response of a material to fracture depends on its compressive strength, brittleness, and grain structure. The fact that the concrete sample was as easy to fracture as fine-grained simulant suggests that the interrelation of material properties affects the removal rate by the end effector. It is suggested that removal rates could be predicted if the end effector was tested with materials of known properties and compared to the physical properties of the actual saltcake waste material.

Shock energy can be raised by increasing the internal volume of the end effector. This approach may be effective if combined with containment of the fluid flow. An example of flow containment is inserting the tool outlet into a hole in the simulant before firing the tool. The containment serves to resist fluid outflow and thus increases pressure within the hole. The pressure serves to fracture the simulant material hydraulically. Better containment of the outflow could greatly increase the hydraulic fracturing pressure. An example is the addition of a seal between the tool outlet and the simulant hole. Most likely, the reason why the coarse-grained simulant is so much easier to fracture is probably because the fluid forced at high pressures through the material pores caused increased fracturing.

Shock energy can also be raised by faster operation of the poppet valve within the tool. This could be accomplished by modifications in the poppet valve design.

The geometry of the tool outlet may improve the fracture rate. As an example, the wedge-shaped attachment mounted on the outlet end served to split the flow. The result was increased spalling around the impact area. Further development of the outlet geometry may serve to direct the energy more efficiently. For example, a slot-shaped outlet might be better for causing a controlled fracture line.

5.2 Alternative Fluid System

The use of UHP water as a hydraulic fracturing medium adds water to the waste tank. Efforts in this program have already been made to minimize water use by operating at the highest pressure possible and by timing the control valves to reduce water loss during the vent and charge cycles. Another approach for hydraulic impact operation is to eliminate the water altogether by using an alternative fluid that vaporizes at ambient temperature.

The use of a UHP fluid that will vaporize at ambient temperature has the potential for eliminating liquid waste. With this approach, after the high-pressure fluid exited the end effector, the rapid vaporization at ambient temperature and pressure converts it to a gas, making it suitable for treatment by an air filtration system. If the amount of suspended dust from the fracturing is small, then it would be practical to remove these contaminants by filtration.

Candidate fluids include inert substances such as liquid carbon dioxide, liquid nitrogen, and environmentally safe freons. Development is need for the following elements of a vaporizing liquid ultrahigh-pressure system:

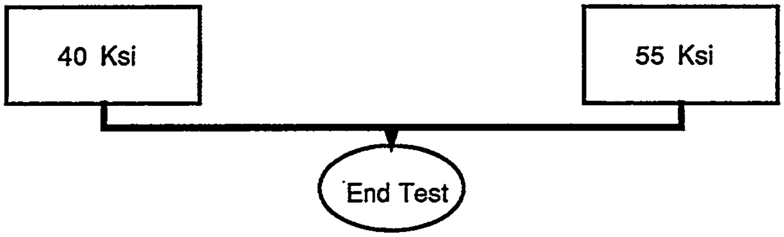
- UHP pumping system for vaporizing liquid operation.
- Compatible Hydraulic Impact End Effector.
- Compatible UHP hose and tubing.
- Compatible low-speed swivel fitting.
- Compatible quick-disconnect fitting.

Other decontamination and decommissioning applications would also benefit from the development of a UHP alternative fluid system because of the potential for eliminating liquid waste. Examples are UHP waterjet decontamination and UHP abrasive-waterjet cutting.

ATTACHMENT 6

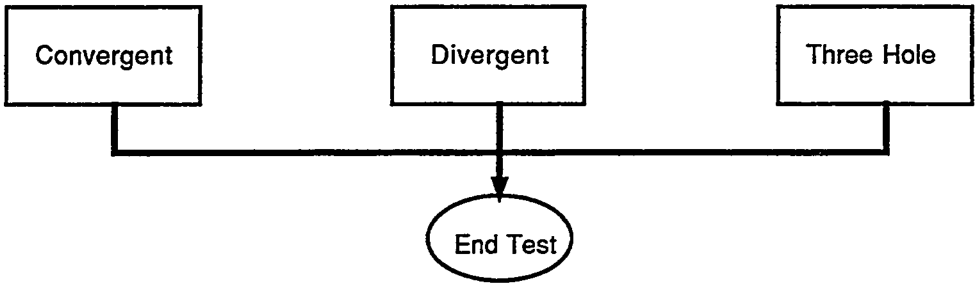
BASELINE TEST

Cubic foot samples
2" stand off
Standard nozzle
4 shots each



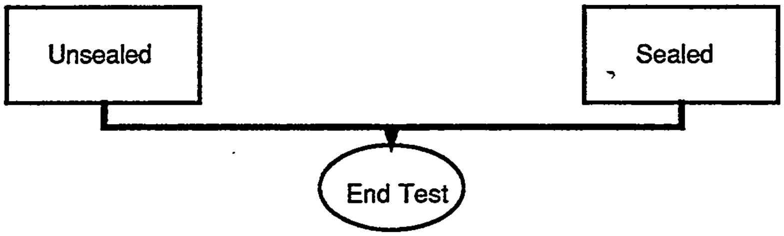
OUTLET GEOMETRY TEST

Cubic foot
samples
2" stand off
55 ksi
4 shots each



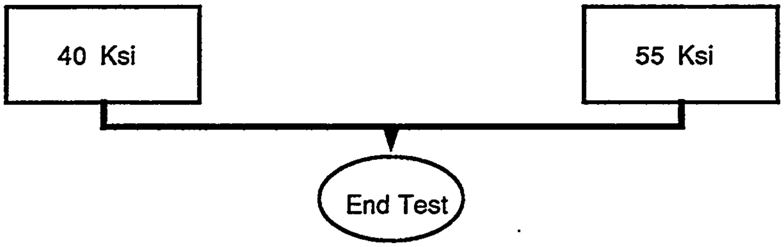
FLUID CONTAINMENT TEST

2000 lb sample
Blind hole
55 ksi
4 shots each



EXCAVATION PATTERN TEST

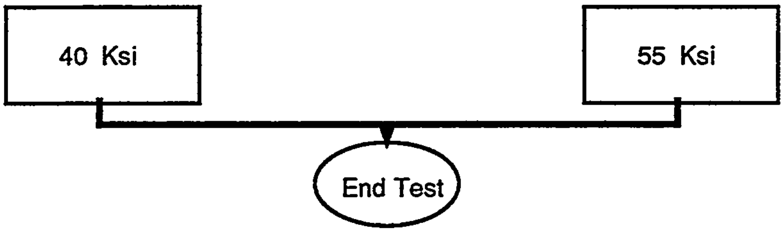
Cubic foot samples
1/4" stand off
Confined surface
12 shots minimum



8000 lb sample
2" stand off
Free surface
12 shots minimum

RUBBLE SIZE CONTROL TEST

Cubic foot samples
1/4" stand off
Confined surface
12 shots minimum



2000 lb sample
2" stand off
Free surface
12 shots minimum

ATTACHMENT 7

SAMPLE DATA SHEET

HYDRAULIC END EFFECTOR

Performed by

IMPACT TESTS IN SIMULATED SALT CAKE

Date

Type of test

Trial number	Sample weight before test, lb	Mark blast locn	Tool in posn	Photo test area	Standoff distance in	Charge pressure PSI	Video on	Video off	Photo test area	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags
		(X)	(X)	(X)			(X)	(X)	(X)						(X)
COMMENTS:															

→ (X) DENOTES ITEMS TO BE PERFORMED AND CHECKED OFF IN TEST PROCEDURE.

→ TRIALS SHOULD ALL BE NUMBERED SEQUENTIALLY, I.E., 1 THRU 20, NOT 1 THRU 4 FOR FIVE DIFFERENT TESTS. THIS IS MAINLY FOR EASY ID ON PHOTOS & VIDEO.

ATTACHMENT 8

Lawrence Livermore National Laboratory
Operational Safety Procedure No: 169.08
Review Level: B

Revised: 7/15/93
Expires: 7/15/94
Page 1 of 20

OFFICIAL COPY

HYDREX

1.0 Reason for Issue

The use of the HYDREX system is not authorized by present procedures and can present hazards which are not completely addressed by the LLNL *Health & Safety Manual.*

2.0 Work Description and Location

2.1 This OSP authorizes the use of the HYDREX (Hydraulic Impact End Effector (HIEE)) system for conducting experiments to determine the effectiveness of the equipment to breakup simulated salt cake. This project supports the cleanup of the Hanford radioactive waste storage tanks. The HYDREX system uses a hydraulic impact end effector having a discharge pulse of approximately 7 cubic inches of water at 40 ksi pressure. The hydraulic pumpset consists of two 10 Hp electrically driven units delivering 4.2 gpm each at 40 ksi pressure. Power requirements are 208V, 3-phase. Test samples (simulated salt cake) are cast fertilizer blocks weighing up to 1 ton each. The HYDREX system has been provided by Quest Integrated, Inc., and all components have been inspected/tested prior to delivery to LLNL.

2.2 This experiment will be carried out in B169, (Rm 1105). The hydraulic pump set will be in a separate room (Rm 1107) from the other equipment.

3.0 Responsibilities

3.1 Maynard Holliday (3-0509 or pager 02267) is identified as the Lead Experimenter for this activity. He is responsible for the safety of this operation and for assuring that all work is performed in accordance with this OSP and applicable sections of the *Health & Safety Manual* and *Environmental Protection Handbook.* In the absence of the Lead Experimenter, Stanley Baker (3-3285 or pager 07338) shall assume these responsibilities as Alternate Lead Experimenter.

3.2 The Lead Experimenter shall review and discuss this OSP with operating personnel upon publication and at six-month intervals thereafter. Revisions and changes to this procedure shall be reviewed with operating personnel when issued. The Lead Experimenter shall certify that this action was taken on the OSP Review Form which is attached to this OSP as Appendix A. A copy of the form shall be sent to the Program Safety Officer (L-580) after each review.

3.3 The Lead Experimenter shall post a current "Official Copy" of the OSP at the work area for reference by the workers. The Lead Experimenter shall also post an up-to-date copy of the completed OSP Review form (Appendix A) at the work area listing persons authorized to operate the equipment associated with this procedure.

3.4 Controlling Changes to Operations or Equipment

Any changes in operations that improve or do not significantly affect safety and environmental controls for this procedure may be approved by the Approving Individual and the ES&H Team 6 Leader concurrently. The Lead Experimenter shall ensure that this action is documented in a memorandum. Any changes in operations that increase the hazard level, introduce additional hazards, or decrease safety shall not be made until a revision of or supplement to this OSP has been reviewed and approved consistent with the review and approval process for the original OSP.

3.5 Before starting operation, the Lead Experimenter shall verify and document that operating personnel have read and understood this OSP and appendices.

4.0 Hazards Analysis

The potential hazards associated with the operation of HYDREX are:

4.1 High pressure

4.1.1 Accidents from a sudden rupture or failure of a high pressure component, or contact with high pressure water, or the water pulse stream itself can cause serious bodily injury or fatality. Also, water injected under the skin can cause infection through water borne micro-organisms.

4.1.2 Remote start-up of the pump set. It is not inconceivable that the pump set could be started inadvertently by someone because it is remotely located relative to the HIEE.

4.1.3 High pressure water pulse injuring personnel, with a potential for injury from secondary effect of debris scatter.

4.1.4 Build-up of static charge from passage of water could present a shock hazard.

4.1.5 The manufacturers calculated safety factor for the high-pressure cylinder assembly is less than 4 as documented in Engineering Safety Note ENE 93-06. The worst case pressure accident that could result from the inadequate safety factor is the release of the end plug.

4.2 Electrical Hazards

Exposure to the 208V 3-phase power can cause serious injury or electrocution.

4.3 Noise Hazards

Exposure to noise created during firing of the unit or operation of the hydraulic pump can result in hearing loss.

4.4 Lifting Hazards

The simulated salt cake targets can weigh up to 1 ton. Other components of the system are heavy as well. Personnel injury or fatality can be caused by manual lifting and improper use or failure of lifting devices.

4.5 Chemical Hazards

Simulated salt cake will be made by mixing potassium and magnesium sulfate-based fertilizer with water in a cement mixer. The chemical fertilizer is considered a nuisance particulate, but may cause eye irritation upon contact. Contact with skin may also cause irritation.

5.0 Controls

The controls specified below will reduce the risk to personnel and the environment to acceptable levels:

5.1 High Pressure Controls

5.1.1 Engineering Safety Note ENE 93-906 has been prepared to address the high-pressure integrity of the system and the stand for the end effector. The HIEE shall not be operated until the high-pressure system has been tested and labeled.

5.1.2 All workers shall implement "Lock and Tag" procedure such that the pump cannot be turned on while maintenance is being performed on the HIEE.

5.1.3 Access to the HIEE experimental area will be controlled by the Lexan barrier that will preclude entrance to the area while the HIEE is being operated. The door to the Lexan barrier shall be interlocked to prevent a shot from occurring while the access door is open or personnel are entering the area. The door shall be opened using the control panel key. The key shall remain in the possession of the Lead Experimenter during target area entries.

5.1.4 In addition to the Lexan barrier, a shrapnel shield shall be in place prior to operation of the HYDREX, see Appendix B. ENE 93-906 includes the calculations for this safety barrier.

5.1.5 The HIEE is grounded to prevent static build-up on equipment.

5.1.6 Only personnel under the direct supervision of the Lead Experimenter or Alternate (they must be present in the room) are authorized to make test firings. The Lexan barrier shall be maintained so that the target area is clearly visible to the operator.

5.1.7 Operating and maintenance procedures provided by the vendor (see Ref. 11.2), including the safety precautions contained within, shall be followed. These precautions are provided as Appendix C and D.

5.1.8 The path of the water jet pulse shall be guarded so that personnel cannot get in the path of the water jet without removal of the interlocked guard/barrier.

5.1.9 The target shall be shielded to contain water and target fragments. Personnel shall not be allowed inside the barrier during a test shot.

5.1.10 The hydraulic system shall be depressurized and deenergized (formally locked and tagged out) prior to breaking a pressure boundary. Appropriate precautions shall be taken to prevent electrical shock when performing maintenance.

5.1.11 Two individuals shall be present in Room 1102 during a test firing.

5.1.12 The system shall be depressurized prior to allowing personnel inside the Lexan barrier or before changing targets.

5.2 Electrical Hazards Controls

5.2.1 All work with electrical equipment shall comply with the provisions of the LLNL *Health & Safety Manual* (Chapter 23 "Electricity" and Supplement 26.13 "General Lock and Tag Procedures") and the Engineering *Electrical Safety Policy.*

5.2.2 Personnel performing electrical work shall be briefed on the specific hazards of the facility before being allowed to work on the experimental facilities. The Lead Experimenter shall ensure this training.

5.2.3 All high voltage locations shall be properly identified, shielded, and/or interlocked.

5.2.4 All major components of the system shall be properly electrically grounded to system ground.

5.2.5 No design modification to any equipment involving high voltage shall be made without the Lead Experimenter's written authorization.

5.2.6 Presence of an exposed high voltage conductor within an enclosure shall be clearly indicated by labels outside the enclosure.

5.2.7 Access panels, doors, and covers that shield high voltage shall be bolted closed.

5.2.8 The experimental doors to the system shall be interlocked.

5.3 Noise Controls

5.3.1 All participants shall be trained in control of noise hazards by Team #6 Industrial Hygiene prior to start-up. It is the responsibility of the Lead Experimenter to arrange the training. During firing, the jet nozzle shall be maintained as close as possible to targets to minimize the noise produced. Hearing protection (ear muffs and ear plugs) shall be worn at all times in Room 1200 when the hydraulic pumps are operating, and in Room 1102 during firing of the unit. Personnel access to the mechanical room shall be restricted. Noise placards shall be posted at all entrances to the noise hazard areas. Strobe lights shall be located outside the entrance to Room 1102 and inside Room 1102; which will be activated during test runs.

5.4 Lifting Controls

Forklifts shall be rated for the load. They shall be inspected and load tested in accordance with applicable portions of the *Health & Safety Manual*. Lifting devices shall not be used unless they are within the required inspection/test interval. The operator shall visually inspect lifting devices and shall remove from service and tag-out any device not passing such an inspection.

5.5 Chemical Hazards

The fertilizer shall be mixed in an outside location. Employees will work upwind and minimize creation of dust. If airborne dust may contact eyes, chemical goggles shall be worn. An operational eyewash is located on the south side of Building 169C. Butyl rubber gloves or the equivalent shall be worn to minimize skin exposure. Disposable Tyveck ® coveralls may be worn at the discretion of the Lead Experimenter.

6.0 Environmental Concerns and Controls

6.1 All effluent (water and salt cake) shall be contained to prevent entry into a storm drain or sanitary sewer. Accidental spills shall be wiped up and the cleanup materials disposed of with the process effluent.

6.2 Although process effluent is not hazardous waste, it may not be sewerable. The Environmental Analyst shall be contacted to determine proper disposal procedures.

6.3 Any waste chemicals/solutions will be handled as hazardous waste according to the policies and practices outlined in the Environmental Protection Department's *Guidelines for Waste Accumulation Areas* (UCAR - 10192/Rev. 1), and the *Preparation Guide for Generators of Hazardous Chemicals and Radioactive Waste at LLNL* - March 1987.

7.0 Training

7.1 All authorized operators shall have completed the following safety courses:

7.1.1	HS-4360	Noise (retraining required annually)
7.1.2	HS 5030	Pressure Safety Orientation
7.1.3	HS-5040	Intermediate Pressure Safety - For maintenance personnel.
7.1.4	HS-5050	High Pressure Safety - For maintenance personnel.

7.1.5	HS-5031	Pressure Safety Requalification (operators shall take this course every five years after the successful completion of HS-5030, HS-5040, and HS-5050) - For maintenance personnel.
7.1.6	HS-5620	Fork Truck Safety
7.1.7	HS-5245	Lock and Tag Procedure

7.2 All personnel (LLNL and contract) who generate or handle hazardous waste shall attend EP-0006 "Hazardous Waste Handling Practices" within six months of being newly hired or transferred to the new position and annually thereafter.

7.3 The Lead Experimenter is required to complete HS-4050 "Health Hazard Communication."

8.0 Maintenance

8.1 The vendor supplied maintenance procedures (Ref. 11.2) shall be followed when performing maintenance on the system.

8.2 Maintenance procedures for the HIEE equipment are covered in Appendix C.

8.3 The Lead Experimenter is responsible for ensuring that all required maintenance of safety systems and equipment is conducted at the recommended frequencies. This includes scheduling maintenance with Plant Engineering, or where applicable, outside vendor service organization.

8.4 For maintenance records of health and safety-type equipment, notify the area Health and Safety Technician.

8.5 When in service, all cranes, hoists, and slings shall be inspected prior to use or at least monthly. (NOTE: HIEE staff currently do not plan to use the crane for material handling. As long as the crane is out of service, monthly testing is not required. A monthly inspection by a qualified operator is required if the crane is placed back in service.)

8.6 Cranes and lifting fixtures shall be load tested every three years. Records shall be maintained by Plant Engineering.

8.7 The forklift shall be tested and maintained as required per the LLNL *Health & Safety Manual* Supplement 29.04A. Records shall be maintained by the Automotive Fleet Division.

9.0 Quality Assurance

9.1 The Lead Experimenter shall ensure the completion and documentation of all training requirements including on-the-job training if applicable.

9.2 Pressure components associated with the HYDREX system are inspected every three years. Every six years, the components are recertified by pressure testing. Records of such tests shall be maintained by the Lead Experimenter.

9.3 Only certified pressure inspectors and installers may work on pressure bearing components of the system.

9.4 All pressure components shall be inspected/tested and certified by the vendor prior to delivery to LLNL. All pressure components shall be pressure rated for the application.

9.5 For verification of safety routines, checks, and inspections regarding quality assurance, contact area Health and Safety Technician.

10.0 Emergency Response Procedures

10.1 In the event of an emergency, dial 911 from a safe location. Stay on the line until the dispatcher knows the nature of the incident and location.

10.2 All electrical shock victims shall be transported to Medical by the Fire Department due to the potential for delayed cardiac failure.

10.3 Injuries and medical illness that do not require an ambulance response, but do warrant medical attention should be transported to Medical by an uninjured party. If in doubt of the seriousness of the injury, dial Ext. 911.

10.4 Procedures for major emergencies are covered in the *Disaster Preparedness and Emergency Response Plan for Laser Programs*, Laser Program, July 1991.

10.5 Notify Hazards Control and appropriate management staff when time permits.

10.6 Workers shall wear tags containing the statement, "Potential Victim of High-Pressure Water Injection," and Medical shall have prior notice of the potential treatment required for a high-pressure hazard.

11. References

11.1 *LLNL Health & Safety Manual,* and Supplements.

11.2 *Hydraulic Impact End Effector for Lawrence Livermore National Laboratories, Assembly, Operations, Spare Parts, and Maintenance Manual*, Quest Integrated, Inc., June 1992.

11.3 *Electrical Safety Policy,* Electronics Engineering Department, LED 61-00-A1A.

11.4 *Environmental Protection Handbook,* Environmental Protection Department.

11.5 LLNL *Course Catalog*, Employee Development Division.

11.6 *Disaster Preparedness and Emergency Response Plan for Laser Programs*, Laser Program, July 1991.

11.7 *LLNL Engineering Design Safety Standards*, M-012, Revision 7.

12.0 Review and Approval

The following reviewers have distributed this procedure to appropriate personnel within their organizations for review of technical accuracy. The controls listed in this procedure are adequate for the subject work to be done.

Maynard O. Holliday
M. Holliday
Responsible Individual

Michael Trent
M. G. Trent
ES&H Team 6 Leader

for A. Heywood
Approving Individual

Controlled Distribution:

Borzileri, C.	L-384
Carr, R. B.	L-446
Casamajor, A.	L-580
Cotter, S.	L-449
Chase, D.	L-633
Document Services	L-468
Dorsey, G.	L-449
Environmental Mon. Grp.	L-255
Fischer, L.	L-467
Fire Safety Div.	L-388
Graham, W.	L-446
Heywood, A. C.	L-590
H.C. Team 6 (2)	L-449
Holliday, M. (2 - 1 to post)	L-591
McLouth, L.	L-449
Meeker, D. J.	L-469
Mitchell, W.	L-449
Wilder, R.	L-250

APPENDIX A
OSP REVIEW

This OSP was reviewed by the Lead Experimenter,______________________, and the operating personnel assigned to Building No. 169, Room Nos. 1200 and 1102. The listed hazards and their controls are clearly understood.

Initial Review

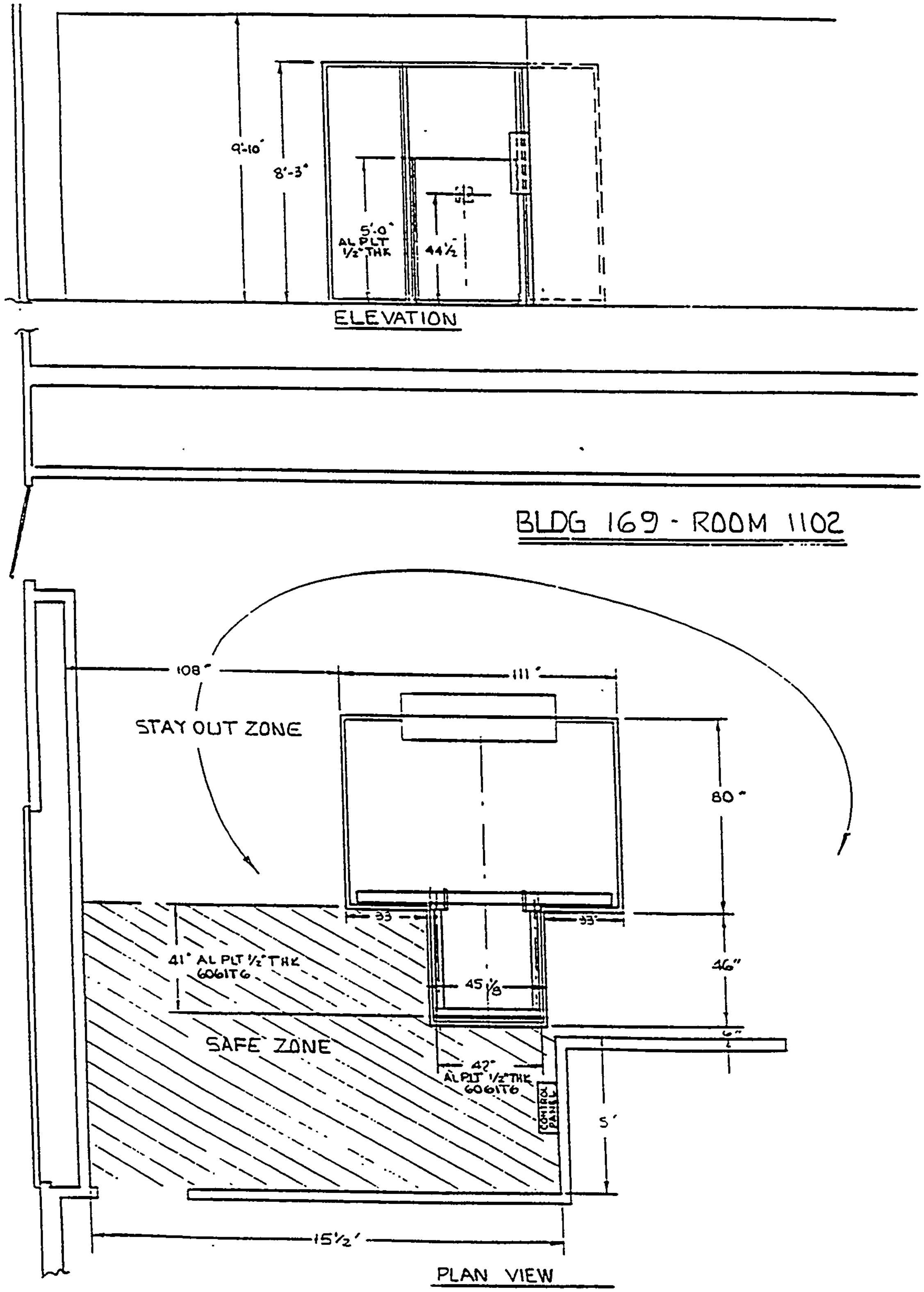
Name	Signature	Date

Review After 6 Months

Name	Signature	Date

Note: After each 6-month review, a copy of this completed form shall be sent to the Laser and Environmental Programs Assurances Office, L-580.

APPENDIX B
LAYOUT OF HYDREX LEXAN BARRIER AND SAFETY SHIELD



APPENDIX C

HYDRAULIC IMPACT END EFFECTOR OPERATING PROCEDURE
Reference QUEST drawing A65177

HYDRAULIC IMPACT END EFFECTOR OPERATING PROCEDURE
Reference QUEST drawing A65177

I. Principle of Operation

The hydraulic end effector is an Ultra High Pressure (UHP) water device that discharges a small volume burst of water at very high velocities. As such several safety concerns were considered in the design of the end effector and it's operating system. These concerns lead to the incorporation of several features to provide "Fail Safe" operation. Among these features are remote operation, the automatic discharge of the tool in the event of power failure or emergency shutdown, low velocity discharge of water in the event of an open mode failure of the tool charging system, automatic discharge of the tool anytime an activating switch is moved from an activated position to an off position, and control switches interruptible by an "Emergency - Stop" switch and arranged such that likely accidental operation of power switches will tend toward the off position.

The end effector is remotely operated by the operation of electrical switches. These switches operate pneumatic solenoid valves and relays to operate the tool. The tool is connected to the UHP power source through a UHP normally closed (N.C.) pneumatically operated valve. In parallel with this valve is a UHP normally open (N.O.) valve connected to a vent line. Air pressure to these valves is controlled by electric solenoid valves controlled by switches in the control panel. To operate the tool, the UHP power source is turned on and set at pressure. The control panel is then activated to provide power to the switches. A switch is then turned to the charge (on) position. When this is done electricity is applied to the solenoid valves activating them. This provides air pressure to the two UHP valves closing the N.O. valve and opening the normally closed valve. The closing of the N.O. valve shuts off the vent line sealing the unit while opening the N.C. valve supplies UHP water to the end effector pressurizing it.

To discharge the tool the switch is turned to the discharge position. This shuts off current to the two solenoid valves closing them. The closing of these valves shuts of the air to the UHP valves allowing the N.C. valve to close and the N.O. valve to open. This cuts off the UHP supply and vents the tool supply line. Anytime the supply line vents the tool discharges.

By this sequence it is seen that any loss of air to the UHP valves discharges the tool. Thereby if the air system should fail the tool will discharge. As air is only supplied to the tool when electrical current is on to the solenoid valves, any loss of current will discharge the tool. The tool is thereby a "Fail Safe" operating device as any failure of air supply or electrical power causes a discharge of the tool. In the event that the N.C. valve should fail in an open mode so that UHP water is constantly supplied to the tool, the N.O. valve is still open allowing this water to flow down the large diameter vent line dropping the water velocity to low levels and preventing pressure build-up and a charged tool condition.

Further safety is provided by the power switches being arranged so that they must be pulled out to activate power. This provides the safety feature that any accidental knocking against these switches will push them in cutting electrical power and discharging the tool. A charge indicator light is also provided that lights anytime either of the control switches is in an on position.

II. Startup

1. Check to insure that UHP power unit is off.
2. Pull up E-stop on control panel to activate switch.
3. Pull up control power switch (green button) to activate controls.
4. Turn manual mode (bottom) switch to "Charge" position, check that indicator light is on, turn switch to "Off".
5. Turn auto mode switch to "Auto", check that indicator light cycles on and off with cycle timer setting, turn switch to "Off".
6. Push control power switch to shutoff power to controls.
7. At UHP power unit, turn on water supply.
8. Check water outlet to insure that water is flowing through the unit.
9. Check pressure control to insure that it is at the minimum setting
10. Turn on switch to power unit.
11. At control panel, check to insure that Auto mode and manual mode switches are in off position.
12. Pull up control power switch to activate controls.

III. End Effector Operation

A. Manual Mode Operation

1. Check to insure that all personnel are away from end effector.
2. At UHP power unit, set pressure setting to desired operating level.
3. Move end effector to desired aiming position.
4. At control panel, turn manual mode (bottom) switch to "Charge" position.
5. Wait for a minimum of 10 seconds.
6. Turn manual mode switch to "Discharge". This will fire the end effector.
7. Repeat steps 3 through 5 as required.
8. When firing is completed turn manual mode switch to "OFF"

B. Automatic Mode Operation

1. Check to insure that all personnel are away from end effector.
2. At UHP power unit, set pressure setting to desired operating level.
3. Move end effector to desired aiming position.
4. At control panel, set cycle timer settings to desired charge and discharge times.
5. Turn auto mode (top) switch to "Auto" position. Tool will charge and fire according to timer settings.
6. To stop tool from firing, turn auto mode switch to "Discharge".
7. Repeat steps 3 through 5 as required.
8. When firing is completed turn auto mode switch to "OFF"

IV. Shutdown

1. AT control panel check that manual mode and auto mode switches are in "OFF" position
2. Push control power switch (green button) to deactivate controls.
3. At UHP power unit, turn switches to shutoff unit.
4. Turn off water supply.
5. At control panel, press E-stop button to totally shutoff all power.

Assembly and Maintenance Procedure
For Hydraulic End Effector/Strain Relief Assembly

Drawing D65360

These instructions should be read before doing assembly, repair or maintenance work. Detailed assembly drawings are included in the manual for reference.

Item No.	Description	Instructions
1	Fasteners	Fasteners used are 1/4", 5/16", 3/8" and 1/2". These require 7/16", 1/2", 9/16" and 3/4" wrenches, respectively. Fasteners are 18-8 stainless and grade 8 carbon steel.
2	Washers	Washers should be used where the fastener contacts an aluminum surface.
3	Lubrication	UHP Components, Fittings and Tubing: - Blue Goop Lubricant (FS#A-2185) Blue Goop should be applied to threads on UHP joints and to the retaining pins (item 7-No. 65049 on assembly drawing No. 65003) on the Hydraulic End Effector. Use Blue Goop to lubricate the threads the first time the joint is made up. Apply the lubricant to the male and female threads.

APPENDIX D

SAFETY PRECAUTIONS

Spec. No. A-4964
Revised 8/25/92

SPEC. No. A-4964
Revised 8/25/92
Page 1/4

SAFETY PRECAUTIONS

Quest Integrated, Inc., (QI^2) and Flow International, Inc., equipment produces a high-energy-density waterjet used for cutting, drilling, and/or shape-forming. Misuse of this equipment or carelessness in its application can be extremely hazardous both to operating personnel and to other personnel in its immediate vicinity. Therefore, your waterjet equipment must be treated with the same caution given other high-speed cutting tools.

The general safety precautions and protective clothing requirements given in this section should be reviewed by personnel working either with or near the equipment. Specific cautions are highlighted in the operating and service procedures to which they apply. Note that OSHA and state safety agency rules must be complied with in addition to those given either in this section or elsewhere in this manual.

QI^2 and Flow International, Inc., assume no responsibility for improper use of the equipment and shall be held blameless and free from any claims resulting from misuse of the equipment or failure to use the proper safety gear or to comply with the end-user safety administrator's recommendations.

OPERATING SAFETY

- Carefully follow the instructions given in warning notices posted on the equipment.
- Ensure that the working area around the equipment is clean and free of debris prior to startup. Do not clean around the equipment while it is in operation.
- Ensure that all protective guards or panels are in place before operating the equipment.
- Ensure that all personnel are clear of the equipment before starting it.
- Shield and bundle equipment hoses and/or cables such that they do not obstruct the operator's freedom of movement.
- Do not allow the waterjet stream to contact any part of your body. Such contact may cause serious injury.
- Do not point the waterjet at anyone while operating the equipment.

MAINTENANCE SAFETY

Mechanical Systems

- Ensure that the working area around the equipment is clean and free of debris prior to servicing it.
- Do not touch water coming from weep holes in fittings and parts with bare hands or try to stop the leakage by plugging the holes.
- Use only ultra-high-pressure fittings, valves, and tubing certified for 60,000 psi (4250-bar) continuous operation when making alterations or additions to the high-pressure water system.
- Do not alter or eliminate stress-relief tubing coils.
- Limit bends in high-pressure tubing to the manufacturer's recommended bending radii.
- Any protective shielding removed from high-pressure tubing and hoses during servicing must be replaced when servicing is complete. Failure to replace shielding may result in serious injury to personnel or damage to the equipment.
- Ensure that all fittings are torqued to specification after servicing.

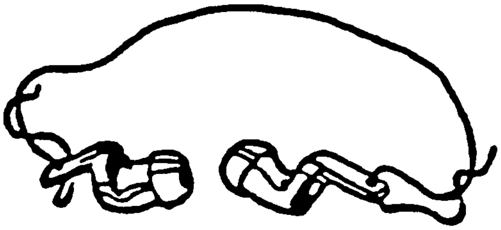
High-Pressure Waterjet Tools

- Turn off equipment and relieve water pressure before replacing nozzles, tips and bits.
- Place a notice on the power supply control panel warning that the equipment is being serviced and is not available for use until servicing is complete.
- Replace all protective covers and shielding on equipment before returning it to operation.
- Check for leakage after nozzle or tip replacement and correct immediately if discovered.
- Use only QI^2 manufactured or approved waterjet nozzles, cleaning tips, and drilling or cutting bits.

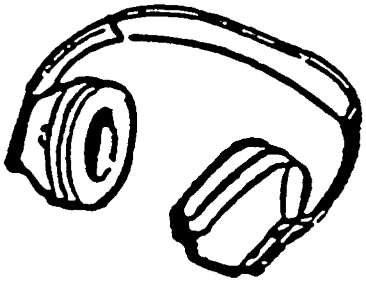
Diesel or Gasoline Engines

- Do not allow the engine to exhaust into an enclosed work area. Either ensure that adequate ventilation is provided or route the exhaust outdoors.
- Do not overfill the fuel tank or operate the engine in an explosive or flammable environment.
- Do not allow the engine to contact flammable materials while it is hot.

Ear Protection - Operators and other personnel exposed to noise levels of more than 90 dBa for more than one hour must wear suitable ear protection. Ear plugs and muffs usually suffice.

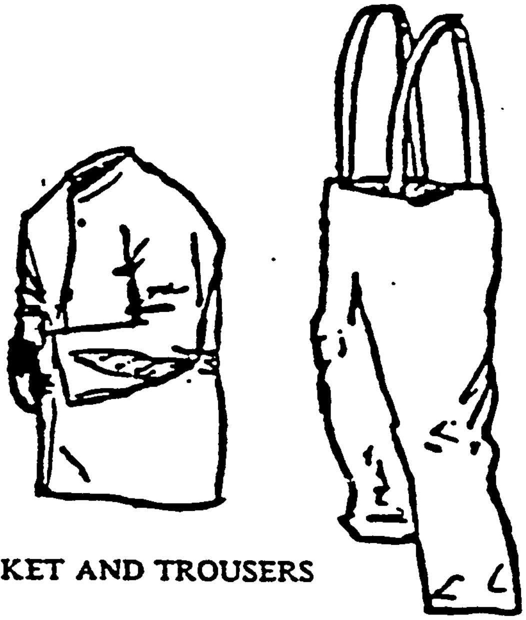


EAR PLUGS
(short exposure)



EAR MUFFS
(long exposure)

Body Protection - Waterproof garments protect the operator only from spray and flying debris. They do NOT deflect direct jet impact. Therefore, an operator must take care never to point a waterjet either at himself or other personnel.



JACKET AND TROUSERS

QI^2 recommends that users consult work-site safety personnel to obtain approval of safety equipment for System operations.

EMERGENCY MEDICAL INFORMATION

Immediate hospital attention should be given personnel who sustain equipment-related injuries while operating the System. In such cases, it is vital that medical personnel be apprised of all facts relevant to such injuries. Therefore, all operating personnel should be provided with waterproof emergency medical tags or cards describing the nature of their work and the possibility of injury inherent in the use of a waterjet cutting device. The tag or card also should bear the following standard notice:

> This person has been working with water jetting at pressures to 55,000 psi (374 MPa, 3740 bar, 3867 kg/cm^2) with a jet velocity of 3000 fps (914 mps). This should be taken into account during diagnosis. Unusual infections with microaerophilic organisms occurring at lower temperatures have been reported. These may be gram-negative pathogens such as are found in sewage. Bacterial swabs and blood cultures may therefore be helpful.

Controlled Distribution:

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OSP169.08:swc

Corrections or changes to this distribution, should be noted on this page and mailed to Sarita Cotter, L-449

ATTACHMENT 9

MECHANICAL ENGINEERING DEPT.
ENERGY SYSTEMS ENGINEERING DIVISION

SAFETY NOTE ENE93-906

HYDRAULIC IMPACT END EFFECTOR

JULY 1993

Prepared by: Paul Densley
Paul Densley
SAIC Project Engineer

Reviewed by:
Dave Hipple
Pressure Consultant Howard Patton
7/21/93

Checked by: Bruce J. Schumacher
Bruce Schumacher
Project Engineer ESED

Approved by:
Scott Couture
Section Leader R & A Roy D McDaniel
7/22/93

Approved by:
Howard Woo
Senior Staff Engineer ESED

Approved by: Ron Carr
Ron Carr
Division Leader ESED

cc. E. Grasz
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High Pressure Safety Grp. Chuck Borzileri L-434

ENERGY SYSTEMS ENGINEERING DIVISION

Mail Station L-491

Ext 2-0406

MEMORANDUM

21 July, 1993

To: Paul Densley
From: Howard G. Patton
Subject: Review of Engineering Safety Note ENE93-906

I have reviewed the Engineering Safety Note ENE93-906 and have the following observations, recommendations and comments. I request that these comments be attached to the Engineering Note.

1. Having reviewed the Engineering Safety Note I conclude the system design to be in conformance with LLNL Mechanical Engineering Standards. Due time constraints of my own I did not review the calculations made by M. Holliday. I understand they have been reviewed by others.
2. I have discussed the system and its construction with Paul Densley and he has satisfied my questions.
3. I toured the facility with Paul and concluded that the installation is acceptable with one exception. My concern is the location of the operator during the manual charging operation. Lack of familiarity with the operation of the "gun" and the possibility of a miss fire with the operator at the console and the possibility of debris or shrapnel striking the operator causes me to make the recommendation discussed below.
4. I viewed a video tape, supplied by Paul, and determined that the actual firing is less dramatic that I might have supposed. The recoil is not significant.

Recommendation:

During manual charging the operator is positioned in a less than desirable location. Should a failure occur debris could ricochet over the top of the enclosure or through the opening for the high pressure hose. Additionally, the operator could be exposed to high pressure water. Therefore, I recommend the first several firings (5) be conducted using the auto-remote mode until it is demonstrated that the area in front of the console is safe and the gun is operating as expected.

Howard G. Patton

HGP:
cc:
H. Woo
R. Carr
D. Hipple
file

University of California
LAWRENCE LIVERMORE
NATIONAL LABORATORY

A. Description

Item This safety note describes a high-energy water cannon end effector called the Hydraulic Impact End Effector (HIEE) system (see Figure 1). The system consists of four major parts:

1. Pump Set -- The pump set is a commercial product rated for safe operation at 40 ksi (Omega 0010 built by Flow International). Two of these pumps are mounted on a common skid and manifolded together on the high pressure side by the manufacturer.

2. High pressure hose -- The Ultra High Pressure (UHP) hose is also a commercially unmodified component rated at 55 ksi operating pressure with a minimum fatigue life of 30,000 cycles. The hose is properly secured every seven feet and has a Kellum grip at the pump set end and an independently secured, heavy walled strain relief sleeve at the end effector end.

3. End effector -- The water cannon is a commercial product (HYDREX) manufactured by Quest Integrated, Incorporated. The water cannon uses the energy stored in a volume of water compressed to 40 ksi to generate a powerful hydraulic shock. It has been tested at Quest at 55 ksi and demonstrated at Hanford operating at 40 ksi.

4. Test stand -- The Test Stand for the Hydraulic Impact End Effector is a LLNL built fixture. This test stand was originally part of a larger structure built as a device delivery stand for the Nevada Test Site. It had a rated load of 2000 pounds (See References).

Purpose Designed to be used to break up adherent solid wastes from single-shell tanks at the Hanford Nuclear Reservation near Richland Washington. Work at LLNL will include performance testing of this end effector on salt cake simulant to quantify average particle size and material removal rate based on varying standoff distances, effector angles and nozzle geometry's. This work will be completed by September 30, 1993. It is expected that less than fifty shots will be required to obtain the data for the testing. Less than five of these shots will be made with the strain bar section in place. The remaining shots will be made using the solid bar section. The Maximum Operating Pressure, MOP, is 40 ksi. The working fluid is water. The Maximum Allowable Working Pressure (MAWP) is also 40 ksi. See Figure 3 for operational schematic.

Location The pump set is located in Bldg. 169, room 1200 and the other parts of the system are located in Bldg. 169, room 1102 (See Figure 2).

Responsible User Maynard Holliday (3-0509) is identified as the Lead Experimenter with Stanley Baker (3-3285) designated as Alternate Lead Experimenter.

B. Hazards

This semi-manned water cannon system represents a potential high pressure hazard to personnel from the pressurized water. The Health and Safety Manual states all equipment with liquid pressures greater than 1.5 ksi should have a safety note. This pressure system has a 40 ksi rating and therefore requires this safety note.

Failure to properly support the water cannon could create local life safety issues only of a type and magnitude routinely encountered by, and accepted by, the general public. The test stand is therefore in the seismic hazard category II as determined from Section 5.2 of the ME Design Safety Standards Manual. The test stand is fully described in Engineering Note 93-079.

C. Hazard Mitigation

1. Pump Set -- On the high pressure discharge of the pump itself there is a relief valve/ pressure control valve that is designed to regulate and maintain high pressure water in the high pressure delivery system. This is accomplished with a valve that bypasses water to drain as the relief pressure is reached (Refer to Figure 4). At the operating pressure of 40 ksi this valve will have some flow through it. A staked bushing ensures that the pressure control/relief valve cannot be increased above the maximum operating pressure of 40 ksi. Also if a pump exceeds 40 ksi, the pressure will relieve through a seal internal to the pump and the pump will be automatically shutdown by the thermal control switches on the motor starters. As no modifications have been made to this vendor supplied equipment, no further evaluation was made of the pump set.

2. High Pressure Hose -- No modifications were made the hoses and all connections will be made by high pressure technicians. The hoses were successfully tested at 150% of the MAWP in the LLNL High Pressure Lab (See attached data sheet). No further evaluation is deemed necessary.

3. End Effector -- The end effector has a theoretical discharge of 7 cubic inches at 40 ksi. The maximum operating pressure (MOP) is 40 ksi. The maximum allowable working pressure (MAWP) is also 40 ksi. The energy contained in the water cannon and related plumbing when pressurized to MAWP of 40 ksi, assuming adiabatic (isentropic) expansion of the compressed water is 6.2 equivalent grams TNT (See attachment 1).

   The factor of safety for the cylinder at the manufacturers maximum rated working pressure was less than 4.0. Consultations have taken place with the LLNL high pressure lab personnel on the potential hazards of this system and the administrative controls necessary for safe operation. With the Factor of Safety under the LLNL standard of 4.0 it was deemed acceptable to operate this device since access to the experimental area near the HIEE will be restricted (Semi-manned area) and a half inch 6061 T6 Aluminum shrapnel barrier is in place around the HIEE (See Figure 5). The Lexan panels define an area around the gun that will be cleared of personnel whenever the HIEE is pressurized. This experimental test area is safety interlocked to preclude HIEE energization if the door is opened. The HIEE cannot be fired with a handheld control panel, thus precluding an operator from being near the nozzle and firing the HIEE. The barrier material and thickness calculations (Attachment 2) are based on the Thor formula (DOE-TIC-11268) for compact fragments from Appendix G, Personnel and Equipment Shields, of the DOE High Pressure Safety Manual. Because there will be no personnel present in the area of the end effector when pressurized, and because the Stainless Steel 15-5 material was chosen specifically for the pressure chamber of the HIEE because it does not fail generating fragments these results are extremely conservative.

   All technicians operating this equipment will have completed the appropriate pressure safety training.

4. Test stand -- For the purposes of this analysis, the design weight of the hydraulic impact end effector is 250 pounds. The stand is show in Figure 1. Determination of the center of gravity of the stand and HIEE (Attached) was shown to be centered in the lateral direction, 3.5 inches along the longitudinal direction, and 25.6 inches from the floor. Due to the low center of gravity, the substantial structural elements and the inability of personnel to place themselves in a position of jeopardy, there is no feasible seismic hazard not acceptable to the program. An Engineering Note (93-079) describing the design of the test stand substantiates this structural integrity.

   The strain bar is an instrumented section of the system which is designed to measure the forces resulting from discharging the HIEE. The only way to cost effectively measure these forces is through using a thin (0.045") walled tube. The strain bar will be used to obtain the reaction forces (approximately five discharges) and then be replaced with the solid bar for the remaining testing. This thin walled section has a factor of safety less than the standard 3.0 based upon yield. Therefore additional support for the HIEE will be provided by using Willer brand rigging straps wrapped around the cross member of the test stand and under the HIEE whenever the strain bar is in place. These straps have rated loads of 7900, 3950 and 2975 pound in the vertical, basket and choker configurations respectively.

D. Procedures

See Operational Safety Procedure (OSP) No. 169.08 entitled HYDREX for discussion of procedures for safe operation of the HIEE.

E. Pressure Testing

Pump Set was tested by manufacturer to 40ksi. High Pressure Hoses have been tested by LLNL as stated above. End Effector tested by manufacturer to 50ksi. No further pressure testing is deemed required.

F. Inspection and Labeling

Before certifying the water cannon system for use, the LLNL Pressure Inspector must verify the following:

The LLNL Pressure Inspector will signify acceptance of the system by attaching a LLNL pressure tested label that states:

Assembly S/N: **D65003**
Safety Note: **ENE93-906**
MAWP: **40 KSI**
Fluid: **WATER**
Temperature: **AMBIENT**
Remarks: **END EFFECTOR IS FOR REMOTE OPERATION ONLY**
Test No. T.R.
Expiration Date
By: Date:

G. References

Engineering Safety Note ENN92-904 "Mechanical Engineering Department Nuclear Test Engineering Division Safety Note, Greenwater Device Delivery Cart/Rail System, April 16, 1992.

Engineering Note 93-079, Hydraulic Impact End Effector, PJ Densley, 7/93.

DOE High Pressure Safety Manual, Appendix G Personnel & Equipment Shields, Final Draft by D. Chambers 5/7/93.

H. Attachments

1. High Pressure Lab Test Report, TR No. 01367, 4/2/93.

2. HIEE Shrapnel Barrier Calculation, M. Holliday, 6/93.

FIGURE 1

HIEE AND TEST STAND

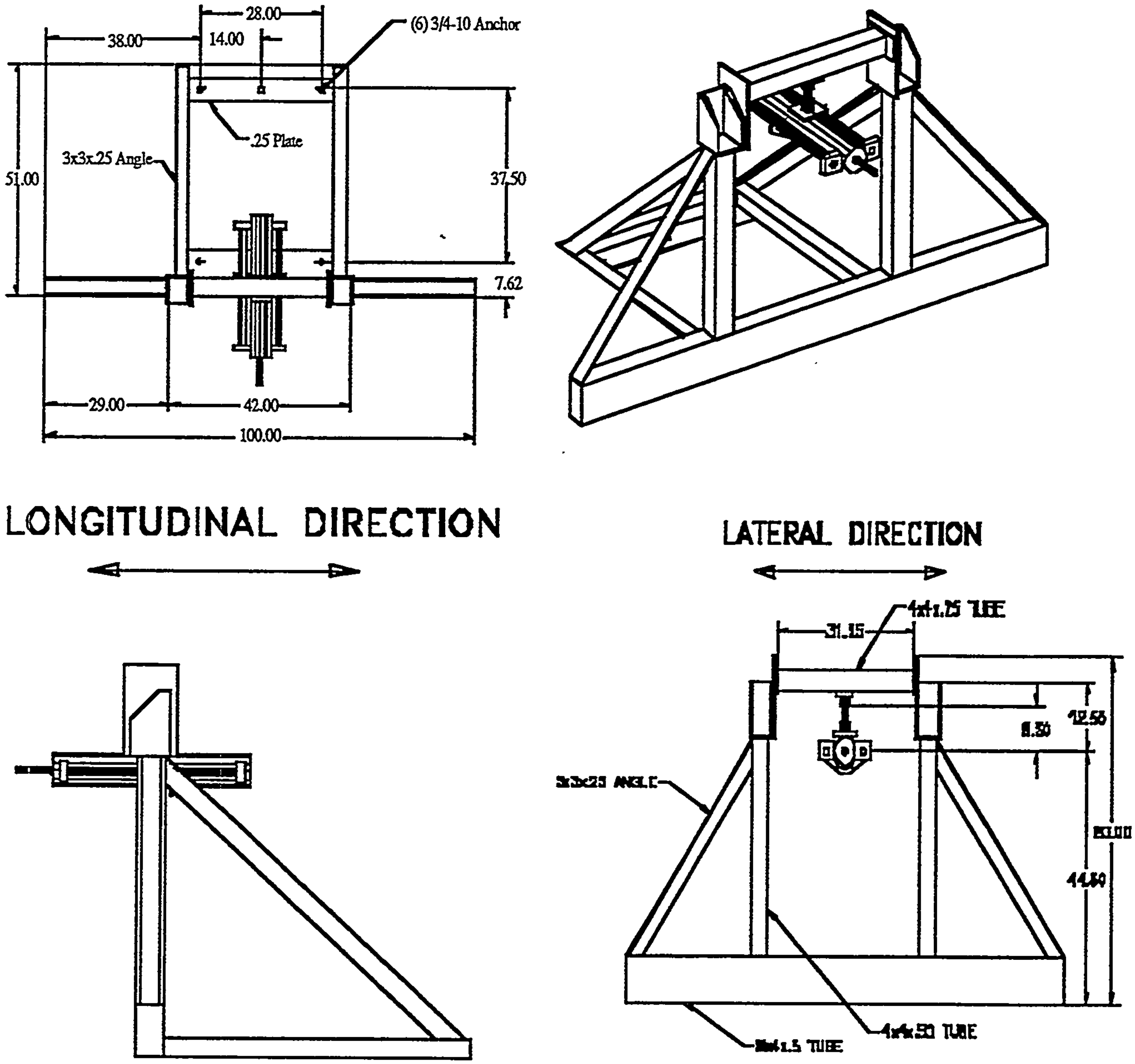


FIGURE 2

BUILDING 169 FLOOR PLAN

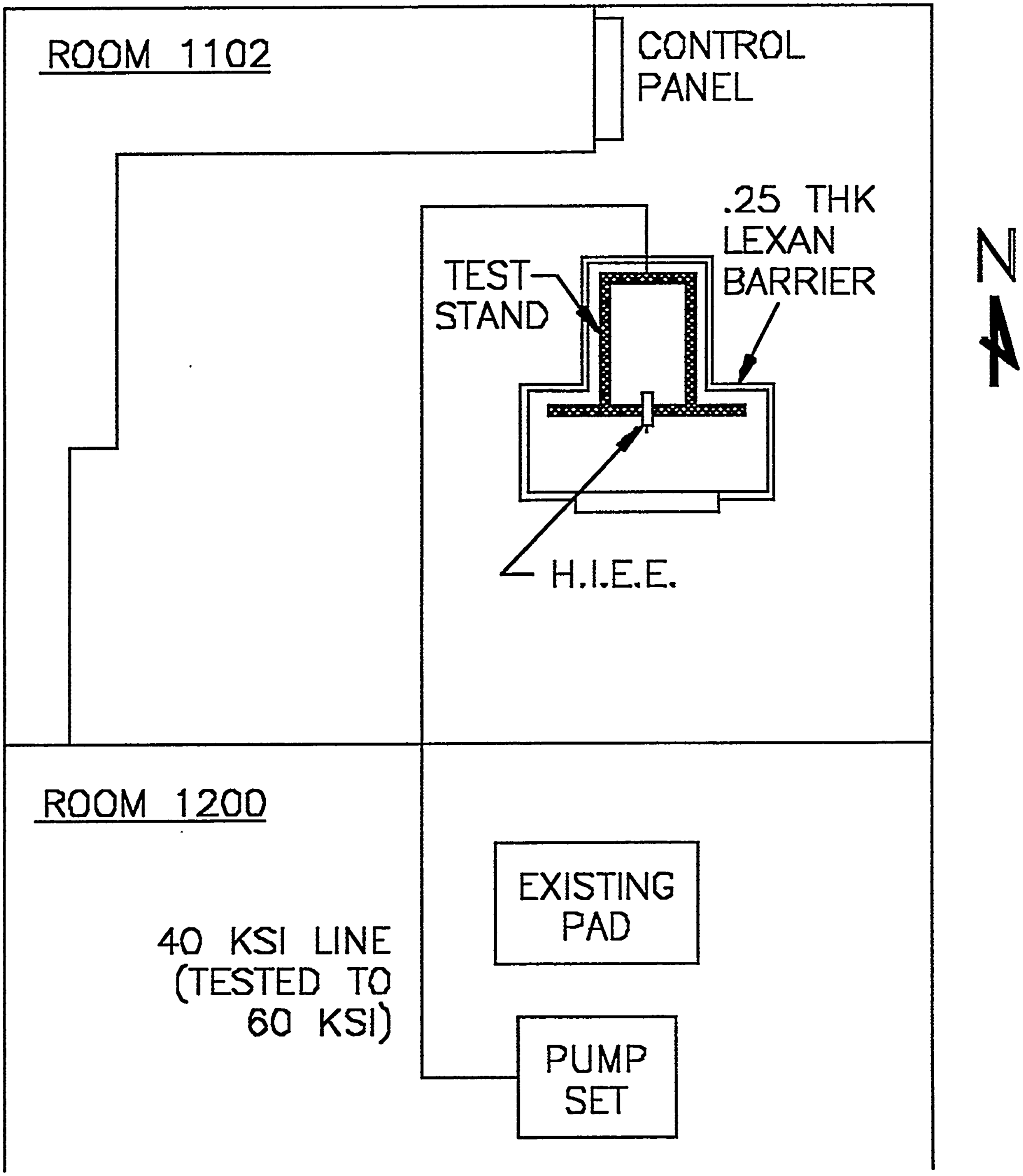


FIGURE 3

HIEE SYSTEM OPERATION SCHEMATIC

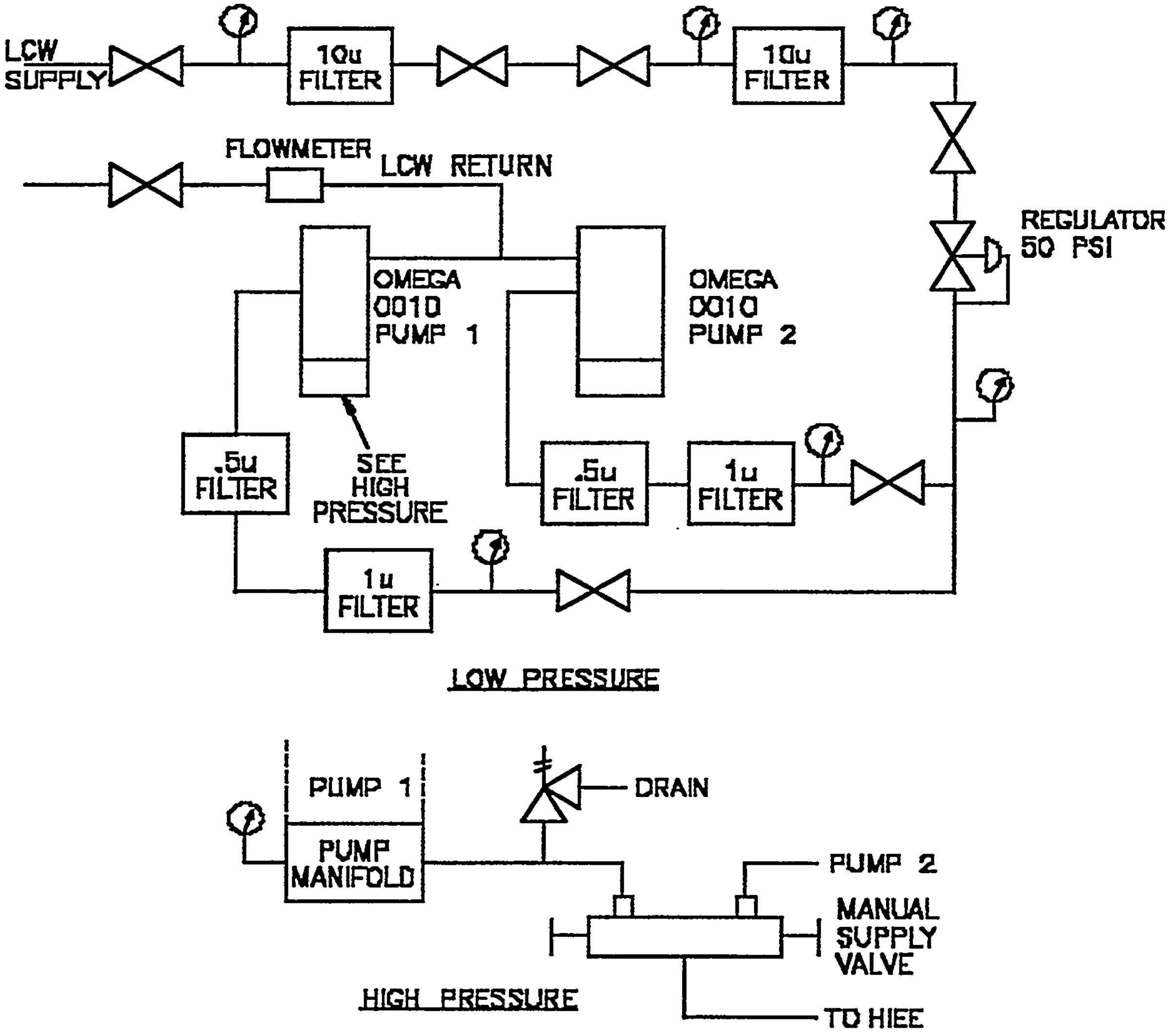


FIGURE 3A

HIEE FLOW DIAGRAM

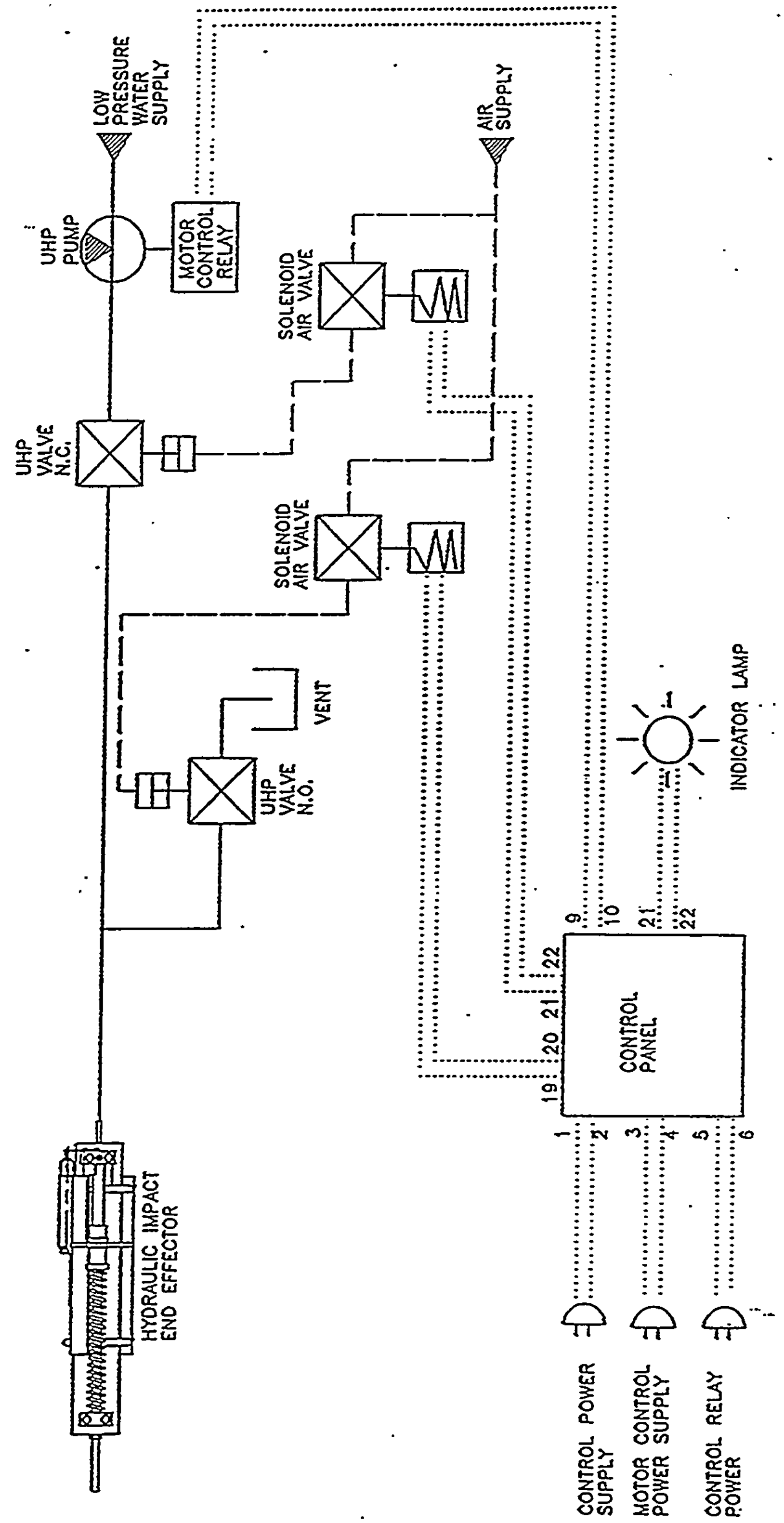


FIGURE 4

PRESSURE CONTROL/RELIEF VALVE

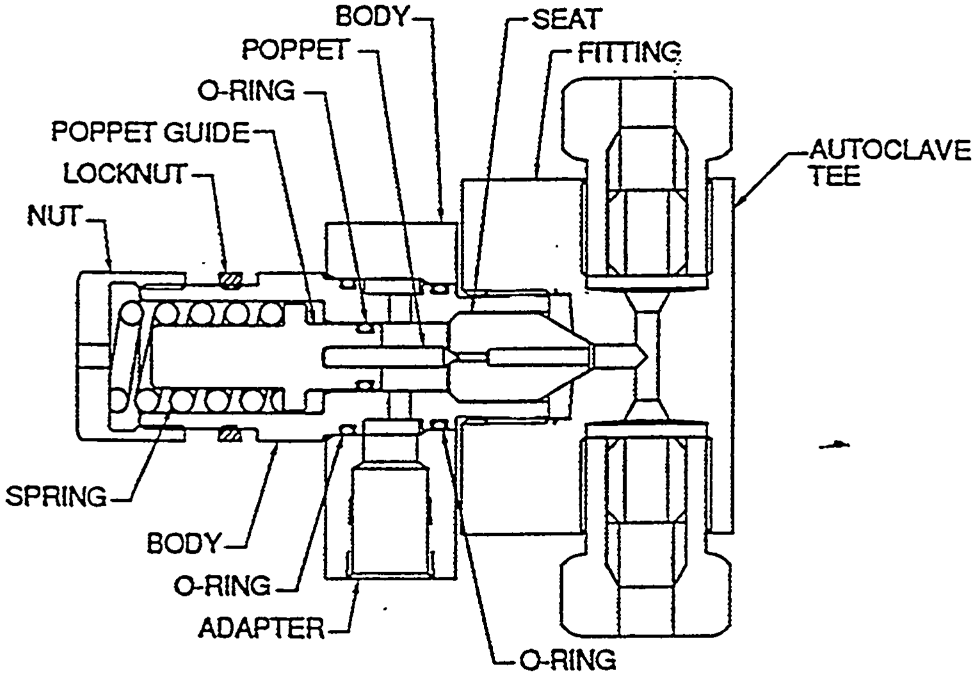
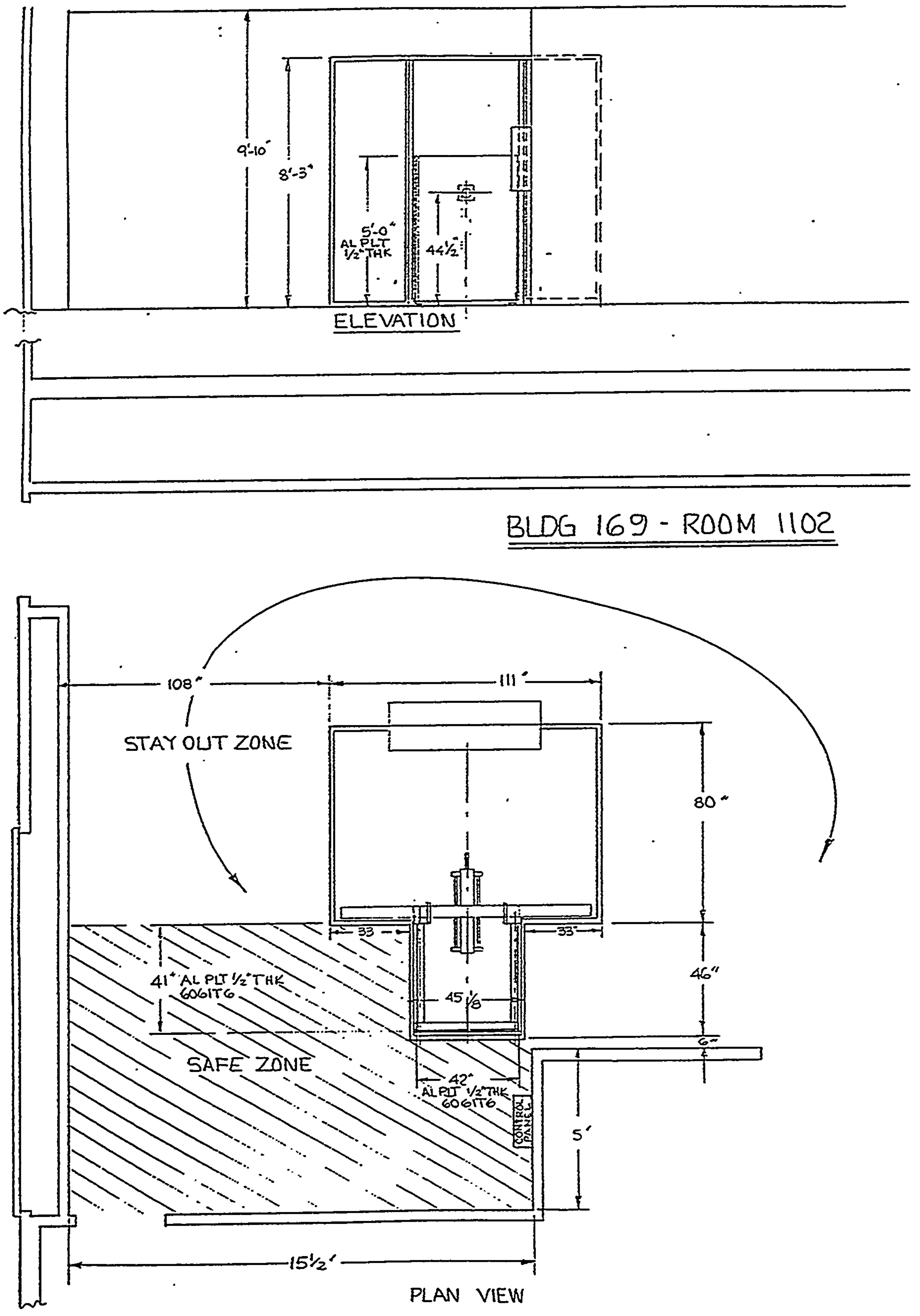


FIGURE 5

ROOM 1102 LAYOUT



ATTACHMENT 1

TEST REQUEST
HIGH PRESSURE LAB
Bldg. 343 2-9596

TR No. 01367

Title/Part Description: Pressure Test 4 EA. Lines to 150% of 40KSI

Requested by: Stan Baker Ext: 33285

Account No.: 5807-43 Bldg. 1631 Rm. 100

Date of TR: 4-1-93

Requested Completion Date: 4-2-93

Type of Request: ☑ Proof test (per Engineering Safety Note No. ______)
☐ Burst ☐ Leak ☐ Bonders ☐ Other: ______

Test Fluid: ☑ Water ☐ Helium ☐ Hydrogen ☐ Other: ______

Special Conditions: ☐ Classified ☐ Toxic/radioactive

Specify details: ______

Test Procedure: ☐ Check if requestor wants to witness test.

Data Acquisition: ☑ Computer plots ☐ LVDT

Test To 60KSI 5 Min hold.

Results:
Pressure Tested 4 Each 55ksi FLOW Hose
DE2 1092.
Pressure Tested to 60ksi MAWP 40 KSI

Test performed by: R. Carnahan Date: 4-1-93

I, the requestor of this test(s), realize that I am responsible for pointing out to the Building 343 Facility Engineer or Supervisor any known or expected hazardous conditions or materials, such as toxic or radioactive components, which could be generated or released during this test(s).

Signature of Requestor: Stanley Baker Approved by: ______
Bldg. 343

ATTACHMENT 2

LAWRENCE LIVERMORE LABORATORY – UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

FILE NO.

PAGE

SUBJECT HIEE Shrapnel Barrier Calculation

NAME M. Holliday

DATE 6/93

Using the end plug as the largest credible fragment, for the barrier thickness per DOE Pressure Safety Draft Man①, W_f = 4 lbs (1.8 kgs)③

Calculating the mechanical strain energy in the pressurized vessel ①

$$E_{thick\ cyl} = \pi r_i^2 L \left(\frac{P_0^2}{Y}\right) \frac{r_i^2}{(r_0^2 - r_i^2)} \left[\frac{3(1-2\upsilon)}{2} + (1+\upsilon)\frac{r_0^2}{r_i^2}\right]$$

Where $r_i \equiv$ Cylinder inner radius = 1.25 in

$L \equiv$ Cylinder Length = 30 in

$P_0 \equiv$ Pressure @ failure = 40,000 psi

$Y \equiv$ Youngs modulus of elasticity = $29.5 \cdot 10^6$ psi②

$\upsilon \equiv$ Poissons Ratio = .272②

$r_0 \equiv$ Cylinder outer radius = 2.5 in

$$E_{thick\ cyl} = \pi (1.25\,in)^2 (30\,in) \left(\frac{(40{,}000\ lbs/in^2)^2}{29.5 \cdot 10^6\ lbs/in^2}\right) \frac{(1.25\,in)^2}{(2.5\,in)^2 - (1.25\,in)^2}$$

$$\left[\frac{3(1-2(.272))}{2} + (1+.272)\frac{2.5^2}{1.25^2}\right]$$

$$E_{thick\ cyl} = 7983\,(.333)\,(.684 + 5.08)$$

$$= 15{,}344 \text{ in-lbs} = 1.28 \cdot 10^3 \text{ ft-lbs}$$

① Ref - Appendix G ~DOE Pressure Safety Draft Manual eqn. 1, pg. 7

② Ref - Alloy Digest, Armco 15-5 PH Heat Treatable Stainless Steel

SUBJECT HIEE Barrier Calculation (contd.)

NAME M. Holliday
DATE 6/93

Energy of the Fragment $\equiv E_f = E_{thick\,cyl} + U$ ④

Adding the Stored Energy from Liquid Stored Energy Content to the Mech. Strain E

$$E_f = E_{thick\,cyl} + U = 1.28 \cdot 10^3 \text{ ft-lbs} + 2.11 \cdot 10^4 \text{ ft-lbs}$$

$$E_f = 2.24 \cdot 10^4 \text{ ft-lbs}$$ * Note this assumes 100% energy transmission to fragment

$$E_f = \frac{1}{2} m V^2$$ (Solving for V^2)

$$V^2 = \frac{2E_f}{m} = \frac{2(2.24 \cdot 10^4 \text{ ft-lbs})}{.124 \text{ slugs}^{①}}$$ (.155 slugs) ~ Weight of 5 lb. fragment

$$V^2 = 3.6 \cdot 10^5 \text{ ft}^2/\text{sec}^2, \quad V = 601 \text{ ft/s} = 183 \text{ m/s}$$

Using Eqn. 38 from Appendix G ~ DOE Pressure Safety Draft Manual, Table 7 pg. 29

$$t = \frac{1}{A_f}\left[\frac{V_{50}}{10^{C1}(7000)(W_f)^{\beta}}\right]^{1/\alpha 1}$$

From Table 6 pg. 29
$C1 \equiv$
$\alpha 1 \equiv$
$\beta 1 \equiv$
} Thor Material Constants

$$A_f = \pi \cdot 1.25^2 \text{ in}^2 = 4.9 \text{ in}^2$$

$V_{50} \equiv$ fragment Velocity in ft/s $= 601$ ft/s (Velocity @ which fragments have a 50% probability of perforating a shield of a given thickness t.)

$W_f = 4$ lbs ③

$t =$ Shield thickness in inches

③ Weight given by Quest Inc 6/3/93 per phone conversation (4 lbs = .124 slugs)

SUBJECT: HIEE Barrier Calculation for Al 6061-T6

NAME: M. Holliday
DATE: 6/93

Scaling Law for Extrapolation to compare Shield thickness of 2024 Al to 6061 T6 Al

$$\frac{\text{Depth of Penetration for 2024 Al}^{①}}{\text{Depth of Penetration for 6061 Al}} = \frac{\cancel{\left(\frac{\rho_f}{\rho_s}\right)} L_f \cancel{\frac{A_f}{A_{f_0}}} \ln\left(1+\frac{V_f^2}{6\,\frac{\sigma_{Y2024}}{\rho_{S2024}}}\right)}{\cancel{\left(\frac{\rho_f}{\rho_s}\right)} L_f \cancel{\frac{A_f}{A_{f_0}}} \ln\left(1+\frac{V_f^2}{6\,\frac{\sigma_{Y6061}}{\rho_{S6061}}}\right)}$$

$V_f \equiv$ Fragment Velocity = 601 ft/s

$\sigma_{Y2024} \equiv$ Yield Strength 2024 T4 Al = 11,000 lbs/in² $\rho_{S2024} \equiv$ Density = .1 lbs/in³

$\sigma_{Y6061} \equiv$ Yield Strength 6061 T6 Al = 8,000 lbs/in² $\rho_{S6061} \equiv$ Density = .098 lbs/in³

$$\frac{D_{T2024}}{D_{T6061}} = \frac{\ln\left(1+\frac{(601\,\text{ft/s}\cdot 144\,\text{in})^2}{6\left(\frac{11{,}000\,\text{lbs/in}^2}{\frac{.1\,\text{lbs/in}^3}{g=386.4\,\text{in/s}^2}}\right)}\right)}{\ln\left(1+\frac{(601\,\text{ft/s}\cdot 144\,\text{in})^2}{6\left(\frac{8{,}000\,\text{lbs/in}^2}{\frac{.098\,\text{lbs/in}^3}{g=386.4\,\text{in/s}^2}}\right)}\right)} = \frac{3.413}{3.703}$$

$\frac{D_{T2024}}{D_{T6061}}$ = .922 take reciprical to multiply by calculated thickness for T2024
= 1.085

① Ref ~ Appendix G ~ DOE Pressure Safety Draft Manual eqn. 48 pg. 34

LAWRENCE LIVERMORE LABORATORY · UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

FILE NO.

PAGE

SUBJECT HIEE Barrier Calculation for Al 6061-T6

NAME M. Holliday

DATE 6/93

For 2024 T3 Al (From Table 6 pg. 29)

$$\left.\begin{aligned} C1 &= -.941 \\ \alpha 1 &= 6.185 \\ \beta 1 &= .903 \end{aligned}\right\} \text{For T3 2024 Aluminum}$$

Eqn. 38, Appendix G – DOE Pressure Safety Draft Manual

$$t = \frac{1}{A_f}\left[\frac{V_{50}}{10^{C1}(7000)(W_f)^{\beta}}\right]^{\frac{1}{\alpha 1}}$$

$$t = \frac{1}{4.9\,in^2}\left[\frac{601\ ft/s}{10^{-.941}(7000)(4\,lbs)^{.903}}\right]^{\frac{1}{6.185}}$$

$t = .204(.780)$

$t = .159$ in X3 for safety

$3t = .477$ in. x by scaling factor $\frac{D_{T6061}}{D_{T2024}}$

$3t \times (1.085) \approx .50$

L-398-2 (REV. 10/71)

ATTACHMENT 10

MECHANICAL ENGINEERING DEPT.
ENERGY SYSTEMS ENGINEERING DIVISION

ENGINEERING NOTE ENE93-079

HYDRAULIC IMPACT END EFFECTOR

JULY 1993

Prepared by:
Paul Densley
SAIC Project Engineer

CALCULATIONS -

This Engineering Note is for the design of a test stand which will support the Hydraulic Impact End Effector (HIEE). It will be installed in B-169, Rm 1102, a slab floor on grade. The seismic catagory of this equipment is II.

Calculations were made to prove the adequacy of the test stand. By observation, the stand is deemed strong enough to hold the 250 pound HIEE. Therefore, calculations were made only on the anchors, the strain bar, and the supporting member which are the weakest structures with the highest stresses. The resulting factors of safety are shown in the following table. "NL" in the static column means there is no loaded or stressed condition. Static factors of safety exceed those required in the "Design Safety Standards" except as noted.

TABLE OF FACTORS OF SAFETY

Feature	Static	Seismic	Page
Anchors in shear	NL	15.8	3
Anchors in tension	NL	2.8	4
Bending stress in posts	NL	40.1	5
Post buckeling	NL	103.7	5
HIEE attachment bolts	45.5	35.2	6
Strain bar *	1.0	0.5	7
Solid strain bar	13.1	7.3	8
Welds	6.7	1.9	9
Horizontal member	35.3	15.8	11,12

* For purposes of measuring reaction loads a thin walled cylindrical tube supports the HIEE (See Figure 1) that has a safety factor of 1.1 under operating loads. To add additional support for the HIEE in case of a catastrophic failure of the tube, Willer brand rigging straps are wrapped around the cross member and under the HIEE. These straps have rated loads of 7900, 3950 and 2975 lbs in the vertical, basket and choker configurations respectively.

The HIEE uses a blast of compressed water to break up hard salt cake. The pressure is 40 ksi. The liquid stored energy content is given by (Ref H):

$$U = \frac{P_I^2 v}{B}$$

Where:
P_i = Maximum Allowable Working Pressure (MAWP) (psi) = 40 ksi
v = Volume of the Vessel (Ref I) = 95 in^3
B = Liquid Bulk Modulus (Water) = 300 ksi

$$U = \frac{(40{,}000\ \text{psi})^2 (95\ \text{in}^3)}{(300{,}000\ \text{psi})}$$

$U = 2.53\ \text{E5 in-lb}$ converting to equilivant grams TNT

$$U = (2.53\ \text{E5 in-lb})\left(\frac{\text{ft}}{12\ \text{in}}\right)\left(\frac{\text{lb TNT}}{1.55\ \text{E6 ft/lb}}\right)\left(\frac{454\ \text{gm}}{\text{lb}}\right) = 6.2\ \text{gm TNT}$$

The stand is a welded and bolted structure with a damping ratio of 5%. It is contructed of steel shapes.

Steel plate - ASTM A36 (Ref B)
$S_y = 36$ ksi
$S_u = 58$ ksi
$E = 30 \times 10^6$

Steel angle - ASTM A36 (Ref C, p.1-49)
3 x 3 x .25 angle
$I = 1.24 \text{ in}^4$ $S = .577 \text{ in}^3$
$A = 1.44 \text{ in}^2$ wt = 4.9 lbs/ft

Steel Structural Tubing - ASTM A500 (Ref G)
$S_y = 46$ ksi
$S_u = 58$ ksi
$E = 30 \times 10^6$

4 x 4 x .5 tubular steel (Ref C, p. 1-96)
$I = 12.3 \text{ in}^4$ $S = 6.13 \text{ in}^3$
$A = 6.36 \text{ in}^2$ wt = 21.63 lbs/ft

4 x 4 x .25 tubular steel (Ref C, p. 1-96)
$I = 8.22 \text{ in}^4$ $S = 4.11 \text{ in}^3$
$A = 4.59 \text{ in}^2$ wt = 12.21 lbs/ft

Strain bar - ASTM A108 (Ref D) Dimensions shown in Figure 7.
$S_y = 54$ ksi
$S_u = 64$ ksi
$E = 29 \times 10^6$

All bolts are Grade 5 - .5 in Ø (Ref E)
$S_y = 92$ ksi
$S_t = 120$ ksi
$S_p = 85$ ksi (proof strength)

Hilti Drop-In Anchors - .75 in Ø (Ref F)
(2000 psi concrete assumed)
2210 lbs Tension
3800 lbs Shear

The stand is show in Figure 1. Determination of the center of gravity of the stand and HIEE (Ref A) was shown to be centered in the lateral direction, 3.5 inches along the longitudinal direction, and 25.6 inches from the floor. Due to the low center of gravity, the substantial structural elements and the inability of personnel to place themselves in a position of jeapority, there is no feasible seismic hazard not acceptable to the program. However, the following analysis is provided.

From Section 5.2, Figure 1 of the "Design Safety Standards" with 5% damping for the Livermore Site of Category II, the maximum lateral and vertical accelerations are:

$a_l = 2.12 \times .47$ .9964   say 1.0 g
$a_v = 2.12 \times .47$ .9964   say 1.0 g

For a very conservative approach these values will be applied to the calculations although it is expected that a detailed analysis of the stand would result in a much smaller acceleration.

For the Floor Anchors

The total weight of the stand and HIEE is 1006.4 lbs   say 1010 lbs

Shear per bolt - one direction

Shear = wt x $(a_l)/6$ = 1010 lbs x (1.0)/6 = 168.3 lbs   say 170 lbs

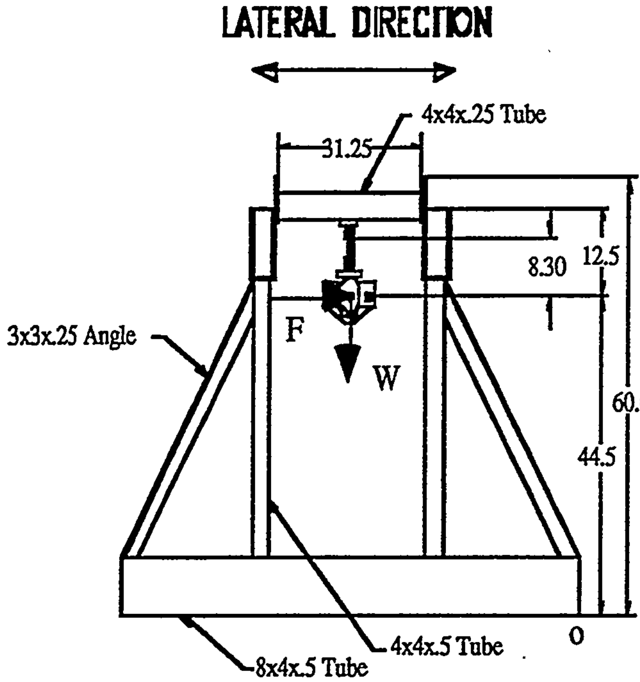
Shear in two directions

$$\text{Shear}_2 = \sqrt{a_l^2 + a_l^2} = \sqrt{170^2 + 170^2} = 240.4 \text{ lbs/bolt}$$ say 240 lbs/bolt

$$FS = \frac{3800 \text{ lbs}}{240 \text{ lbs}} = \underline{\mathbf{15.8}}$$

Overturning

LATERAL



$F = w \times a_l = (1010 \text{ lbs}) \times (1.0) = 1010 \text{ lbs}$

W = w - vertical component

$= 1010 \times (1 - 1.0) = 0 \text{ lbs}$

$\Sigma M_0 = 0 = F \times 46 - W \times 16.375 - T \times 64.5$

where T is the tension

$= (1010 \text{ lbs})(46 \text{ in}) - (0 \text{ lbs})(16.375 \text{ in}) - T(64.5 \text{ in})$

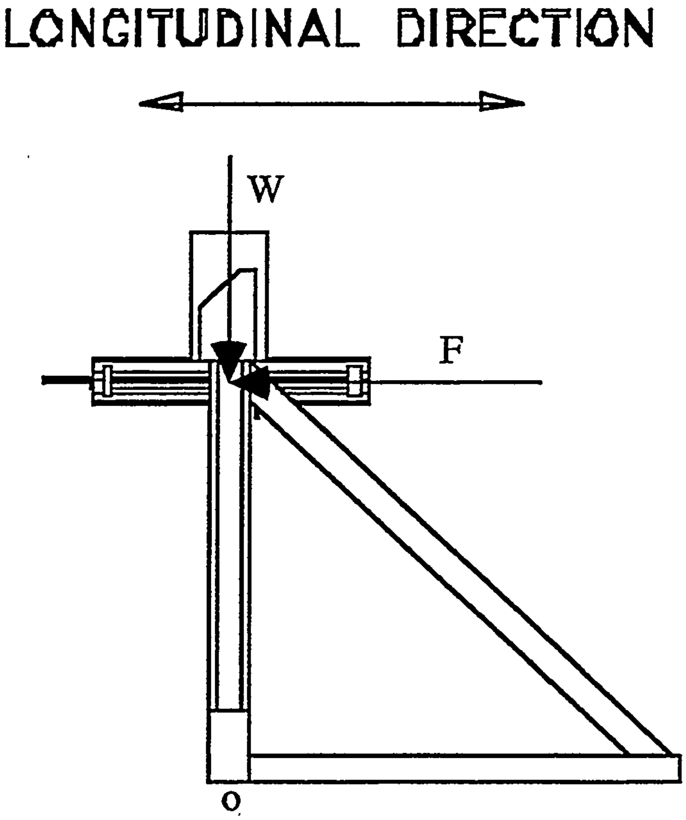
$= 46{,}460 \text{ in-lb} + 0 \text{ in-lb} - T(64.5 \text{ in})$

Therefore T = 720.3 lbs say 720 lbs

The tension per bolt assuming only the two outermost bolts resist this lateral overturning is given by

$$T/2 = \frac{720 \text{ lbs}}{2} = 360 \text{ lbs}$$

LONGITUDINAL



$\Sigma M_0 = 0 = T \times 37.5 - F \times 46$

$= T(37.5 \text{ in}) - (1010 \text{ lbs})(46 \text{ in})$

$= T(37.5 \text{ in}) - 46{,}460 \text{ in-lb}$

Therefore T = 1239.8 lbs say 1240 lbs

The tension per bolt assuming only the three outermost bolts resist this longitudinal overturning is given by

$$T/3 = \frac{1240 \text{ lbs}}{3} = 413.3 \text{ lbs} \quad \text{say } 415 \text{ lbs}$$

The worst case anchor loading would be the combination of these two on any one of the six anchor bolts. Therefore,

Tension = 360 lbs + 415 lbs = 775 lbs

$$FS = \frac{2200 \text{ lbs}}{775 \text{ lbs}} = \underline{2.8}$$

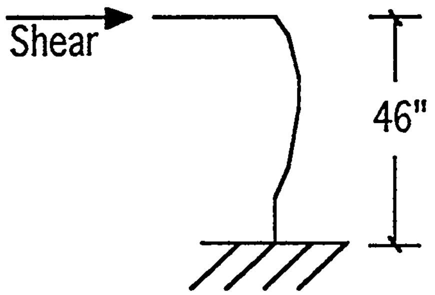
Check by interaction formula:

$$\left(\frac{240}{3800}\right)^{5/3} + \left(\frac{775}{2210}\right)^{5/3} =$$

$.0100 + .1744 = .1844 < 1.0$ OK

Bending Stress in 4 x 4 x .5 Post

Use the combined shear (240 lbs) for the weight on the beam.



$$M = \frac{WL}{2} = \frac{(240 \text{ lbs})(46 \text{ in})}{2} = 5520 \text{ in-lb}$$

$$S = \frac{Mc}{I} = \frac{(5520 \text{ in-lb})(2 \text{ in})}{12.3 \text{ in}^4} = 897.6 \text{ psi}$$

$$FS = \frac{(36{,}000 \text{ psi})}{(897.6 \text{ psi})} = \underline{\mathbf{40.1}}$$

Leg Buckeling

Assume the worst case loading is the Longitudial case. The load on one post would be:

$$= \frac{W}{2} = \frac{1010 \text{ lbs}}{2} = 505 \text{ lbs} \qquad \text{(Static)}$$

Now include the 1.0 loading for the worst case seismic:

$P = w + a_V = (505 \text{ lbs})(1 + 1.0) = (505 \text{ lbs})(2.0) = 1010 \text{ lbs}$

$l = 46$ in $\qquad r = 1.39 \qquad$ (Ref C, p. 1-96)

$$\frac{l}{r} = \frac{46}{1.39} = 33.1 \qquad \text{Short Column}$$

Using the AISC formula for short, short columns (Ref B, p. 5-43)

$$\frac{P}{A} = 17{,}000 - .485\left(\frac{l}{r}\right)^2 = 17{,}000 - .485\,(33.1)^2 = 16{,}469 \text{ psi}$$

Therefore, $P = A \times 16{,}469 \text{ psi} = (6.36 \text{ in}^2)(16{,}469 \text{ psi}) = 104{,}742 \text{ lbs}$

$$FS = \frac{(104{,}742 \text{ lbs})}{(1010 \text{ lbs})} = \underline{\mathbf{103.7}}$$

HIEE Attachment

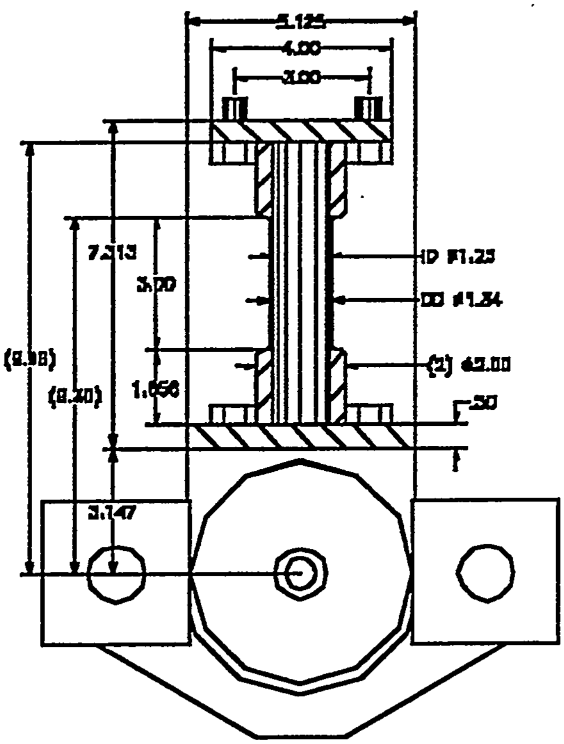


FIGURE 7

For bolts, the worst condition, highest load is the combined three axis shear plus the 376 lbs from the HIEE. Assume only one set of the eight, .5 bolts resist this condition.

$\Sigma a = \sqrt{a_l^2 + a_l^2 + a_v^2} \;\; = \sqrt{(1.0)^2 \text{ x } 3} = 1.73$

Total Force = (250 lbs x 1.73) + 376 lbs
= 808.5 lbs say 810 lbs
Shear load per bolt = 810 lbs/4 = 202.5 lbs

$$\text{Shear stress} = \frac{F}{A} = \frac{202.5 \text{ lbs}}{.343 \text{ in}^2} = 590.4 \text{ psi}$$

$$FS = \frac{(20{,}784 \text{ psi})}{(590.4 \text{ psi})} = \underline{35.2}$$

For the static case,

Total Force = (250 lbs + 376 lbs) = 626 lbs
Shear load per bolt = 626 lbs/4 = 156.5 lbs

$$\text{Shear stress} = \frac{F}{A} = \frac{156.5 \text{ lbs}}{.343 \text{ in}^2} = 456.3 \text{ psi}$$

$$FS = \frac{(20{,}784 \text{ psi})}{(456.3 \text{ psi})} = \underline{45.5}$$

Bearing Load

The seismic load = 202.5 lbs with the bearing area = .25 x .5 = .125 in^2.

$$S_b = \frac{F}{A} = \frac{202.5 \text{ lbs}}{.125 \text{ in}^2} = 1620 \text{ psi}$$

$$FS = \frac{(20{,}784 \text{ psi})}{(1620 \text{ psi})} = \underline{12.8}$$

The static load = 156.5 lbs with the bearing area = .25 x .5 = .125 in^2.

$$S_b = \frac{F}{A} = \frac{156.5 \text{ lbs}}{.125 \text{ in}^2} = 1252 \text{ psi}$$

$$FS = \frac{(20{,}784 \text{ psi})}{(1252 \text{ psi})} = \underline{16.6}$$

Strain Bar - ASTM A108

Assume the worst condidtion is again the combined three axis plus the HIEE recoil of 376 lbs in the longitudinal direction only.

Max stress = Bending Stress + Tensile Stress

$$= \frac{L}{S} + \frac{F_v}{A}$$

Where: L = Bending Moment = Pl
Lateral $P_1 = 250 \times a_l = (250 \text{ lbs})(1.0) = 250$ lbs
Long. $P_2 = 250 \times a_l + 376 = (250 \text{ lbs})(1.0)+(376 \text{ lbs}) = 626$ lbs

$$P = \sqrt{(P_1)^2 + (P_2)^2} = \sqrt{(250 \text{ lbs})^2 + (626 \text{ lbs})^2} = 674.1 \text{ lbs} \qquad \text{say } 675 \text{ lbs}$$

then $L = (675 \text{ lbs})(8.3 \text{ in}) = 5602.5$ in-lb say 5605 in-lb
$l = 8.3$ in $d_o = 1.34$ in $d_i = 1.25$ in

$$S = \frac{\pi\,(d_o{}^4 - d_i{}^4)}{32\,d_o} = \frac{\pi\,((1.34)^4 - (1.25)^4)}{(32)(1.34)} = .057 \text{ in}^3$$

$$A = \frac{\pi\,(d_o{}^2 - d_i{}^2)}{4} = \frac{\pi((1.34)^2 - (1.25)^2)}{4} = .183 \text{ in}^2$$

$F_v = 250 \times a_v = (250 \text{ lbs})(2.0) = 500$ lbs

$$\text{Max stress} = \frac{(5605 \text{ in-lb})}{.057 \text{ in}^3} + \frac{500 \text{ lbs}}{.183 \text{ in}^2} = 101{,}065.6 \text{ psi}$$

$$\text{FS} = \frac{(54{,}000 \text{ psi})}{(101{,}065.6 \text{ psi})} = \underline{.5}^{*} < 1.0 \text{ may fail in seismic event}$$

For the static case:
Lateral $P_1 = 250 \times a_l = (250 \text{ lbs})(0) = 0$ lbs
Long. $P_2 = 250 \times a_l + 376 = (250 \text{ lbs})(0)+(376 \text{ lbs}) = 376$ lbs

$$P = \sqrt{(P_1)^2 + (P_2)^2} = \sqrt{(0 \text{ lbs})^2 + (376 \text{ lbs})^2} = 376 \text{ lbs}$$

then $L = (376 \text{ lbs})(8.3 \text{ in}) = 3120.8$ in-lb say 3120 in-lb

$$\text{Max stress} = \frac{(3120 \text{ in-lb})}{.057 \text{ in}^3} + \frac{250 \text{ lbs}}{.183 \text{ in}^2} = 56{,}103 \text{ psi}$$

$$\text{FS} = \frac{(54{,}000 \text{ psi})}{(56{,}103 \text{ psi})} = \underline{1.0}^{*}$$

---

[*] For purposes of measuring reaction loads a thin walled cylindrical tube supports the HIEE (See Figure 1) that has a safety factor of 1.0 under operating loads. To add additional support for the HIEE in case of a failure of the tube, Willer brand rigging straps are wrapped around the cross member and under the HIEE. These straps have rated loads of 7900, 3950 and 2975 lbs in the vertical, basket and choker configurations respectively.

[*] For purposes of measuring reaction loads a thin walled cylindrical tube supports the HIEE (See Figure 1) that has a safety factor of 1.0 under operating loads. To add additional support for the HIEE in case of a failure of the tube, Willer brand rigging straps are wrapped around the cross member and under the HIEE. These straps have rated loads of 7900, 3950 and 2975 lbs in the vertical, basket and choker configurations respectively.

Solid Strain Bar - ASTM A36

Assume the worst condition is as before and look at the top of the bar.

Max stress = Bending Stress + Tensile Stress

$$= \frac{L}{S} + \frac{F_V}{A}$$

Where: L = Bending Moment = Pl
Laterial $P_1 = 250 \times a_l = (250 \text{ lbs})(1.0) = 250 \text{ lbs}$
Long. $P_2 = 250 \times a_l + 376 = (250 \text{ lbs})(1.0)+(376 \text{ lbs}) = 626 \text{ lbs}$

$$P = \sqrt{(P_1)^2 + (P_2)^2} = \sqrt{(250 \text{ lbs})^2 + (626 \text{ lbs})^2} = 674.1 \text{ lbs}$$ say 675 lbs

then $L = (675 \text{ lbs})(9.96 \text{ in}) = 6723 \text{ in-lb}$
$l = 8.3 \text{ in} + 1.66 \text{ in} = 9.96 \text{ in}$ $d = 2.0 \text{ in}$

$$S = \frac{\pi (d^3)}{32} = \frac{\pi ((2.0)^3)}{(32)} = .785 \text{ in}^3$$

$$A = \frac{\pi (d^2)}{4} = \frac{\pi (2.0)^2}{4} = 3.14 \text{ in}^2$$

$F_V = 250 \times a_V = (250 \text{ lbs})(2.0) = 500 \text{ lbs}$

$$\text{Max stress} = \frac{(6723 \text{ in-lb})}{.785 \text{ in}^3} + \frac{500 \text{ lbs}}{3.14 \text{ in}^2} = 8723.6 \text{ psi}$$

$$FS = \frac{(64{,}000 \text{ psi})}{(8723.6 \text{ psi})} = \underline{7.3}$$

For the static case:
Laterial $P_1 = 250 \times a_l = (250 \text{ lbs})(0) = 0 \text{ lbs}$
Long. $P_2 = 250 \times a_l + 376 = (250 \text{ lbs})(0)+(376 \text{ lbs}) = 376 \text{ lbs}$

$$P = \sqrt{(P_1)^2 + (P_2)^2} = \sqrt{(0 \text{ lbs})^2 + (376 \text{ lbs})^2} = 376 \text{ lbs}$$

then $L = (376 \text{ lbs})(9.96 \text{ in}) = 3744.9 \text{ in-lb}$ say 3745 in-lb

$$\text{Max stress} = \frac{(3745 \text{ in-lb})}{.785 \text{ in}^3} + \frac{250 \text{ lbs}}{3.14 \text{ in}^2} = 4850 \text{ psi}$$

$$FS = \frac{(64{,}000 \text{ psi})}{(4850 \text{ psi})} = \underline{13.1}$$

Welds

The welds which are .25 fillet welds. The length of the weld is π x 2.0 in = 6.28 in. The worst case would be the Strain Bar.

Max stress = Bending Stress + Tensile Stress

$$= \frac{L}{S} + \frac{F_V}{A}$$

Where: L = Bending Moment = Pl
Laterial $P_1 = 250 \times a_l = (250\ \text{lbs})(1.0) = 250$ lbs
Long. $P_2 = 250 \times a_l + 376 = (250\ \text{lbs})(1.0)+(376\ \text{lbs}) = 626$ lbs

$$P = \sqrt{(P_1)^2 + (P_2)^2} = \sqrt{(250\ \text{lbs})^2 + (626\ \text{lbs})^2} = 624.1\ \text{lbs} \qquad \text{say } 675\ \text{lbs}$$

then L = (675 lbs)(9.96 in) = 6723 in-lb
l = 9.96 in $\quad d_o = 2.0$ in $\quad d_i = 1.25$ in

$$S = \frac{\pi\,(d_o^4 - d_i^4)}{32\,d_o} = \frac{\pi\,((2.0)^4 - (1.25)^4)}{(32)(2.0)} = .666\ \text{in}^3$$

$$A = \frac{\pi\,(d_o^2 - d_i^2)}{4} = \frac{\pi((2.0)^2 - (1.25)^2)}{4} = 1.91\ \text{in}^2$$

$F_V = 250 \times a_V = (250\ \text{lbs})(2.0) = 500$ lbs

$$\text{Max stress} = \frac{(6723\ \text{in-lb})}{.666\ \text{in}^3} + \frac{500\ \text{lbs}}{1.91\ \text{in}^2} = 10{,}356.4\ \text{psi}$$

$$\text{Load on the weld} = \frac{S}{l} = \frac{(10{,}356.4\ \text{psi})}{6.28\ \text{in}} = 1649.1\ \text{lbs} \qquad \text{say } 1650\ \text{lbs}$$

$$FS = \frac{(3200\ \text{lbs})}{(1650\ \text{lbs})} = \underline{1.9}$$

For the static case:
Laterial $P_1 = 250 \times a_l = (250\ \text{lbs})(0) = 0$ lbs
Long. $P_2 = 250 \times a_l + 376 = (250\ \text{lbs})(0)+(376\ \text{lbs}) = 376$ lbs

$$P = \sqrt{(P_1)^2 + (P_2)^2} = \sqrt{(0\ \text{lbs})^2 + (376\ \text{lbs})^2} = 376\ \text{lbs}$$

then L = (376 lbs)(9.96 in) = 3744.9 in-lb say 3745 in-lb

$$\text{Max stress} = \frac{(3745\ \text{in-lb})}{.666\ \text{in}^3} + \frac{250\ \text{lbs}}{1.91\ \text{in}^2} = 2972\ \text{psi}$$

$$\text{Load on the weld} = \frac{S}{l} = \frac{(2972\ \text{psi})}{6.28\ \text{in}} = 473\ \text{lbs}$$

$$FS = \frac{(3200\ \text{lbs})}{(473\ \text{lbs})} = \underline{6.7}$$

Horizontal Member - 4 x 4 x .25 ASTM A36

Assume worst case with three axis loading. Solve by superposition.

Lateral Direction - Reference formula 3d, page 107 Roark's Sixth Edition

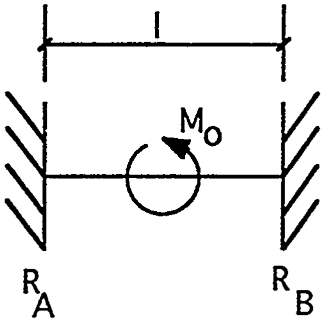
$P_1 = 250 \times a_l = (250 \text{ lbs})(1.0) = 250 \text{ lbs}$

$M_o = (12.26 \text{ in})(250 \text{ lbs}) = 3065 \text{ in-lb}$

$R_A = \frac{-6 M_o a}{l^3}(l-a) = -\frac{3 M_o}{2l}$ when $a = \frac{l}{a}$ and $l = 31.25$ in

$R_A = -\frac{3 M_o}{2l} = -\frac{3(3065 \text{ in-lb})}{2(31.25 \text{ in})} = -147.1 \text{ lbs}$ say -150 lbs

$R_B = -R_A = -(-150 \text{ lbs}) = 150 \text{ lbs}$



Applied Moment

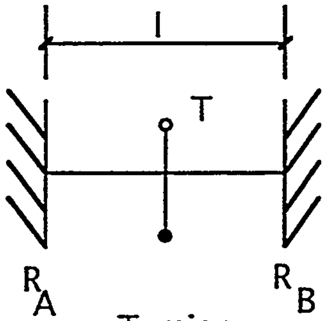
Longitudinal Direction - Reference formula 16, page 352 Roark's Sixth Edition

$P_2 = 250 \times a_l + 376 \text{ lbs} = 250 \text{ lbs} + 376 \text{ lbs} = 626 \text{ lbs}$

$T = (12.46 \text{ in})(626 \text{ lbs}) = 7799.9 \text{ in-lb}$ say 7800 in-lb

average stress $= \frac{T}{2t(a-t)(b-t_1)} = \frac{T}{2t(a-t)^2}$ when $a = b$ and $t = t_1$

average stress $= \frac{(7800 \text{ in-lb})}{2(.25 \text{ in})(4 - .25 \text{ in})^2} = 1109.3 \text{ psi}$ say 1110 psi



Torsion

Vertical Direction - Reference formula 1d, page 101 Roark's Sixth Edition

$P_3 = 250 \times a_v = (250 \text{ lbs})(2.0) = 500 \text{ lbs}$

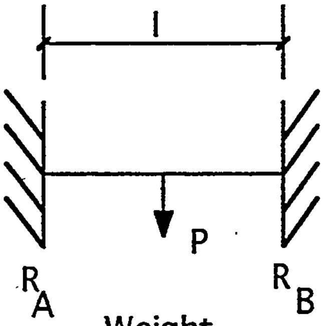
$M = \frac{P_3 l}{8} = \frac{(500 \text{ lbs})(31.25 \text{ in})}{8} = 1953.1 \text{ in-lb}$ say 1955 in-lb

$R_A = \frac{P_3}{l^3}(l-a)^2(2l+a) = \frac{P_3}{2}$ when $a = \frac{l}{2}$

$R_A = \frac{500 \text{ lbs}}{2} = 250 \text{ lbs}$

$R_B = \frac{P_3 a^2}{l^3}(3l - 2a) = \frac{P_3}{2}$ when $a = \frac{l}{2}$

$R_B = \frac{500 \text{ lbs}}{2} = 250 \text{ lbs}$



Weight

Maximum stress = bending stress + shear stress

Thebending stress from the Lateral and Vertical Directions are in the same plane and therefore are additive. There is no bending stress associtied with the Longitudinal Direction (pure torsion assumed). Twice the shear stresses for all three cases is added to give an indication of the total stress. This is very conservative in that the square root of the sum of the squares will always be smaller than the sum. Therefore:

$$\text{Max Stress} = \frac{M}{S} + \frac{P}{A}$$

$$= \frac{(3065 \text{ in-lb} + 1955 \text{ in-lb})}{4.11 \text{ in}^3} + \left(\frac{(150 \text{ lbs} + 250 \text{ lbs})}{3.59 \text{ in}^2} + 1110 \text{ psi} \right)(2) = 3664.3 \text{ psi}$$

$$\text{FS} = \frac{(58{,}000 \text{ psi})}{3664.3 \text{ psi}} = \underline{\mathbf{15.8}}$$

For the static case, $a_l = 0$, and $a_v = 1$. Plugging these values into the above formulas gives:

Lateral Direction - Reference formula 3d, page 107 Roark's Sixth Edition

$P_1 = 250 \text{ x } a_l = (250 \text{ lbs})(0) = 0 \text{ lbs}$
$M_o = (12.26 \text{ in})(0 \text{ lbs}) = 0 \text{ in-lb}$

$$R_A = \frac{-6\, M_o\, a}{l^3}(l\text{-}a) = -\frac{3\, M_o}{2l} \quad \text{when } a = \frac{l}{a} \text{ and } l = 31.25 \text{ in}$$

$$R_A = -\frac{3\, M_o}{2l} = -\frac{3(0 \text{ in-lb})}{2(31.25 \text{ in})} = 0 \text{ lbs}$$

$$R_B = -R_A = -\ (0 \text{ lbs}) = 0 \text{ lbs}$$

Longitudinal Direction - Reference formula 16, page 352 Roark's Sixth Edition

$P_2 = 250 \text{ x } a_l + 376 \text{ lbs} = 0 \text{ lbs} + 376 \text{ lbs} = 376 \text{ lbs}$
$T = (12.46 \text{ in})(376 \text{ lbs}) = 4684.9 \text{ in-lb}$ say 4690 in-lb

$$\text{average stress} = \frac{T}{2t(a\text{-}t)(b\text{-}t_1)} = \frac{T}{2t(a\text{-}t)^2} \quad \text{when } a = b \text{ and } t = t_1$$

$$\text{average stress} = \frac{(4690 \text{ in-lb})}{2(.25 \text{ in})(4 - .25 \text{ in})^2} = 667 \text{ psi}$$

Vertical Direction - Reference formula 1d, page 101 Roark's Sixth Edition

$$P_3 = 250 \text{ x } a_V = (250 \text{ lbs})(1) = 250 \text{ lbs}$$

$$M = \frac{P_3 \, l}{8} = \frac{(250 \text{ lbs})(31.25 \text{ in})}{8} = 976.5 \text{ in-lb} \quad \text{say } 975 \text{ in-lb}$$

$$R_A = \frac{P_3}{l^3}(l\text{-}a)^2\,(2l + a) = \frac{P_3}{2} \quad \text{when } a = \frac{l}{2}$$

$$R_A = \frac{250 \text{ lbs}}{2} = 125 \text{ lbs}$$

$$R_B = \frac{P_3\, a^2}{l^3}(3l - 2a) = \frac{P_3}{2} \quad \text{when } a = \frac{l}{2}$$

$$R_B = \frac{250 \text{ lbs}}{2} = 125 \text{ lbs}$$

$$\text{Max Stress} = \frac{M}{S} + \frac{P}{A}$$

$$= \frac{(0 \text{ in-lb} + 975 \text{ in-lb})}{4.11 \text{ in}^3} + \left(\frac{(0 \text{ lbs} + 125 \text{ lbs})}{3.59 \text{ in}^2} + 667 \text{ psi}\right)(2) = 1640 \text{ psi}$$

$$\text{FS} = \frac{(58{,}000 \text{ psi})}{1640 \text{ psi}} = \underline{35.3}$$

FIGURE 1

HIEE AND TEST STAND

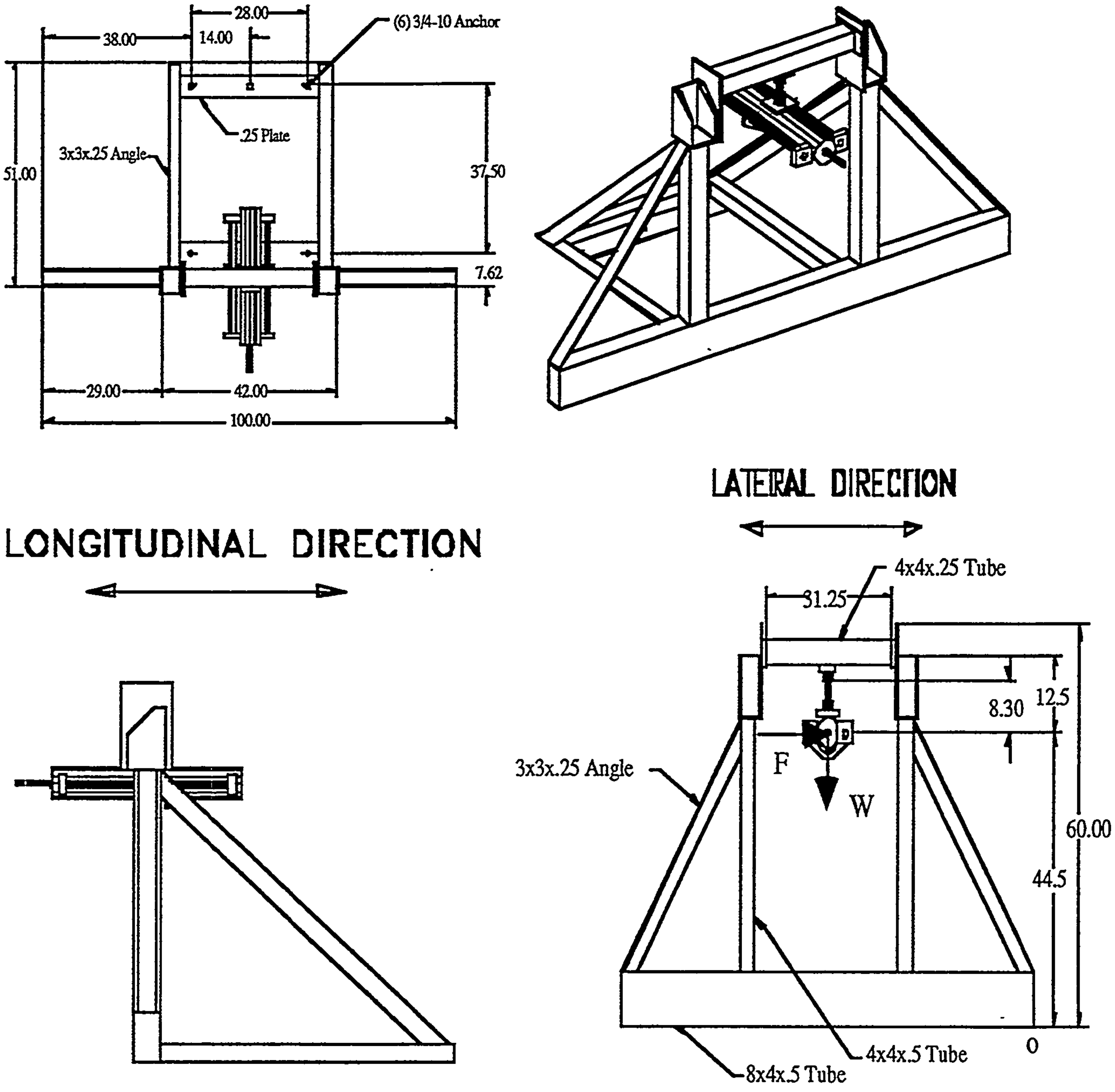


FIGURE 2

BUILDING 169 FLOOR PLAN

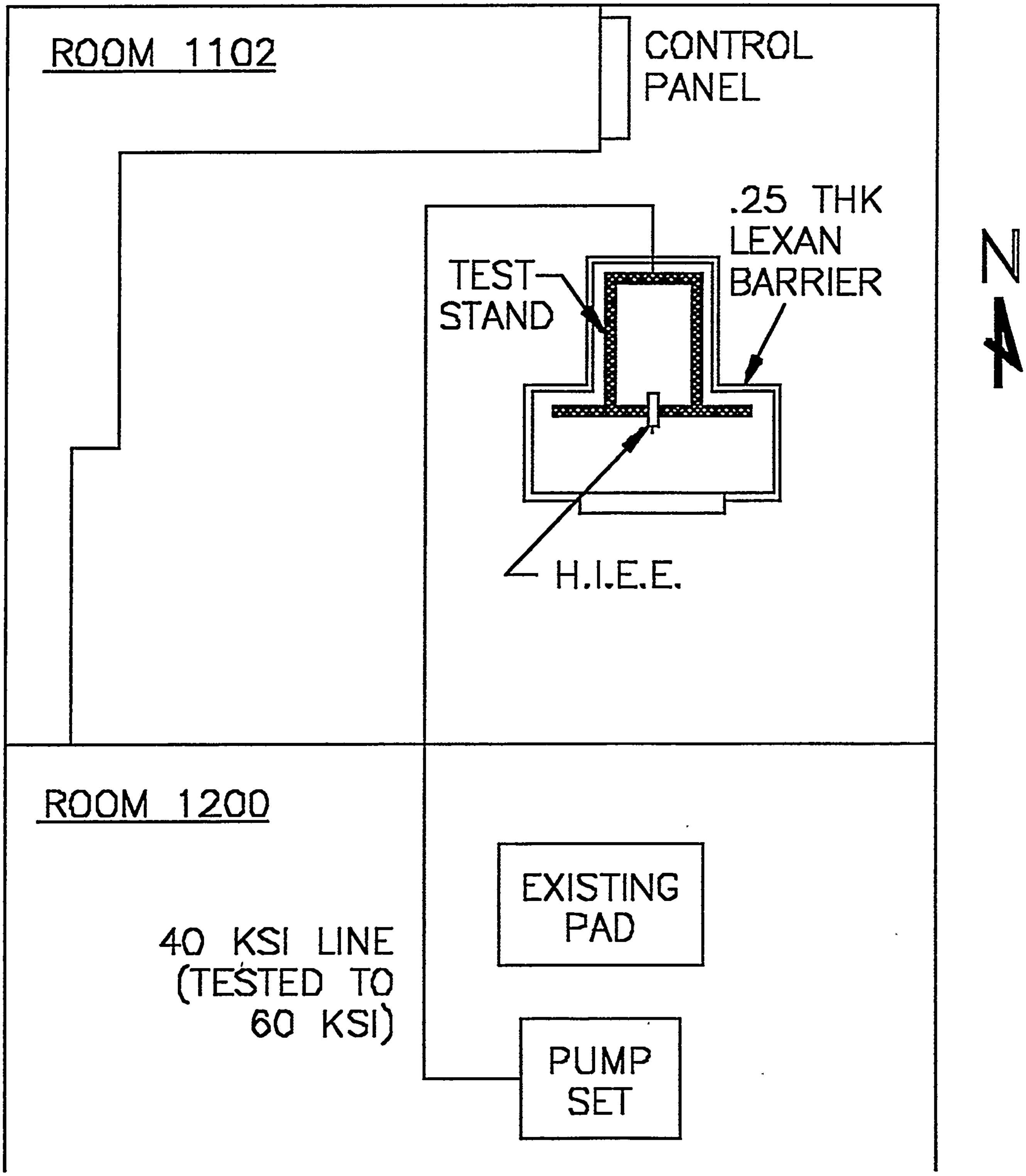


FIGURE 3

HIEE SYSTEM OPERATION SCHEMATIC

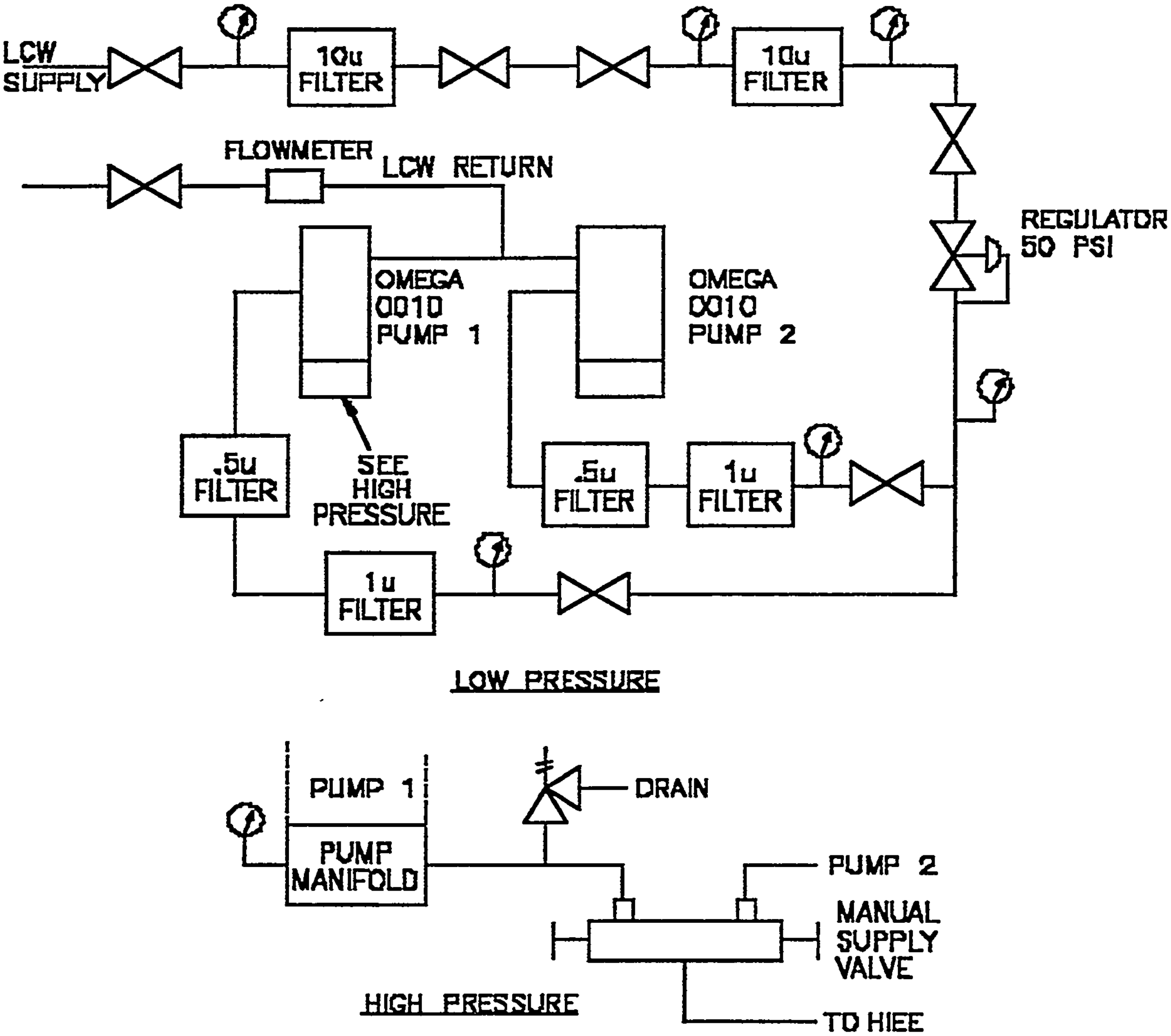


FIGURE 3A

HIEE FLOW DIAGRAM

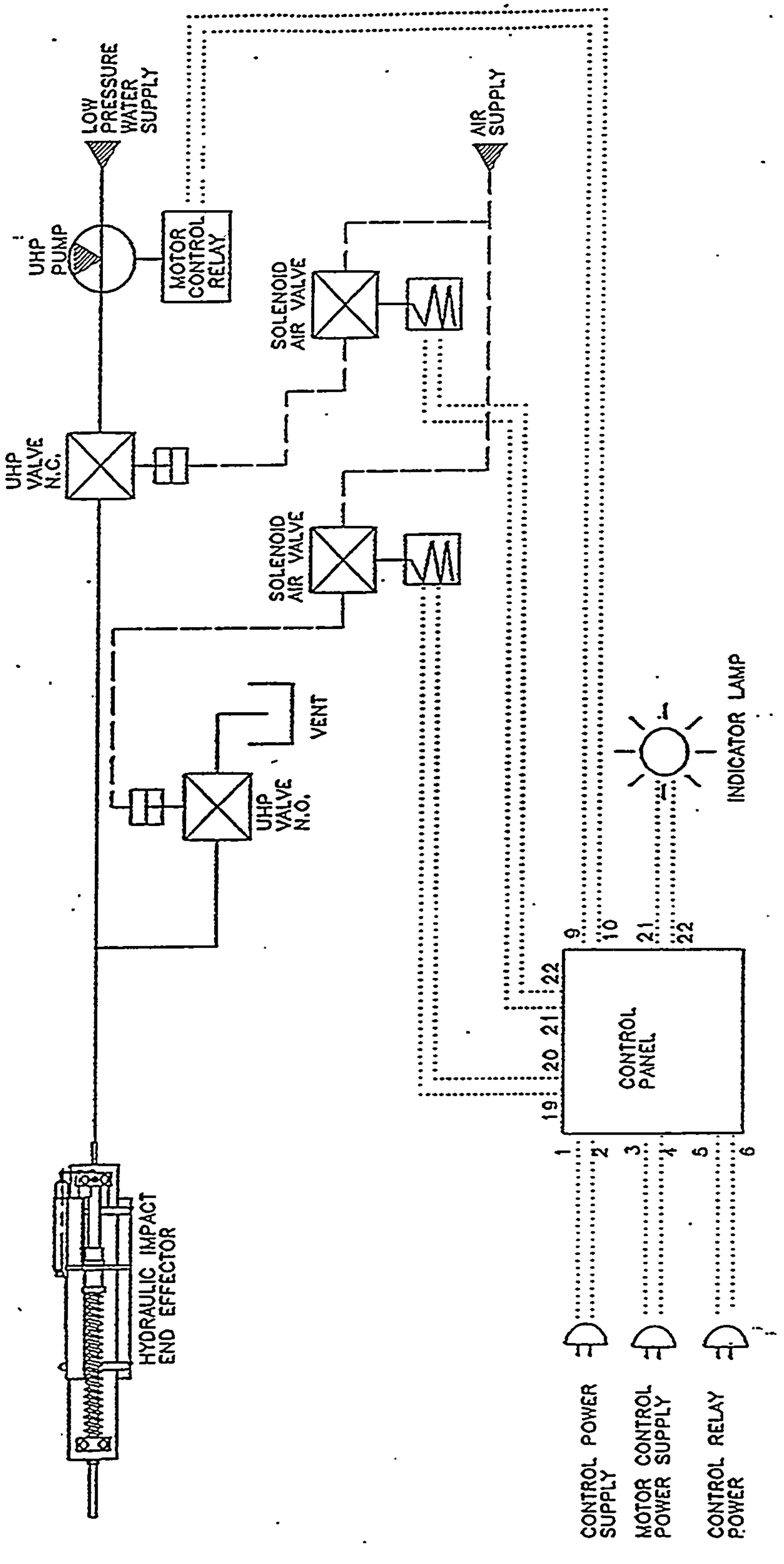


FIGURE 4

PRESSURE CONTROL/RELIEF VALVE

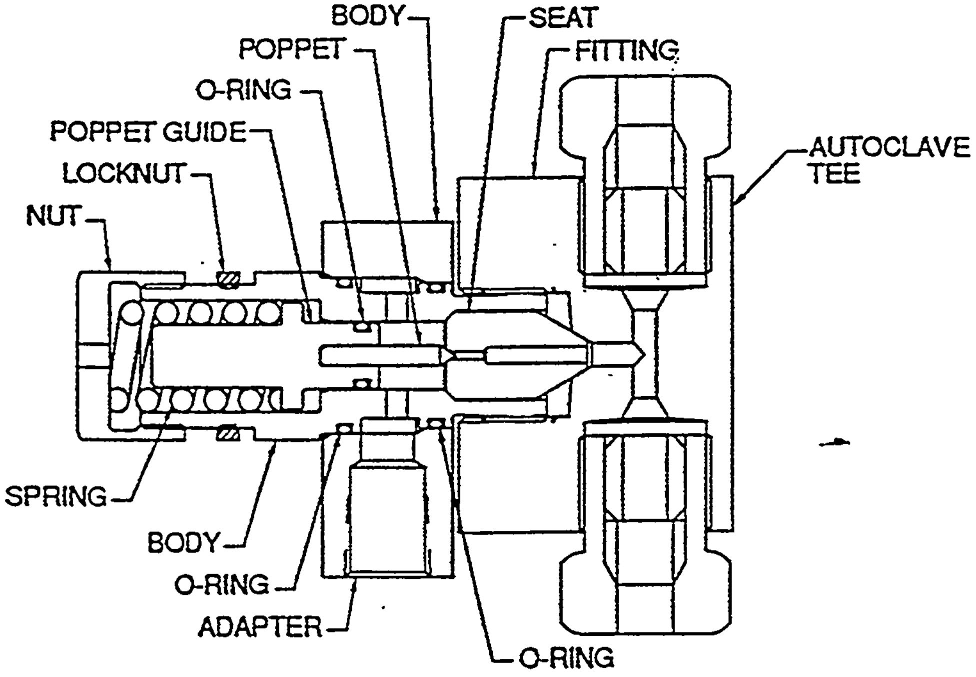
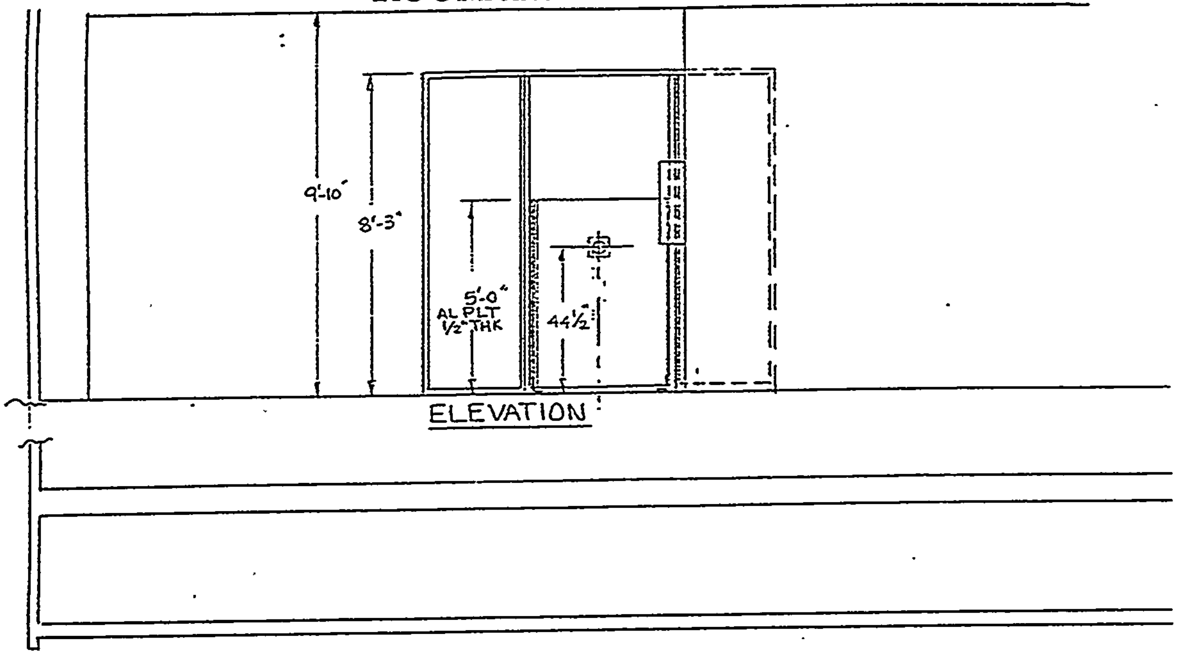
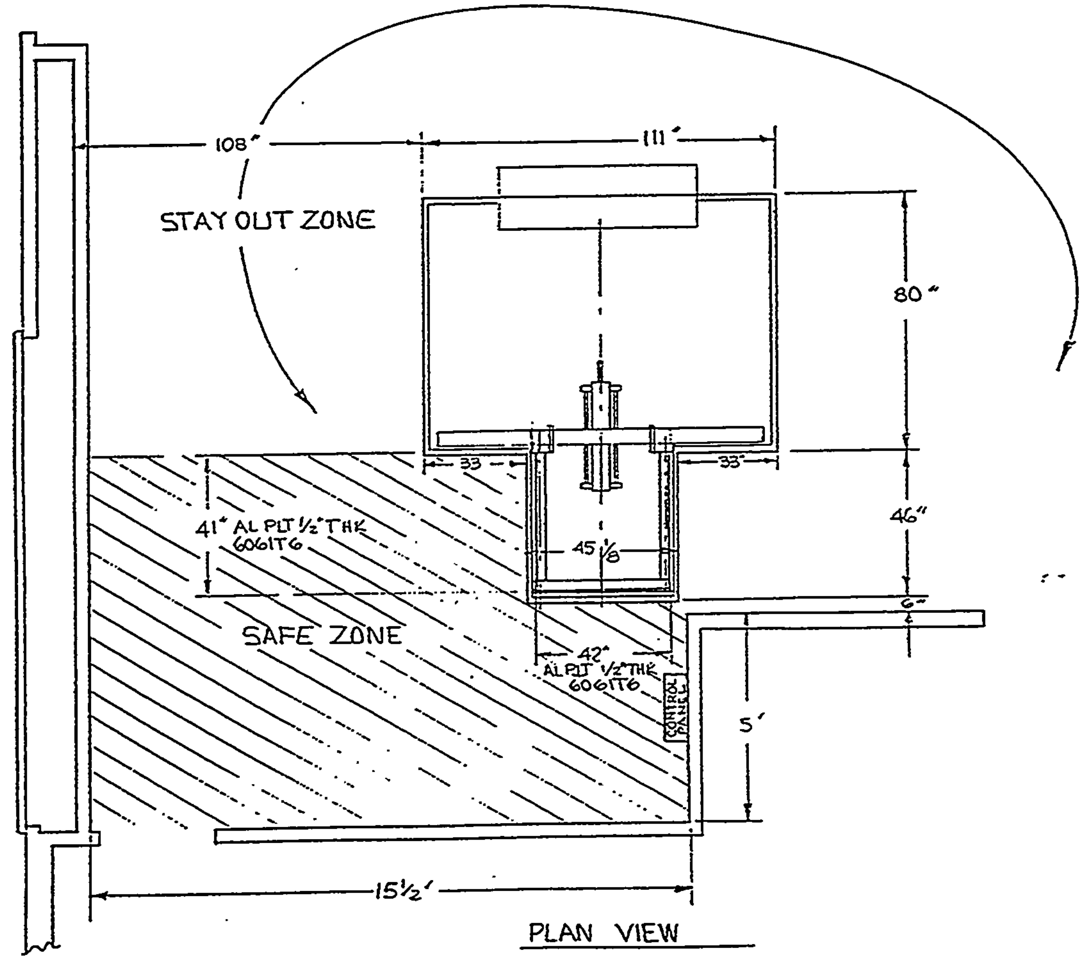


FIGURE 5

ROOM 1102 LAYOUT



BLDG 169 - ROOM 1102



References

A. Center of gravity calculations, PJ Densley, 7\93.

B Marks' Standard Handbookd for Mechanical Engineers, Ninth Edition.

C. American Institute of Steel Construction Manual of Steel Construction , Allowable Stress Design, Ninth Edition , 1989.

D. Engineering Standard Reference No. 14 Steel Bar, Carbon, 1018, Cold Finished; Round Issued by LLNL Standards & Specifications Group , Mechanical Engineering Dept.

E. Shigley, J.E., C.R. Mischke, Mechanical Engineering Design, Fifth Edition, McGraw Hill Books, 1989, page 341.

F. HILTI Technical Bulliton, page 57.

G. Ryerson Stocks & Services, page 308.

H. High Pressure Safety Manual, Supplement 32.03, page 10.

I. Quest FAX 2/5/93.

ENE93 - 906									
		WEIGHT	W						
MEMBER	DIMENSIONS	PER	WEIGHT	xi	wxi	yi	wyi	zi	wzi
		UNIT	(LBS)	(in)	(lb-in)	(in)	(lb-in)	(in)	(lb-in)
Tubes									
Base	8" x 4" x .5" x 101"	35.24 lbs/ft	296.6	0.0	0.0	0.0	0.0	4.0	1186.4
Post (L)	4" x 4" x .5" x 38"	21.63 lbs/ft	68.5	-23.0	-1575.4	0.0	0.0	27.0	1849.4
Post (R)	4" x 4" x .5" x 38"	21.63 lbs/ft	68.5	23.0	1575.4	0.0	0.0	27.0	1849.4
Cross Member	4" x 4" x .25" x 31.25"	21.63 lbs/ft	56.3	0.0	0.0	0.0	0.0	57.0	3210.7
Angles									
Brace (L)	3" x 3" x .25" x 47"	4.9 lbs/ft	19.2	-39.5	-758.1	0.0	0.0	27.0	518.2
Brace (R)	3" x 3" x .25" x 47"	4.9 lbs/ft	19.2	39.5	758.1	0.0	0.0	27.0	518.2
Brace (BL)	3" x 3" x .25" x 60"	4.9 lbs/ft	24.5	-23.0	-563.5	20.7	507.2	23.0	563.5
Brace (BR)	3" x 3" x .25" x 60"	4.9 lbs/ft	24.5	23.0	563.5	20.7	507.2	23.0	563.5
Base (L)	3" x 3" x .25" x 46"	4.9 lbs/ft	18.8	-23.0	-432.0	24.5	460.2	0.8	15.0
Base (R)	3" x 3" x .25" x 46"	4.9 lbs/ft	18.8	23.0	432.0	24.5	460.2	0.8	15.0
Base (B)	3" x 3" x .25" x 38"	4.9 lbs/ft	15.5	0.0	0.0	47.0	729.3	0.8	12.4
.5" Plates									
Cross Support (L)	14" x 8" x .5"	0.28 lbs/in3	15.7	-19.6	-307.3	0.0	0.0	51.2	802.8
Cross Support (R)	14" x 8" x .5"	0.28 lbs/in3	15.7	19.6	307.3	0.0	0.0	51.2	802.8
Base Plug (L)	4" x 8" x .5"	0.28 lbs/in3	4.5	-50.0	-224.0	0.0	0.0	4.0	17.9
Base Plug (R)	4" x 8" x .5"	0.28 lbs/in3	4.5	50.0	224.0	0.0	0.0	4.0	17.9
Forks									
Left Side (L)	6.25" x 6" x .5"	0.28 lbs/in3	5.3	-25.4	-133.4	0.0	0.0	49.1	257.8
	2" x 4" x .5"	0.28 lbs/in3	1.1	-25.4	-28.4	2.0	2.2	54.2	60.7
	.5(4" x 4" x .5")	0.28 lbs/in3	1.1	-25.4	-28.4	-0.3	-0.3	50.4	56.4
Left Side (R)	6.25" x 6" x .5"	0.28 lbs/in3	5.3	-20.6	-108.2	0.0	0.0	49.1	257.8
	2" x 4" x .5"	0.28 lbs/in3	1.1	-20.6	-23.1	2.0	2.2	54.2	60.7
	.5(4" x 4" x .5")	0.28 lbs/in3	1.1	-20.6	-23.1	-0.3	-0.3	50.4	56.4
Left Side (Back)	10.25" x 4.25" x .5"	0.28 lbs/in3	6.1	-23.0	-140.3	2.5	15.2	51.1	311.6
Left Side (Bot)	6" x 4.25" x .5"	0.28 lbs/in3	3.6	-23.0	-82.1	0.0	0.0	46.3	165.3
Right Side (L)	6.25" x 6" x .5"	0.28 lbs/in3	5.3	20.6	108.2	0.0	0.0	49.1	257.8
	2" x 4" x .5"	0.28 lbs/in3	1.1	20.6	23.1	2.0	2.2	54.2	60.7
	.5(4" x 4" x .5")	0.28 lbs/in3	1.1	20.6	23.1	-0.3	-0.3	50.4	56.4
Right Side (R)	6.25" x 6" x .5"	0.28 lbs/in3	5.3	25.4	133.4	0.0	0.0	49.1	257.8
	2" x 4" x .5"	0.28 lbs/in3	1.1	25.4	28.4	2.0	2.2	54.2	60.7
	.5(4" x 4" x .5")	0.28 lbs/in3	1.1	25.4	28.4	-0.3	-0.3	50.4	56.4
Right Side (Back)	10.25" x 4.25" x .5"	0.28 lbs/in3	6.1	23.0	140.3	2.5	15.2	51.1	311.6
Right Side (Bot)	6" x 4.25" x .5"	0.28 lbs/in3	3.6	23.0	82.1	0.0	0.0	46.3	165.3
.25' Plates									
Floor Plate (F)	6" x 38" x .25"	0.28 lbs/in3	16.0	0.0	0.0	6.0	95.8	0.2	3.2
Floor Plate (B)	6" x 38" x .25"	0.28 lbs/in3	16.0	0.0	0.0	43.5	694.3	0.2	3.2
Mtng Plate (L)	4" x 8" x .25"	0.28 lbs/in3	2.2	-19.5	-43.7	0.0	0.0	57.0	127.7
Mtng Plate (R)	4" x 8" x .25"	0.28 lbs/in3	2.2	19.5	43.7	0.0	0.0	57.0	127.7
		Σ w =	756.4	Σ wxi =	0.0	Σ wyi =	3492.1	Σ wzi =	14658.5
	For Test Stand								
	X =	(Σ wxi)/(Σ w) =	(0.0)/ (756.4) =		0.0				
	y =	(Σ wyi)/(Σ w) =	(3492.1)/ (756.4) =		4.6				
	z =	(Σ wzi)/(Σ w) =	(14658.5)/ (756.4) =		19.4				
	Therefore the Test Stand center of gravity is at (0,4.6,19.4)								
The HIEE weighs 250 lbs (design weight). Due to symmetry, it is assumed the center of gravity of the HIEE is along									
the center of the long axis and centered beneath the mounting plate. Then:									
Frame			756.4	0.0	0.0	4.6	3479.4	19.4	14674.2
HEE			250.0	0.0	0.0	0.0	0.0	44.5	11125.0
		Σ w =	1006.4	Σ wxi =	0.0	Σ wyi =	3479.4	Σ wzi =	25799.2
	For the System								
	X =	(Σ wxi)/(Σ w) =	(0.0)/ (1006.4) =		0.0				
	y =	(Σ wyi)/(Σ w) =	(3492.1)/ (1006.4) =		3.5				
	z =	(Σ wzi)/(Σ w) =	(25799.2)/ (1006.4) =		25.6				
	Therefore the Test Stand and the HIEE center of gravity is at (0,3.5,25.6)								

NINTH EDITION

Marks'
STANDARD HANDBOOK
for
MECHANICAL ENGINEERS

Eugene A. Avallone
Theodore Baumeister III

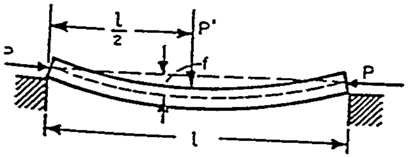
Table 6.2.11a Mechanical Properties of Some Constructional Steels*

ASTM designation	Thickness range, mm(in)	Yield point, min		Tensile strength		Elongation in 200 mm (8 in) min, %	Suitability for welding
		MPa	1,000 lb/in²	MPa	1,000lb/in²		
Structural carbon-steel plates							
ASTM A7†	All thicknesses	228	33	414–517	60–75	21	No
ASTM A373†	To 100 mm (4 in), incl.	221	32	400–517	58–75	21	Yes
ASTM A36	To 100 mm (4 in), incl.	248	36	400–552	58–80	20	Yes
Low- and intermediate-tensile-strength carbon-steel plates							
ASTM A283	(structural quality)						
Grade A	All thicknesses	165	24	310	45	28	Yes
Grade B	All thicknesses	186	27	345	50	25	Yes
Grade C	All thicknesses	207	30	379	55	22	Yes
Grade D	All thicknesses	228	33	414	60	20	Yes
Carbon-silicon steel plates for machine parts and general construction							
ASTM A284							
Grade A	To 305 mm (12 in)	172	25	345	50	25	Yes
Grade B	To 305 mm (12 in)	159	23	379	55	23	Yes
Grade C	To 305 mm (12 in)	145	21	414	60	21	Yes
Grade D	To 200 mm (8 in)	145	21	414	60	21	Yes
Carbon-steel pressure-vessel plates							
ASTM A285							
Grade A	To 50 mm (2 in)	165	24	303–379	44–55	27	Yes
Grade B	To 50 mm (2 in)	186	27	345–414	50–60	25	Yes
Grade C	To 50 mm (2 in)	207	30	379–448	55–65	23	Yes
Structural steel for locomotives and cars							
ASTM A113							
Grade A	All thicknesses	228	33	414–496	60–72	21	No
Grade B	All thicknesses	186	27	345–427	50–62	24	No
Grade C	All thicknesses	179	26	331–400	48–58	26	No
Structural steel for ships							
STM A131							
Grade A	To 13 mm (½ in)	221	32	400–490	58–71	21	No
Grade B	To 25 mm (1 in)						
Grade C	To 50 mm (2 in)						
Grade E	To 50 mm(2 in)						
Grade CS	To 50 mm (2 in)						
Grade R	To 50 mm (2 in)						
High-strength low-alloy steel plates							
STM A242	To 19 mm (¾ in), incl.	345	50	485	70 min	18	Yes
STM A440	Over 19 to 38 mm (¾ to 1½ in), incl.	315	46	460	67 min	18	No
TM A441	Over 38 to 102 mm (1½ to 4 in), incl.	290	42	435	63 min	18	Yes
TM A588	Up to 102 mm (4 in), incl.	345	50	485	70	18	Yes

Table 15.2.13 Typical Short-Column Formulas

Formula	Material	Code	Slenderness ratio
$S_w = 17{,}000 - 0.485\left(\frac{l}{r}\right)^2$	Carbon steels	AISC	$l/r < 120$
$S_w = 16{,}000 - 70\,(l/r)$	Carbon steels	Chicago	$l/r < 120$
$S_w = 15{,}000 - 50\left(\frac{l}{r}\right)$	Carbon steels	AREA	$l/r < 150$
$S_w = 19{,}000 - 100\,(l/r)$	Carbon steels	Am. Br. Co.	$60 < \frac{l}{r} < 120$
$^*S_{cr} = 135{,}000 - \frac{15.9}{c}\left(\frac{l}{r}\right)^2$	Alloy-steel tubing	ANC	$\frac{l}{\sqrt{c}\,r} < 65$
$S_w = 9{,}000 - 40\left(\frac{l}{r}\right)$	Cast iron	NYC	$\frac{l}{r} < 70$
$^*S_{cr} = 34{,}500 - \frac{245}{\sqrt{c}}\left(\frac{l}{r}\right)$	2017ST Aluminum	ANC	$\frac{l}{\sqrt{c}\,r} < 94$
$^*S_{cr} = 5{,}000 - \frac{0.5}{c}\left(\frac{l}{r}\right)^2$	Spruce	ANC	$\frac{l}{\sqrt{c}\,r} < 72$
$^*S_{cr} = S_y\left[1 - \frac{S_y}{4n\pi^2E}\left(\frac{l}{r}\right)^2\right]$	Steels	Johnson	$\frac{l}{r} < \sqrt{\frac{2n\pi^2E}{S_y}}$
$^\dagger S_{cr} = \dfrac{S_y}{1 + \frac{ec}{r^2}\sec\left(\frac{l}{r}\sqrt{\frac{P}{4AE}}\right)}$	Steels	Secant	$\frac{l}{r} <$ critical

$^*S_{cr}$ = theoretical maximum, c = end fixity coefficient,
$c = 2$, both ends pivoted, $c = 2.86$, one pivoted, other fixed,
$c = 4$, both ends fixed, $c = 1$ one fixed, one free.
†e is initial eccentricity at which load is applied to center of column cross section.



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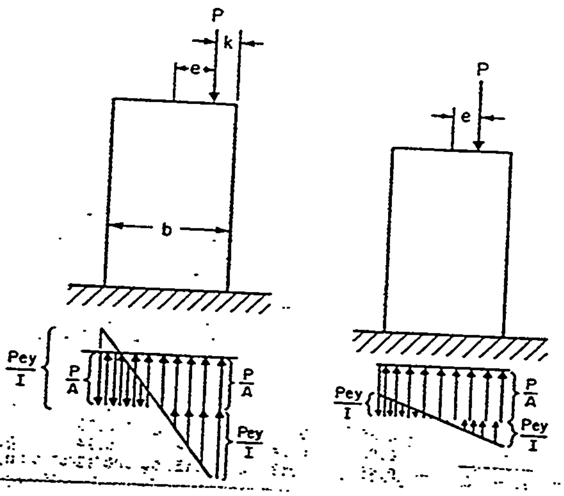
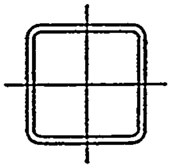
ve for points on the same side of cg as P, and negative posite side. For a rectangular cross section of width b, num stress $S_M = S_c\,(1 + 6e/b)$. When P is outside third of width b and is a compressive load, tensile cur.

rcular cross section of diameter d, $S_M = S_c(1 + 8e/$ ress due to the weight of the solid will modify these

n these formulas e is measured from the gravity gives tension when e is greater than one-sixth the sured in the same direction as e), for rectangular nd when greater than one-eighth the diameter for ar sections.

certain classes of masonry construction, the material tand tensile stress and thus no tension can occur, the oments (Fig. 5.2.55) is taken at th





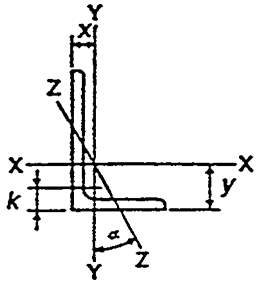
STRUCTURAL TUBING
Square
Dimensions and properties

Dimensions				Properties**					
Nominal* Size	Wall Thickness		Weight per Ft	Area	I	S	r	J	Z
In.	In.		Lb.	In.^{2}	In.^{4}	In.^{3}	In.	In.^{4}	In.^{3}
4.5×4.5	0.2500	¼	13.91	4.09	12.1	5.36	1.72	19.7	6.43
	0.1875	³⁄₁₆	10.70	3.14	9.60	4.27	1.75	15.4	5.03
4×4	0.5000	½	21.63	6.36	12.3	6.13	1.39	21.8	8.02
	0.3750	⅜	17.27	5.08	10.7	5.35	1.45	18.4	6.72
	0.3125	⁵⁄₁₆	14.83	4.36	9.58	4.79	1.48	16.1	5.90
	0.2500	¼	12.21	3.59	8.22	4.11	1.51	13.5	4.97
	0.1875	³⁄₁₆	9.42	2.77	6.59	3.30	1.54	10.6	3.91
3.5×3.5	0.3125	⁵⁄₁₆	12.70	3.73	6.09	3.48	1.28	10.4	4.35
	0.2500	¼	10.51	3.09	5.29	3.02	1.31	8.82	3.70
	0.1875	³⁄₁₆	8.15	2.39	4.29	2.45	1.34	6.99	2.93
3×3	0.3125	⁵⁄₁₆	10.58	3.11	3.58	2.39	1.07	6.22	3.04
	0.2500	¼	8.81	2.59	3.16	2.10	1.10	5.35	2.61
	0.1875	³⁄₁₆	6.87	2.02	2.60	1.73	1.13	4.28	2.10
2.5×2.5	0.3125	⁵⁄₁₆	10.58	3.11	3.58	2.39	1.07	3.32	1.96
	0.2500	¼	7.11	2.09	1.69	1.35	0.899	2.92	1.71
	0.1875	³⁄₁₆	5.59	1.64	1.42	1.14	0.930	2.38	1.40
2×2	0.3125	⁵⁄₁₆	6.32	1.86	0.880	0.880	0.690	1.49	1.11
	0.2500	¼	5.41	1.59	0.766	0.766	0.694	1.36	1.00
	0.1875	³⁄₁₆	4.32	1.27	0.668	0.668	0.726	1.15	0.840

*Outside dimensions across flat sides.

**Properties are based upon a nominal outside corner radius equal to two times the wall thickness.

ANGLES
Equal legs and unequal legs
Properties for designing



Size and Thickness	k	Weight per Ft	Area	AXIS X-X				AXIS Y-Y				AXIS Z-Z	
				I	*S*	*r*	*y*	*I*	*S*	*r*	*x*	*r*	Tan α
In.	In.	Lb.	In.^{2}	In.^{4}	In.^{3}	In.	In.	In.^{4}	In.^{3}	In.	In.	In.	
L4 ×3 × ½	15/16	11.1	3.25	5.05	1.89	1.25	1.33	2.42	1.12	0.864	0.827	0.639	0.543
7/16	7/8	9.8	2.87	4.52	1.68	1.25	1.30	2.18	0.992	0.871	0.804	0.641	0.547
3/8	13/16	8.5	2.48	3.96	1.46	1.26	1.28	1.92	0.866	0.879	0.782	0.644	0.551
5/16	3/4	7.2	2.09	3.38	1.23	1.27	1.26	1.65	0.734	0.887	0.759	0.647	0.554
1/4	11/16	5.8	1.69	2.77	1.00	1.28	1.24	1.36	0.599	0.896	0.736	0.651	0.558
L3½×3½× ½	7/8	11.1	3.25	3.64	1.49	1.06	1.06	3.64	1.49	1.06	1.06	0.683	1.000
7/16	13/16	9.8	2.87	3.26	1.32	1.07	1.04	3.26	1.32	1.07	1.04	0.684	1.000
3/8	3/4	8.5	2.48	2.87	1.15	1.07	1.01	2.87	1.15	1.07	1.01	0.687	1.000
5/16	11/16	7.2	2.09	2.45	0.976	1.08	0.990	2.45	0.976	1.08	0.990	0.690	1.000
1/4	5/8	5.8	1.69	2.01	0.794	1.09	0.968	2.01	0.794	1.09	0.968	0.694	1.000
L3½×3 × ½	15/16	10.2	3.00	3.45	1.45	1.07	1.13	2.33	1.10	0.881	0.875	0.621	0.714
7/16	7/8	9.1	2.65	3.10	1.29	1.08	1.10	2.09	0.975	0.889	0.853	0.622	0.718
3/8	13/16	7.9	2.30	2.72	1.13	1.09	1.08	1.85	0.851	0.897	0.830	0.625	0.721
5/16	3/4	6.6	1.93	2.33	0.954	1.10	1.06	1.58	0.722	0.905	0.808	0.627	0.724
1/4	11/16	5.4	1.56	1.91	0.776	1.11	1.04	1.30	0.589	0.914	0.785	0.631	0.727
L3½×2½× ½	15/16	9.4	2.75	3.24	1.41	1.09	1.20	1.36	0.760	0.704	0.705	0.534	0.486
7/16	7/8	8.3	2.43	2.91	1.26	1.09	1.18	1.23	0.677	0.711	0.682	0.535	0.491
3/8	13/16	7.2	2.11	2.56	1.09	1.10	1.16	1.09	0.592	0.719	0.660	0.537	0.496
5/16	3/4	6.1	1.78	2.19	0.927	1.11	1.14	0.939	0.504	0.727	0.637	0.540	0.501
1/4	11/16	4.9	1.44	1.80	0.755	1.12	1.11	0.777	0.412	0.735	0.614	0.544	0.506
L3 ×3 × ½	13/16	9.4	2.75	2.22	1.07	0.898	0.932	2.22	1.07	0.898	0.932	0.584	1.000
7/16	3/4	8.3	2.43	1.99	0.954	0.905	0.910	1.99	0.954	0.905	0.910	0.585	1.000
3/8	11/16	7.2	2.11	1.76	0.833	0.913	0.888	1.76	0.833	0.913	0.888	0.587	1.000
5/16	5/8	6.1	1.78	1.51	0.707	0.922	0.865	1.51	0.707	0.922	0.865	0.589	1.000
1/4	9/16	4.9	1.44	1.24	0.577	0.930	0.842	1.24	0.577	0.930	0.842	0.592	1.000
3/16	1/2	3.71	1.09	0.962	0.441	0.939	0.820	0.962	0.441	0.939	0.820	0.596	1.000

Prepared by: EMIL KAIKINGER
Date: November 14, 1978

ENGINEERING STANDARD REFERENCE

ISSUED BY

LAWRENCE LIVERMORE LABORATORY

STANDARDS & SPECIFICATIONS GROUP, MECHANICAL ENGINEERING
LIVERMORE

LLL Stock Class 9510
ESR NO. 14 D
Page 1 of 2

SPECIFICATION ASTM A108-73

TITLE: Steel Bar, Carbon, 1018, Cold Finished; Round.

APPLICATION: Used for general construction purposes where strength and toughness are not critical. It can be case hardened and the core strength slightly increased by quenching.

TYPICAL DRAWING CALLOUT:

Part No.	Description	Material	Specification	Stock No.
LLL ESR No. 14	Bar, Round 1/8 Dia. x 4 Ft. Lg.	Steel 1018 Cold Finished	ASTM A108 Grade 1018	9510-10225

UNS G10180

CHEMICAL COMPOSITION*

Element	Percent Min.	Percent Max.
Carbon	0.15.	0.20
Manganese	0.60	0.90
Phosphorus	----	0.04
Sulfur	----	0.05

* Specification requirements; balance of properties are typical manufacturer's average values.

MECHANICAL PROPERTIES (Typical) For 3/4 To 1 1/4 Bars

No min. properties guaranteed except as specified by procuring agency.

Tensile strength, min. ksi	64
Yield Strength, min. ksi	54
% Elongation in 2 in., min.	15
% Reduction of area, min.	40
Brinell hardness, min.	126
Modulus of elasticity in tension, psi	29×10^6
Fatigue strength, ksi	25

ELECTRICAL PROPERTIES (Annealed) Approximate

Electrical resistivity, microhm-cm	$28\text{-}30 \times 10^6$

PHYSICAL PROPERTIES (Annealed) Approximate

Density lb/cu in.	.283
Specific gravity	7.82
Specific heat, Btu/lb/°F	
122-212° F	0.116
302-392° F	0.124
662-752° F	0.143
Thermal coef. expansion/°F	
32-212° F	6.7×10^{-6}
32-752° F	7.9×10^{-6}
32-1112° F	8.0×10^{-6}
Thermal conductivity	
Btu/ft^2/hr/°F	
32° F	30.0
212° F	29.4
392° F	28.2

CORROSION RESISTANCE: Rusted by oxygen and water at room temperatures, rate of attack increasing sharply as ph goes above 4 end decreasing below ph of 8. Diluted salt solutions increase corrosion rate, attacked by acids in general, but satisfactorily resistant to alkalis at normal temperatures. Corrosion rate in ordinary rusting not appreciably affected by carbon or alloy content or by cold working.

MACHINABILITY: Resulting surface of 1018 are lower than 1117. It has machinability of 63% (B-1112 = 100%). Surface cutting speeds of 125 ft. per minute should be used.

WELDABILITY: Welded or brazed by common process.

FORMABILITY: Excellent for cold bending and forming operations.

HEAT TREATMENT: Good case hardening properties, and the core can be slightly hardened by water quenching after carburizing. Case harden by carburizing at 1675° F for 8 hours, pot cool, reheat to 1425° F, water quench and temper at 350° F.

DIMENSIONAL TOLERANCES*

DIAMETER TOLERANCES COLD DRAWN OR TURNED & POLISHED

Dia. Size	Minus	Dia. Size	Minus
1 1/2 & Under	0.002	Over 4 to 6	0.005
Over 1 1/2 to 2 1/2	0.003	Over 6 to 8	0.006
Over 2 1/2 to 4	0.004	Over 8 to 9	0.007

STRAIGHTNESS TOLERANCES

When specific straightness tolerances are required, they should be negotiated with the producer.

* Per ASTM A29-76

FOR LLL USE ONLY

[illegible]

ABOVE DATA BASED UPON RECORDS FILED IN RM 1180, BLDG 131

ENGINEERING STANDARD REFERENCE

ISSUED BY

LAWRENCE LIVERMORE LABORATORY

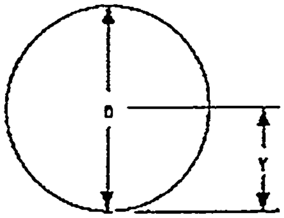
STANDARDS & SPECIFICATIONS GROUP, MECHANICAL ENGINEERING
LIVERMORE

LLL Stock Class 9510
ESR NO. 14 D
Page 2 of 2

SPECIFICATION ASTM A108-73

PROPERTIES OF ROUND SECTION

AREA	MOMENT OF INERTIA I	SECTION MODULUS Z	RADIUS OF GYRATION K	DISTANCE FROM NEUTRAL AXIS TO EXTREME FIBER Y
$.7854D^2$	$.0490D^4$	$.0980D^3$	$\frac{D}{4}$	$\frac{D}{2}$



LLL STOCK

Length 20 To 24 Feet.

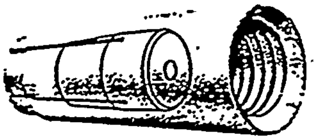
LLL Stock No.	Dia. Inch	O.D. Tol. Minus	Weight Lbs/Ft	Min. Area Sq. In.	Typ. Yield Strength 1000 LBS (1)
9510-10225	1/8	0.002	0.042	0.0118	0.641
* 9510-10226	5/32		0.069	0.0186	1.009
9510-10227	3/16		0.094	0.0270	1.459
9510-10228	1/4		0.167	0.0483	2.608
9510-10229	5/16		0.261	0.0757	4.088
9510-10230	3/8		0.376	0.1092	5.900
9510-10231	7/16		0.511	0.1489	8.043
9510-10232	1/2		0.668	0.1947	10.518
9510-10233	9/16		0.845	0.2467	13.324
9510-10234	5/8		1.043	0.3048	16.461
9510-10235	3/4		1.502	0.4394	23.729
9510-10236	7/8		2.044	0.5985	32.323
9510-10237	1		2.670	0.7822	42.242
* 9510-10238	1 1/16		3.014	0.8833	47.698
9510-10239	1 1/8		3.379	0.9904	54.486
9510-10240	1 3/16		3.766	1.1038	59.605
9510-10241	1 1/4		4.173	1.2232	66.056
9510-10242	1 3/8		5.049	1.4805	79.951
* 9510-10243	1 7/16		5.518	1.6184	87.395
9510-10244	1 1/2		6.008	1.7624	95.171
9510-10245	1 5/8	0.003	7.051	2.0662	111.579
9510-10246	1 3/4		8.178	2.3970	129.440
9510-10247	2		10.680	3.1321	169.137
9510-10248	2 1/8		12.060	3.5365	190.974
9510-10249	2 1/4		13.520	3.9654	214.136
9510-10250	2 3/8		15.060	4.4189	238.623
9510-10251	2 1/2		16.690	4.8969	264.436
9510-10252	2 3/4	0.004	20.200	5.9223	319.805
9510-10253	3		24.030	7.0544	380.941
9510-10254	3 1/4		28.210	8.2753	446.870
9510-10256	3 1/2		32.710	9.5991	518.355
* 9510-10257	3 3/4		37.550	11.0211	595.141
9510-10258	4		42.730	12.5422	677.229
9510-10259	4 1/2	0.005	54.060	15.8690	856.927
9510-10260	5		66.760	19.5957	1058.170
9510-10261	6		96.130	28.2272	1524.273

* No Longer Stocked.

(1) Based on Minimum Area x Typ. Yield Strength of 54 ksi for 3/4 to 1 1/4 Bar. Not Guaranteed.

The Hilti Drop-In Anchor

Product Details



Advantages:

Shallow embedment depth

Internal thread

Anchor is flush with base material

Internal plug

Material

Anchor material is SAE 1110M for the ¼", ⅜" and ½" HDI's.

*Anchor material is AISI 12L14 steel, meeting ASTM specification A 108 for ⅝" & ¾" HDI's.

Anchor material is AISI 303 for stainless steel anchors.

Plated with dull zinc finish for corrosion protection in accordance with ASTM B633, Sc. 1, Type III.

Specification Table

Details		Anchor Size				
D	bolt size	¼"	⅜"	½"	⅝"	¾"
BD	bit diameter	⅜"	½"	⅝"	27/32"	1"
E L HD	rec. min. depth of embedment anchor length hole depth	1"	1 9/16"	2"	2 9/16"	3 3/16"
TL	length of thread/ thread per in.	7/16" 20	⅝" 16	11/16" 13	⅞" 11	1⅜" 10
BMT	base material thickness (in)	3	3⅛	4	5⅛	6⅜
M	tightening torque (max) (ft lbs)	4	11	22	37	80
AS	Spacing required to obtain maximum working load (inches)	3½	5½	7	8⅞	11⅛
AS_{min}	Minimum allowable spacing between anchors (inches) (Refer to Note #1)	2	3⅛	4	5	6⅜
ED	Edge distance required to obtain maximum working load (inches)	3	4¾	6	7⅝	9⅝
ED_{min}	Minimum allowable edge distance (inches)	3	4¾	6	7⅝	9⅝

NOTE: 1) When using AS_{min} reduce load by 50%.

Anchor Spacing and Edge Distance Guidelines

The HDI Anchor Spacings and Edge Distances were calculated using the following information:

	Anchor Spacing			Edge Distance Shear Load Only			Edge Distance Tensile Load Only		
	AS	AS_{min}	f_{AS}	ED	ED_{min}	f_{ED}	ED	ED_{min}	f_{ED}
HDI	3.5E	2.0E	0.5	3.0Emin	3.0Emin	1.00	3.0E	3.0E	1.00

Hilti Drop-In Anchor continued

Load Information

HDI — Allowable Working Loads (lbs)

Anchor Size	2000 PSI Concrete		4000 PSI Concrete		6000 PSI Concrete	
	Tension	Shear	Tension	Shear	Tension	Shear
¼"	480	430	560	450	770	760
⅜"	790	990	1240	1060	1410	1480
½"	1000	1470	1690	1560	2550	2340
⅝"	1390	2220	2420	3050	2600	3400
¾"	2210	3800	4010	4400	4100	5300

Note: The allowable shear values are based on the use of SAE Grade 5 bolts.

Stainless Steel HDI — Allowable Working Loads (lbs)

Anchor Size	4000 PSI Concrete		6000 PSI Concrete	
	Tension	Shear	Tension	Shear
¼"	480	600	740	600
⅜"	1040	1230	1460	1230
½"	1840	2760	2410	2760
⅝"	2630	4510	3770	4510
¾"	3830	5580	5030	5580

Note: The allowable shear values are based on the use of Type 18-8 bolts.

HDI — Allowable Working Load (lbs)

Anchor Size	Anchor Installed in 3000 PSI Lt. Wt. Concrete[1]		Anchor Installed Through Steel Decking Into 3000 PSI Lt. Wt. Concrete[2]	
	Tension	Shear[3]	Tension	Shear[3]
HDI ¼	465	340	530	335
HDI ⅜	755	940	880	1010
HDI ½	1135	1700	1105	1755
HDI ⅝	1465	2835	—	—
HDI ¾	2075	3680	—	—

1. The tabulated shear and tensile values are for anchors installed in structural lightweight concrete having the designated ultimate compressive strength at the time of installation. The concrete must comply with ASTM C 330-77.
2. The tabulated shear and tensile values are for anchors installed through 20 gauge intermediate decking into structural lightweight concrete having the designated ultimate strength at the time of installation. The concrete must comply with ASTM C 330-77.
3. The allowable values are based on the use of SAE Grade 2 bolts installed in the anchors.

Suggested Specifications:

Expansion Anchors	— Expansion anchors shall be flush or shell type which meet Federal Specification FF-S-325, Group VIII, Type 1, for expansion shield anchors. Anchors to be zinc plated in accordance with ASTM B633-78, Sc. 1, Type III. Anchors shall be Hilti HDI anchors as supplied by Hilti Fastening Systems, P.O. Box 21148, Tulsa, OK 74121.
Installation	— Shell or flush type anchors to be installed in holes drilled with Hilti carbide tipped drill bits. Anchors shall be installed per manufacturer's recommendations.

Listings

UL listed, Control No. 767 G, "Pipe Hangers" (⅜"-¾" diameter)

International Conference of Building Officials (ICBO): Evaluation Report No. 2895.

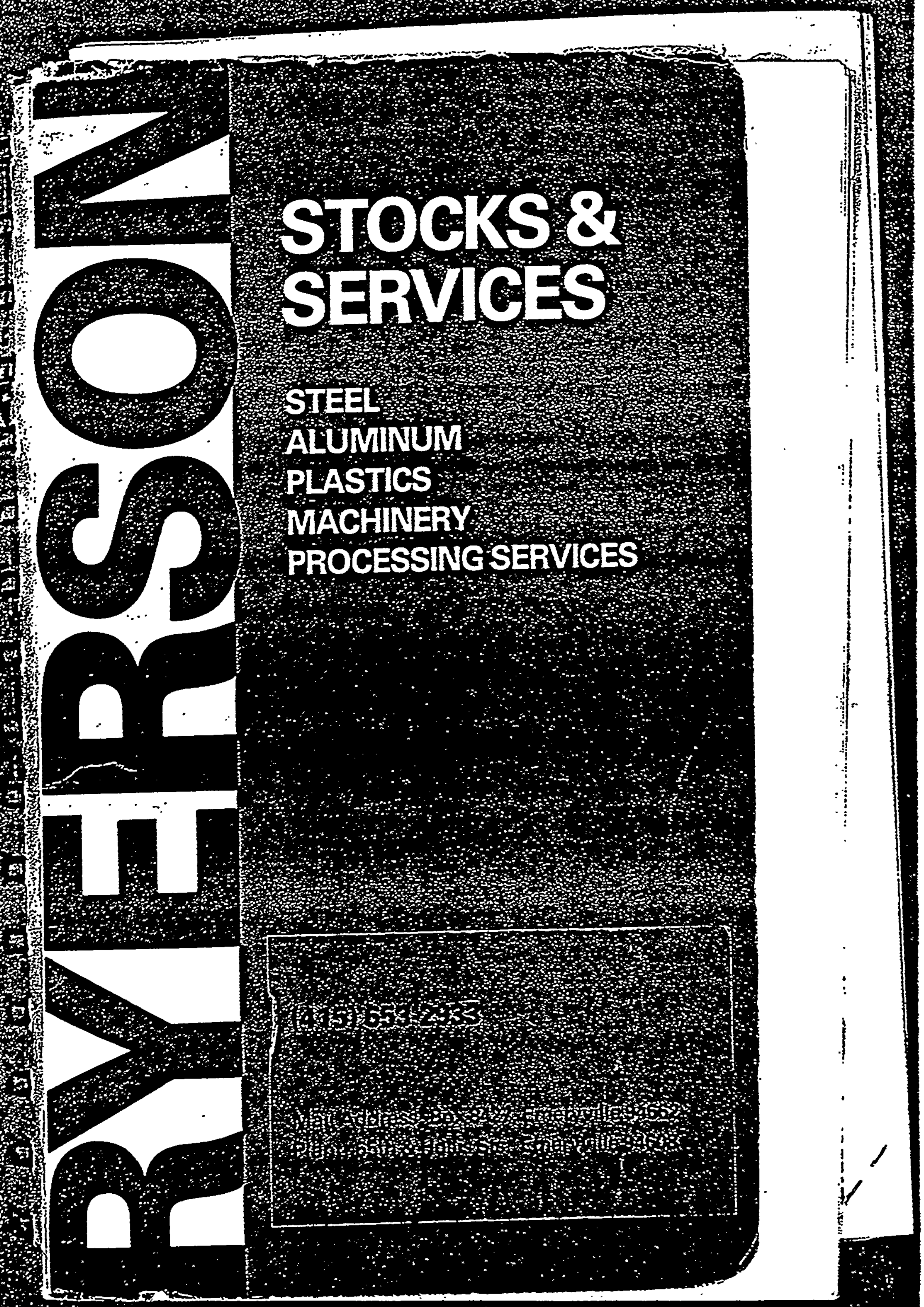
Southern Building Code Congress (SBCC): Report No. 8913.

Approvals

City of Los Angeles: Research Report No. 23709.

Factory Mutual: Serial No. 22765 "Sprinkler Hanger Components — Expansion Shields."

Conforms to Federal Specification FF-S-325, Group VIII, Type 1 for expansion shield anchors.



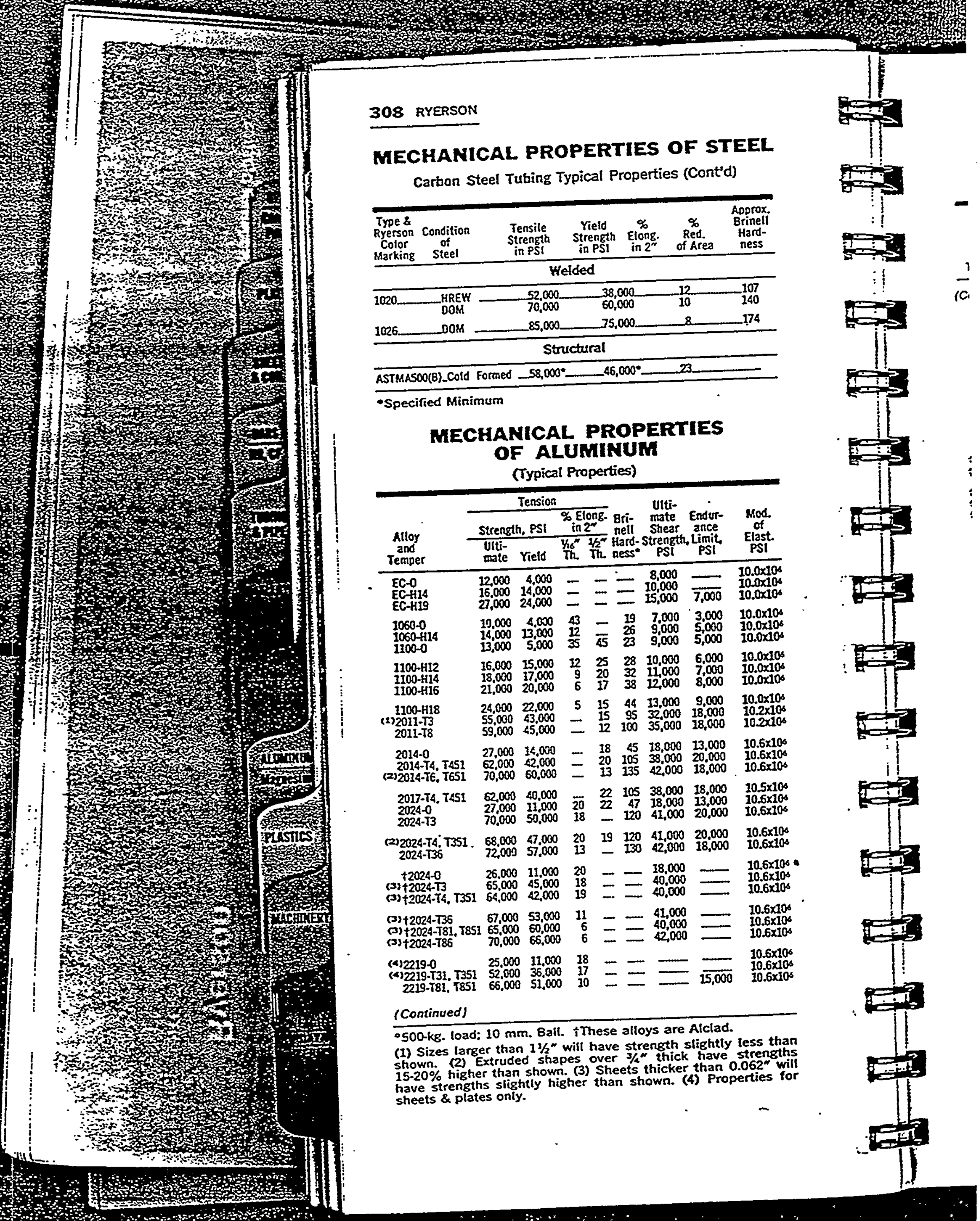
RYERSON

STOCKS & SERVICES

STEEL
ALUMINUM
PLASTICS
MACHINERY
PROCESSING SERVICES

(415) 653-2433

Mail Address: [illegible]
[illegible]



MECHANICAL PROPERTIES OF STEEL

Carbon Steel Tubing Typical Properties (Cont'd)

Type & Ryerson Color Marking	Condition of Steel	Tensile Strength in PSI	Yield Strength in PSI	% Elong. in 2"	% Red. of Area	Approx. Brinell Hard-ness
Welded						
1020	HREW	52,000	38,000		12	107
	DOM	70,000	60,000		10	140
1026	DOM	85,000	75,000		8	174
Structural						
ASTMA500(B)	Cold Formed	58,000*	46,000*		23	

*Specified Minimum

MECHANICAL PROPERTIES OF ALUMINUM

(Typical Properties)

Alloy and Temper	Tension				Bri-nell Hard-ness°	Ulti-mate Shear Strength, PSI	Endur-ance Limit, PSI	Mod. of Elast. PSI
	Strength, PSI		% Elong. in 2"					
	Ulti-mate	Yield	1/16" Th.	1/2" Th.				
EC-0	12,000	4,000	—	—	—	8,000	—	$10.0x10^6$
EC-H14	16,000	14,000	—	—	—	10,000	—	$10.0x10^6$
EC-H19	27,000	24,000	—	—	—	15,000	7,000	$10.0x10^6$
1060-0	19,000	4,000	43	—	19	7,000	3,000	$10.0x10^6$
1060-H14	14,000	13,000	12	—	26	9,000	5,000	$10.0x10^6$
1100-0	13,000	5,000	35	45	23	9,000	5,000	$10.0x10^6$
1100-H12	16,000	15,000	12	25	28	10,000	6,000	$10.0x10^6$
1100-H14	18,000	17,000	9	20	32	11,000	7,000	$10.0x10^6$
1100-H16	21,000	20,000	6	17	38	12,000	8,000	$10.0x10^6$
1100-H18	24,000	22,000	5	15	44	13,000	9,000	$10.0x10^6$
(1)2011-T3	55,000	43,000	—	15	95	32,000	18,000	$10.2x10^6$
2011-T8	59,000	45,000	—	12	100	35,000	18,000	$10.2x10^6$
2014-0	27,000	14,000	—	18	45	18,000	13,000	$10.6x10^6$
2014-T4, T451	62,000	42,000	—	20	105	38,000	20,000	$10.6x10^6$
(2)2014-T6, T651	70,000	60,000	—	13	135	42,000	18,000	$10.6x10^6$
2017-T4, T451	62,000	40,000	—	22	105	38,000	18,000	$10.5x10^6$
2024-0	27,000	11,000	20	22	47	18,000	13,000	$10.6x10^6$
2024-T3	70,000	50,000	18	—	120	41,000	20,000	$10.6x10^6$
(2)2024-T4, T351	68,000	47,000	20	19	120	41,000	20,000	$10.6x10^6$
2024-T36	72,000	57,000	13	—	130	42,000	18,000	$10.6x10^6$
†2024-0	26,000	11,000	20	—	—	18,000	—	$10.6x10^6$
(3)†2024-T3	65,000	45,000	18	—	—	40,000	—	$10.6x10^6$
(3)†2024-T4, T351	64,000	42,000	19	—	—	40,000	—	$10.6x10^6$
(3)†2024-T36	67,000	53,000	11	—	—	41,000	—	$10.6x10^6$
(3)†2024-T81, T851	65,000	60,000	6	—	—	40,000	—	$10.6x10^6$
(3)†2024-T86	70,000	66,000	6	—	—	42,000	—	$10.6x10^6$
(4)2219-0	25,000	11,000	18	—	—	—	—	$10.6x10^6$
(4)2219-T31, T351	52,000	36,000	17	—	—	—	—	$10.6x10^6$
2219-T81, T851	66,000	51,000	10	—	—	—	15,000	$10.6x10^6$

(Continued)

°500-kg. load; 10 mm. Ball. †These alloys are Alclad.

(1) Sizes larger than 1½" will have strength slightly less than shown. (2) Extruded shapes over ¾" thick have strengths 15-20% higher than shown. (3) Sheets thicker than 0.062" will have strengths slightly higher than shown. (4) Properties for sheets & plates only.

The analysis outlined above addresses only hoop stress in a vessel wall and the thickness of end closures. Any number of other design features could be critical to safe design of a pressure vessel. These include the shear stress in threads, the tensile strength of bolt cross-sections, the strength of weldments, the effect of vessel openings, nozzles, and supports, etc. A thorough analysis should therefore be performed for these types of additional features if they are contained in the vessel's design.

For other vessels, such as multi-wall cylinders and other end-closure designs, refer to the references at the end of this supplement. Where stresses in a large high-pressure vessel appear to be complex or excessive, contact a qualified applied mechanics authority for assistance in performing a finite element analysis.

Stored Energy

Calculate the *energy* contained in the fully pressurized vessel and include the calculation in the ESN. Compare this value with the 3.42×10^6 ft-lb (4.63×10^6 J) potential energy of 2.2 lb (1 kg) of TNT.

For example, using Eq. (11), a fully charged, standard size 1 cylinder of nitrogen gas (1.5 ft^3 at 2,200 psi) contains an energy equivalent of about 0.57 lb (0.26 kg) of TNT. This calculation is based on a reversible adiabatic (isentropic) expansion of the confined gas. Note that if pressure (P_1 and P_2) and volume (v_1) are expressed in megapascals and cubic centimeters, respectively, then the energy (U) is in joules (Ref. [9], p. 4-10).

$$U = \frac{P_1 v_1}{k - 1}\left[\,1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right] \qquad (11)$$

NOTE: $k = 1.66$ for He gas;
$k = 1.41$ for H_2, O_2, N_2, and air (from Ref. 9, p. 4-10).
P_1 = Vessel pressure
P_2 = Atmospheric pressure

For the same volume charged with water to the same pressure, the stored energy is considerably less. For this case, Eq. (12) may be used to determine the liquid stored energy content.

$$U = \frac{1}{2}\left(\frac{P_1^2 v}{B}\right) \qquad (12)$$

where B = Liquid bulk modulus, in psi.
= 300,000 psi for water

This calculation yields a value of 1,742 ft. lb. (0.51 gms of TNT).

Testing

All pressure vessels designed at or for operation at LLNL that require an ESN must be remotely pressure tested. Whenever practical, take pressure vessels to the M. E. High Pressure Laboratory, Bldg. 343, for pressure testing.

Hydrostatic-test (preferred) or gas-test all manned-area pressure vessels at 150% of their MAWP. If the vessel body material has a yield strength less than about 55% of its ultimate strength (as with annealed 300 series stainless steel), use the equation (85) on p. 90 of Ref.[8] (the Maximum Energy of Distortion Theory) to insure that the combined stresses at 150% of the MAWP do not exceed the yield strength of the body material. If they do, reduce the test pressure accordingly (but do not reduce below 125% of the MAWP), and include the supporting calculation in your ESN. (See Appendix A, page 39, for a sample calculation.)

Hydrostatic-test or gas-test all remote-operation pressure vessels at 125% of their MAWP unless your Division Leader specifically approves the use of a different test pressure.

If extreme conditions are involved in vessel operation, simulate these conditions during testing, or if simulation is impractical, consider the weakening effect of these conditions when assigning the test pressure. For instance, if it is not practical to test a high-temperature, high-pressure vessel at its working temperature, then test it at 1.5x its MAWP times the ratio of its allowable stress at the test temperature to its allowable stress at the maximum working

Maynard, this is from Supplement 32.03 currently under revision. Matt Fraini 4/5/93

QUEST
INTEGRATED, INC.
formerly Flow Research, Inc.

VIA FACSIMILE 510-422-3165

February 5, 1993
93TD0400

Mr. Maynard A. Holliday
Engineer/Automation & Robotics Section
Telerobotics Group
Lawrence Livermore National Laboratory
University of California
Livermore, California 94551

Dear Maynard:

We enjoyed your visit to QUEST on February 2, and hope your time at Hanford was enjoyable too. Below, please find the answers to the questions we discussed during our meeting.

1. What is the internal volume of the Hydraulic Impact End Effector? The internal volume is 95 cu. in.

2. What is the stored energy of the End Effector? The stored energy of the End Effector is 13,300 ft. lbs. Please note that there was an error in the energy calculation that we provided. The equation should read as follows:

$$W = \frac{P_c(V^{(1/c+1)} - V_0^{(1/c+1)})}{V_0^{(1/c)}(1+1/c)} - P_c(V - V_0)$$

3. What are the dimensions of the strain bar used during the load testing of the End Effector? Attached please find a sketch of the strain bar.

4. What is the maximum working pressure and the factor of safety at this pressure for the End Effector? The maximum working pressure of the End Effector is 40,000 psi. Attached please find several pages on the stress and factor of safety calculations we perform on ultrahigh-pressure vessels. These pages list three different calculations based on three different failure theories. For the End Effector, the factor of safety for each method is:

Lame Solution (Maximum Principal Stress	F.S. = 1.7
Burst Pressure Theory	F.S. = 3.2
Maximum Shear Stress Theory	F.S. = 1.4

Please let me know if any other questions arise or if I may be of further assistance.

Sincerely,

Ron L Lilley

Ron Lilley
Senior Engineer

93TD0400.w4w
Enclosures

21414 - 68th Avenue South
Kent, Washington 98032
Phone: (206) 872-8500
FAX: (206) 872-8967

ATTACHMENT 11

Post-it™ brand

Fax Transmittal Memo 7672

No. of Pages 4
Today's Date 1/12/93
Time

To Paul Densley
From Monte Elmore
Company LLNL
Company PNL
Location
Location Richland WA
Dept. Charge
Fax # (510) 423-8345
Telephone # (510) 423-3304
Fax # (509) 376-0166
Telephone # (509) 376-4309
Original Disposition: ☐ Destroy ☐ Return ☐ Call for pickup

Comments

Paul – WHC asked me to send info to you on K-Mag composition for safety review. This is MSDS sent to me by mfgr. If you need additional, give me a call.

MSDS #20512

WESTERN
AG-MINERALS
COMPANY

Product Health & Safety Data Sheet

I Product Identification

Manufacturer's Name	WESTERN AG-MINERALS COMPANY		
Address	16800 Greenspoint Park Drive, Suite 250N, Houston, TX 77060		
Regular Telephone No.	713/875-5624	Emergency Telephone No.	713/875-5624
Trade Name	K-MAG (Granular, Compacted, Prills, Mini Prills, Standard, Fines)		
Synonyms	Langbeinite, Potassium Magnesium Sulfate, $K_2SO_4{\cdot}2(Mg\ SO_4)$		

II Hazardous Ingredients

Material or Component in Hazardous Concentrations	%	Hazard Data
None		

III Health Effect Information

Eye Contact	May cause irritation of the eyes.
Skin Contact	No known effects.
Inhalation	May cause irritation of the mucous membranes of the nose and throat.
Ingestion	No known effects.
Health Data	The permissible exposure limit (PEL) for nuisance particulates is 15 mg/M^3.
Systemic Effects	Potassium sulfate and magnesium sulfate are considered to be of a low order of toxicity.

See Disclaimer of Warranty on Page 4.

(Approved by U.S. Department of Labor. "Essentially similar to Form OSHA 20, Material Safety Data Sheet")

MSDS #20512

VI Fire Protection Information

Flash Point (Test Method)	NA	Autoignition Temperature (° F)	NA

Flammable Limits In Air % By Vol.	Lower	NA	Upper	NA

Extinguishing Media	NA
Special Fire Fighting Procedure	None Indicated
Unusual Fire and Explosive Conditions	None
Hazardous Combustion Products	None

VII Reactivity Data

Stability (thermal, light, etc.)	Stable	X	Conditions to Avoid	NA
	Unstable			

Incompatibility (materials to avoid)	None
Hazardous Decomposition Products	None

Hazardous Polymerization	Stable	X	Conditions to Avoid	NA
	Unstable			

VIII Environmental Precautions

Steps to be taken if Material is Released or Spilled	Dust may be vacuumed or swept up.
Waste Disposal Method	Disposal methods must conform to local, state and federal regulations. Large quantities may be disposed of at approved sanitary landfills.

MSDS #20512

IV Emergency & First Aid Procedures

Eye Contact	Wash eyes with water. If large particles are embedded in the eye, seek medical attention.
Skin Contact	None required
Inhalation	Remove to fresh air
Ingestion	None required

V Personal Health Protection Information

Eye Protection	Safety glasses or goggles may be worn to protect eyes from dust.
Skin Protection	None Required
Respiratory Protection	If dust concentrations exceeds the PEL a half mask dust respirator should be worn. Disposable type dust mask could be used if the exposure is of a short duration or if dust concentration is relatively low. NOTE: Respirators must be NOISH approved.
Ventilation	Adequate ventilation to reduce dust concentrations to below the PEL must be provided.
Other	Wash hands and face with soap and water before eating or smoking.

IX Special Precautions

MSDS #20512

Handling and Storage Requirements	None
Precautionary Statements	None

X Physical Properties

Boiling Point (°C)	Unknown	Melting Point (°C)	927 °C	Solubility Soluble in water	
Vapor Pressure (mm Hg,temp.)	NA	Specific Gravity (H_2O =1)	2.8	Appearance, Color, Odor, etc. Tetrahedral Crystals, pink to gray color.	
Molecular Weight	415	Percent Volatile by Volume (%)	NA	Other	
Vapor Density (air = 1)	NA	Evaporation Rate (= 1)	NA		

Approved: G.R. Hagstrom

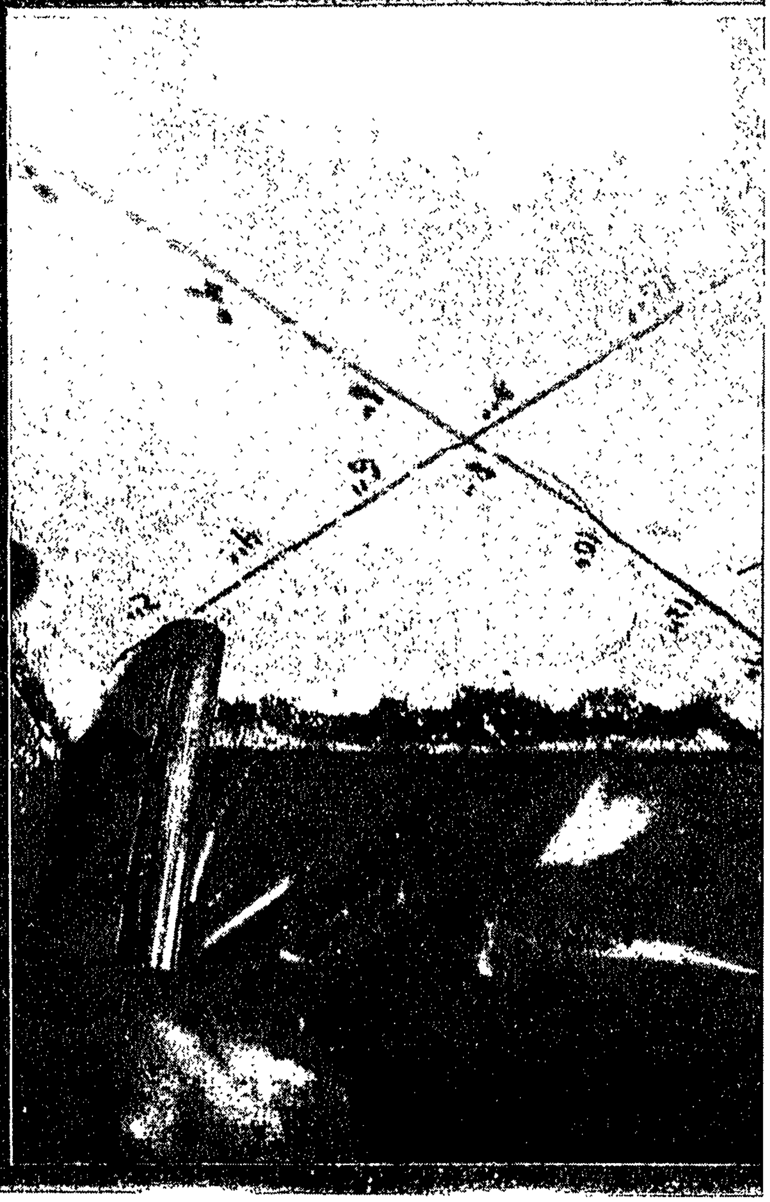
Date: August 1991

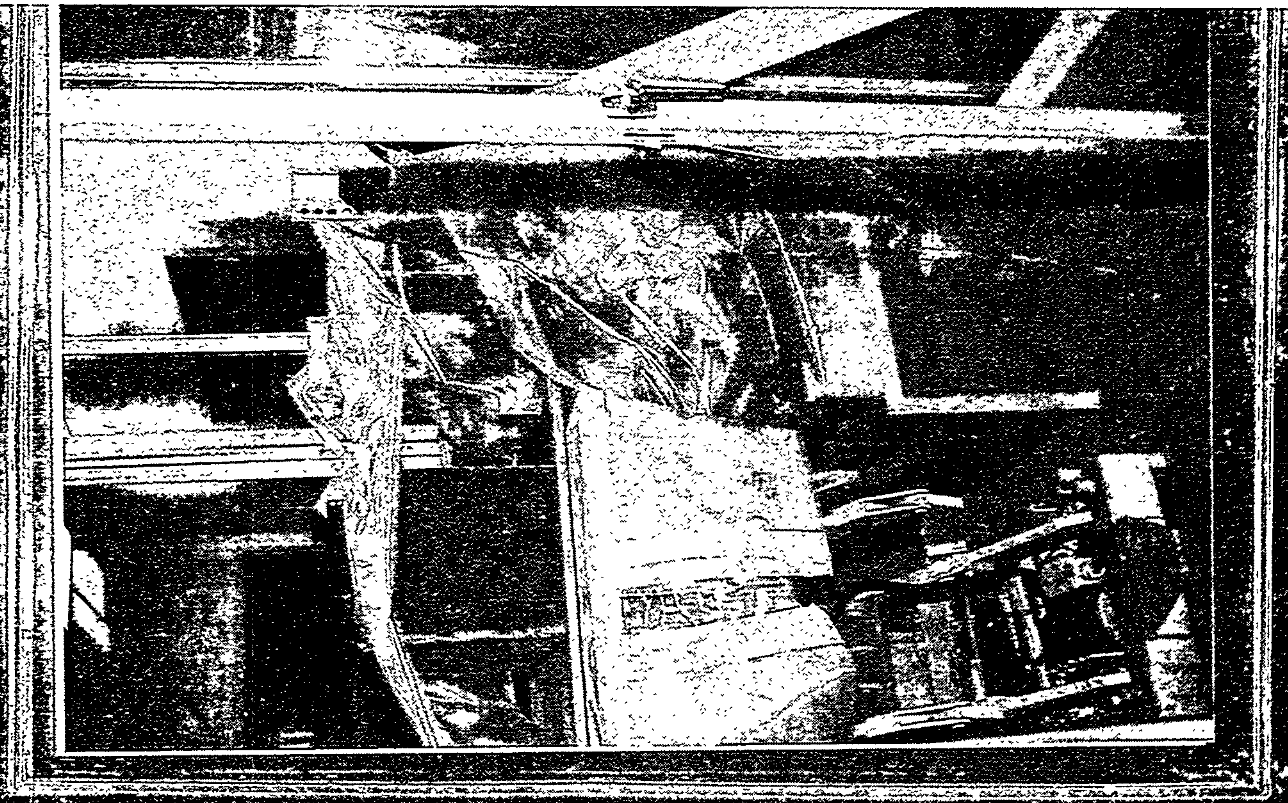
The above information is based on data available to us and is believed to be correct. However, NO WARRANTY of MERCHANTABILITY, FITNESS for any use or any other warranty is expressed or to be implied regarding the accuracy of these data, the results to be obtained from the use thereof, the hazards connected with the use of the material, or that any such use will not infringe any patent. Since the information contained herein may be applied under conditions beyond our control and with which we may be unfamiliar, we do not assume any responsibility for the results of its use. This information is furnished upon the condition that the person recieving it shall make his own determination of the suitability of the material for his particular purpose.

Required under USDL Safety and Health Regulations for Ship repairing, Shipbuilding, and Shipbreaking (29 CFR 1915, 1916, 1917).

ATTACHMENT - 12


10"
4"
4"
4"
6"
4"
2"


12"
10"
8"
4"
6"
4"
4"
2"



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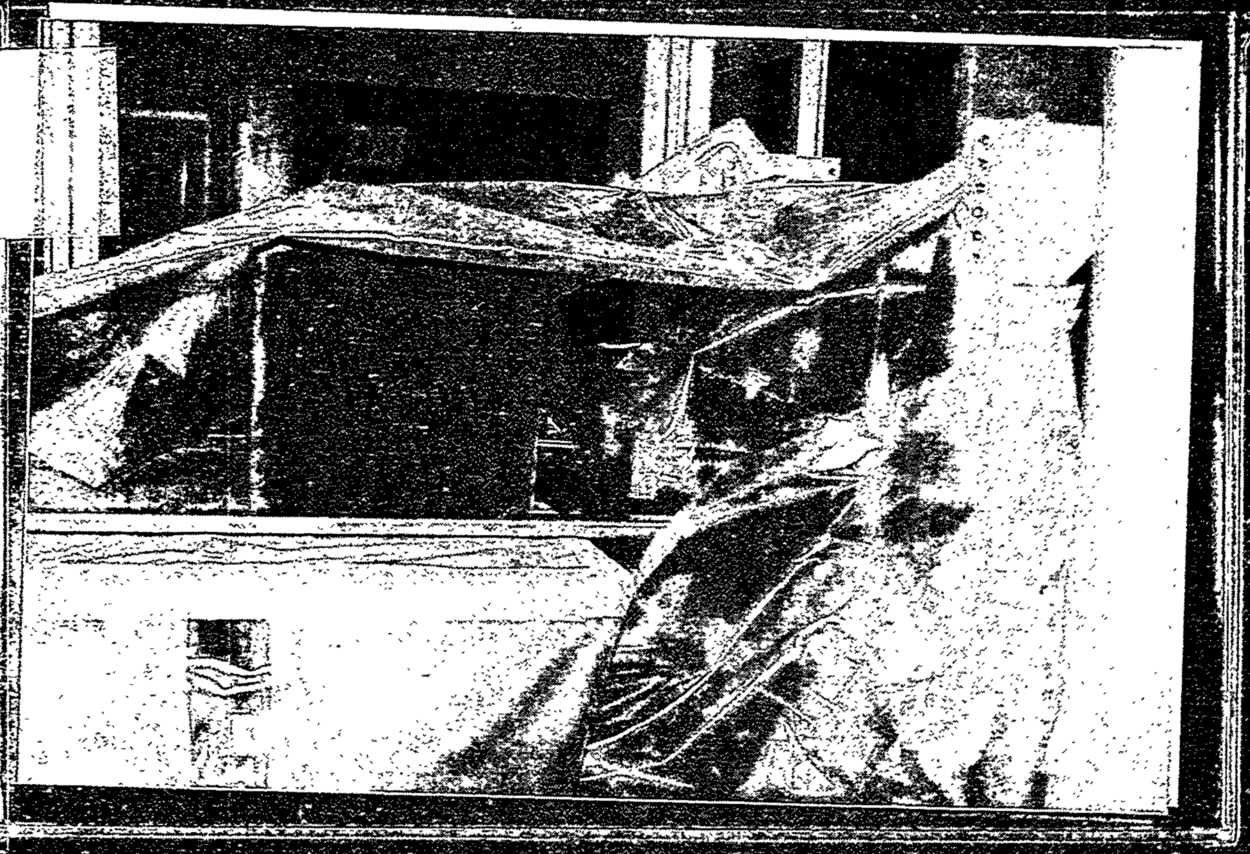

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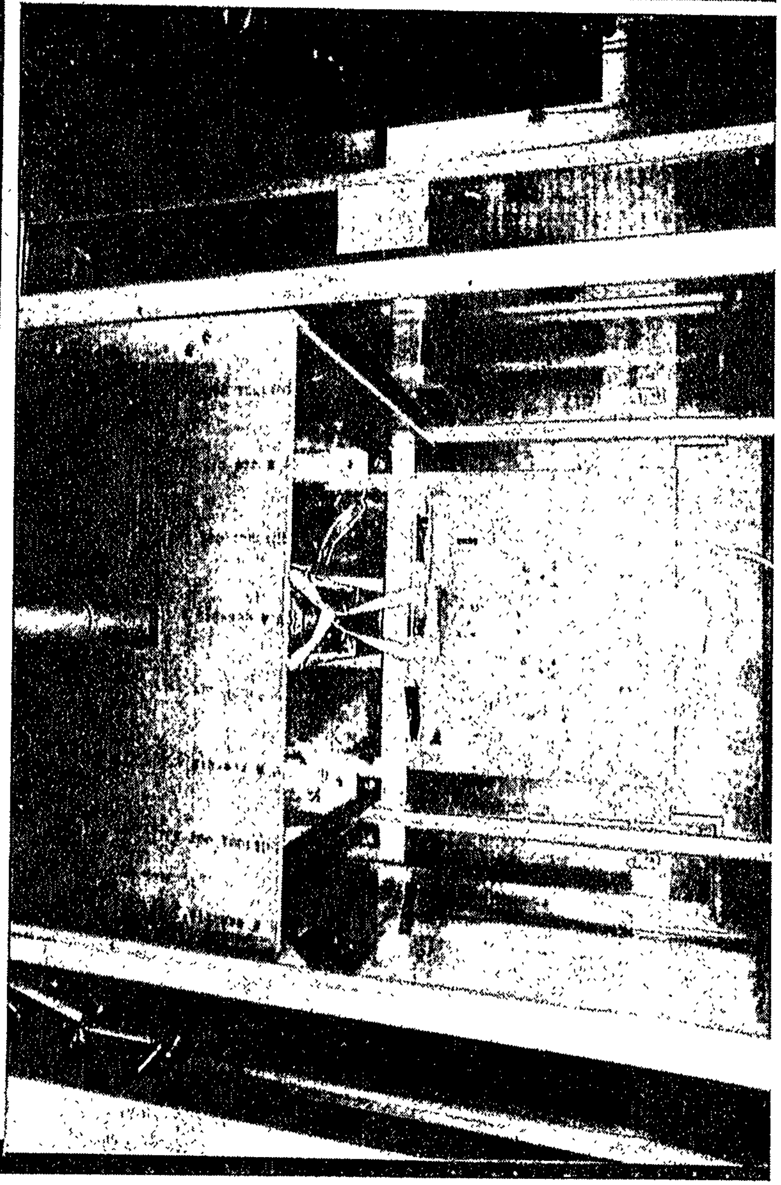

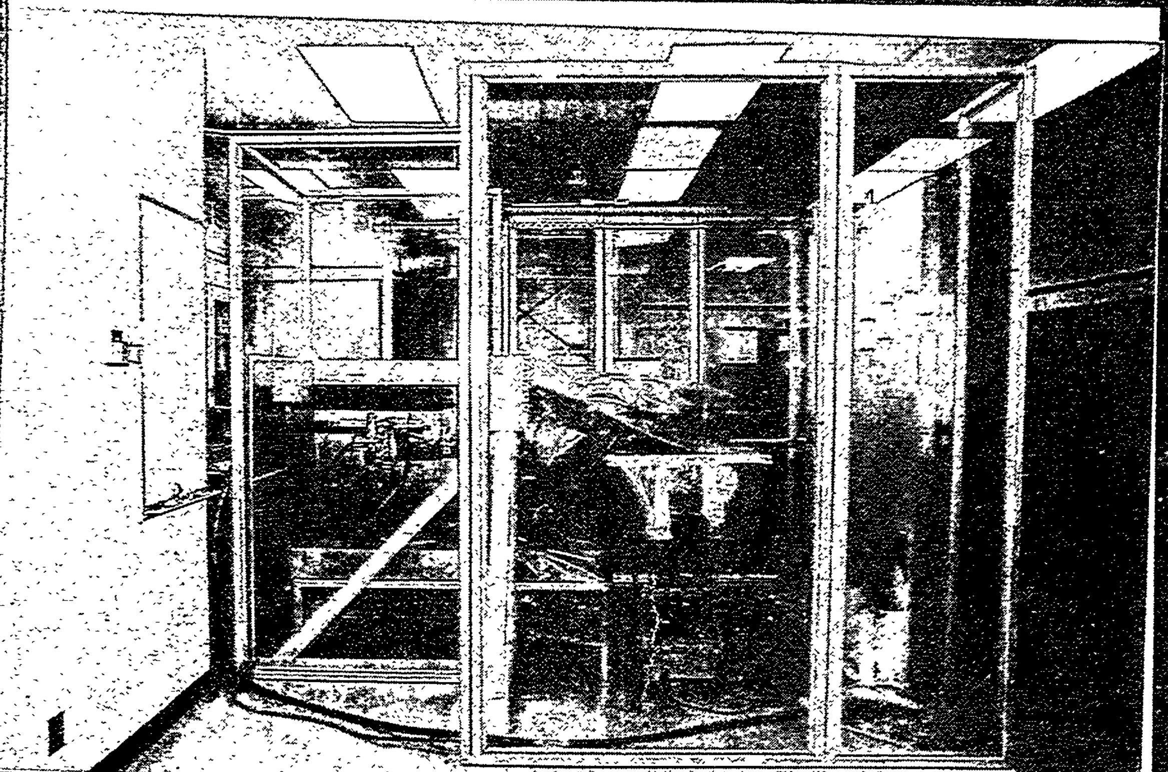

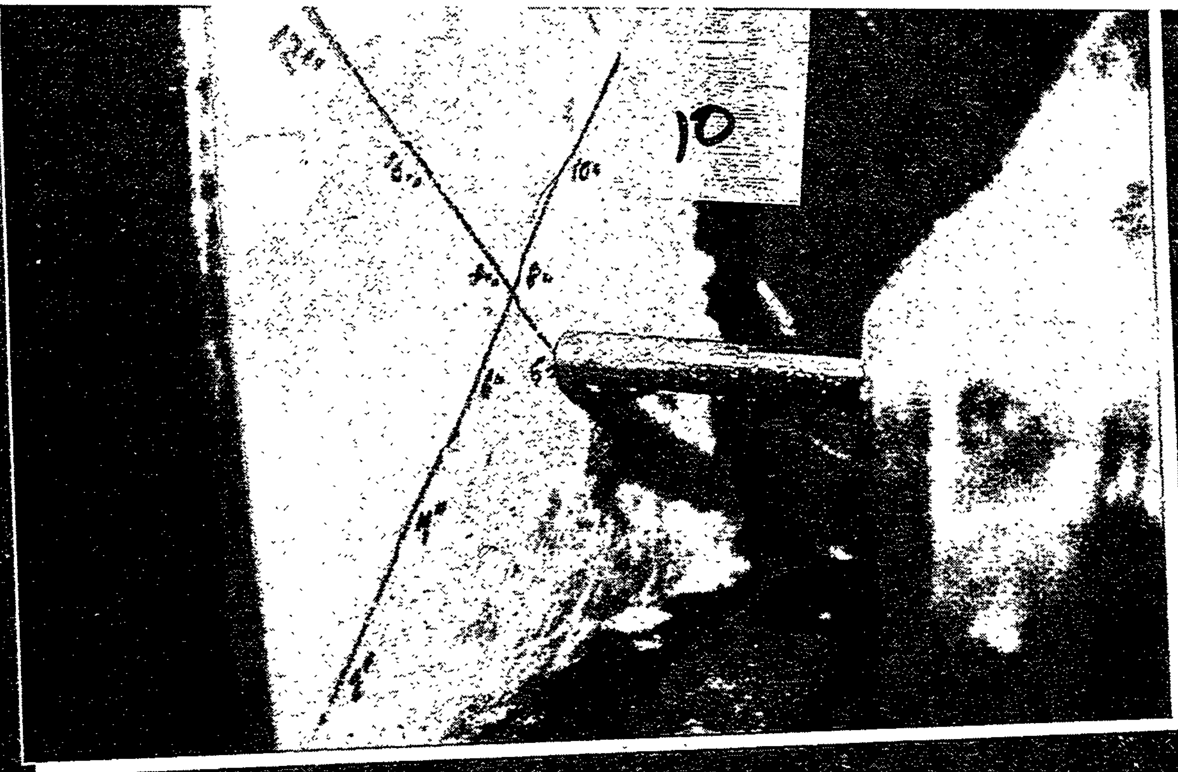
10
12"
16"
10"
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16"
12"
10"
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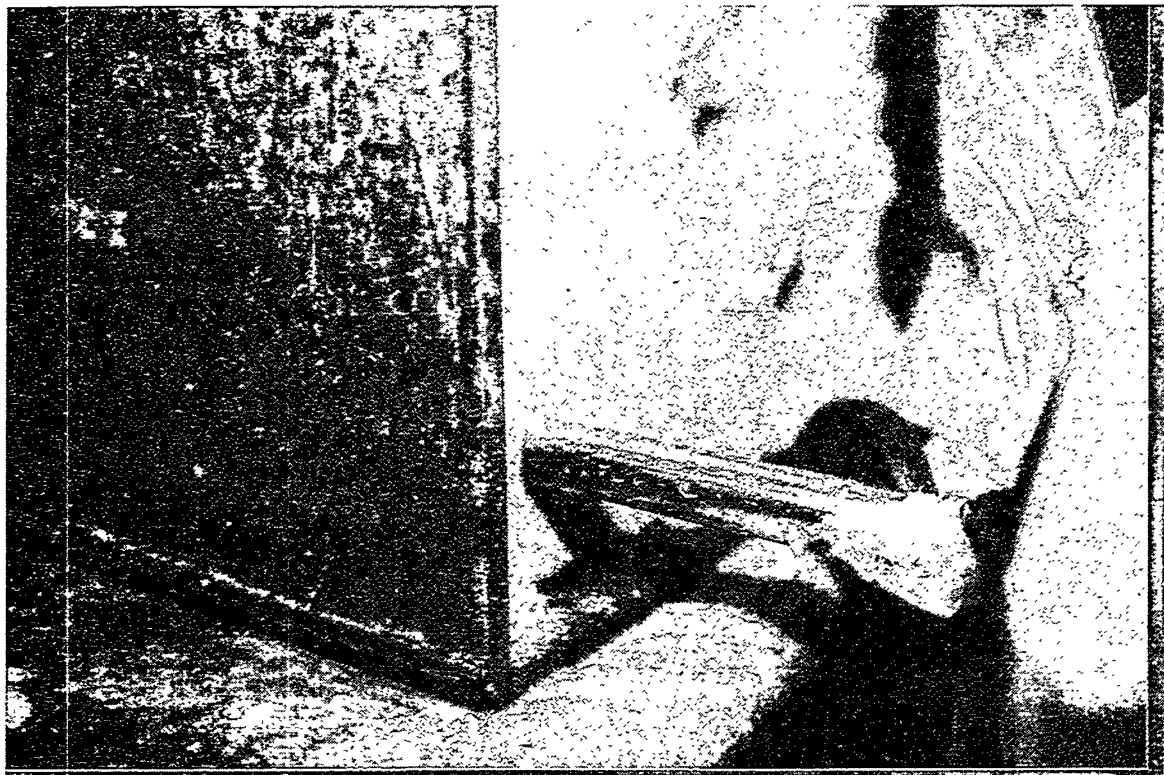
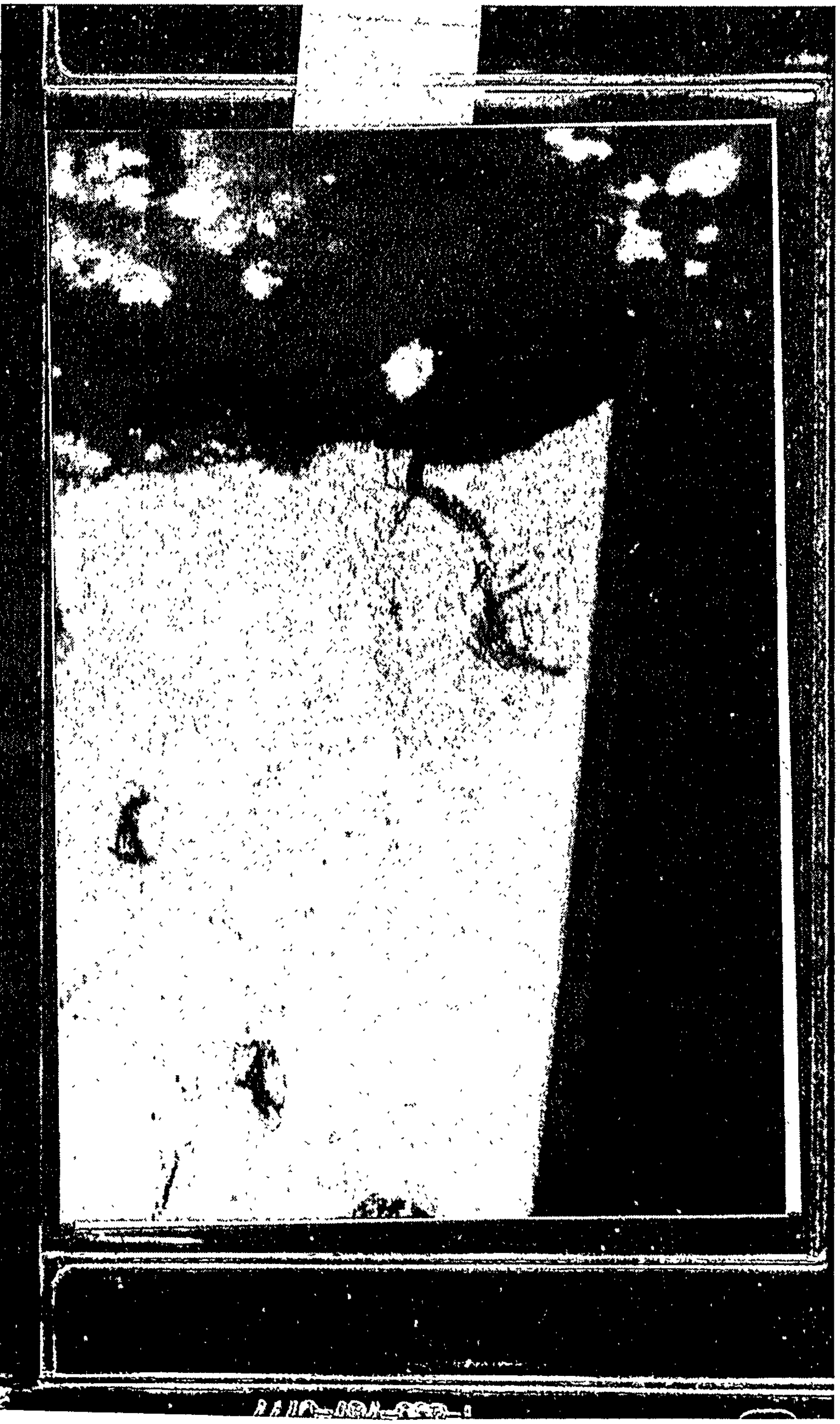
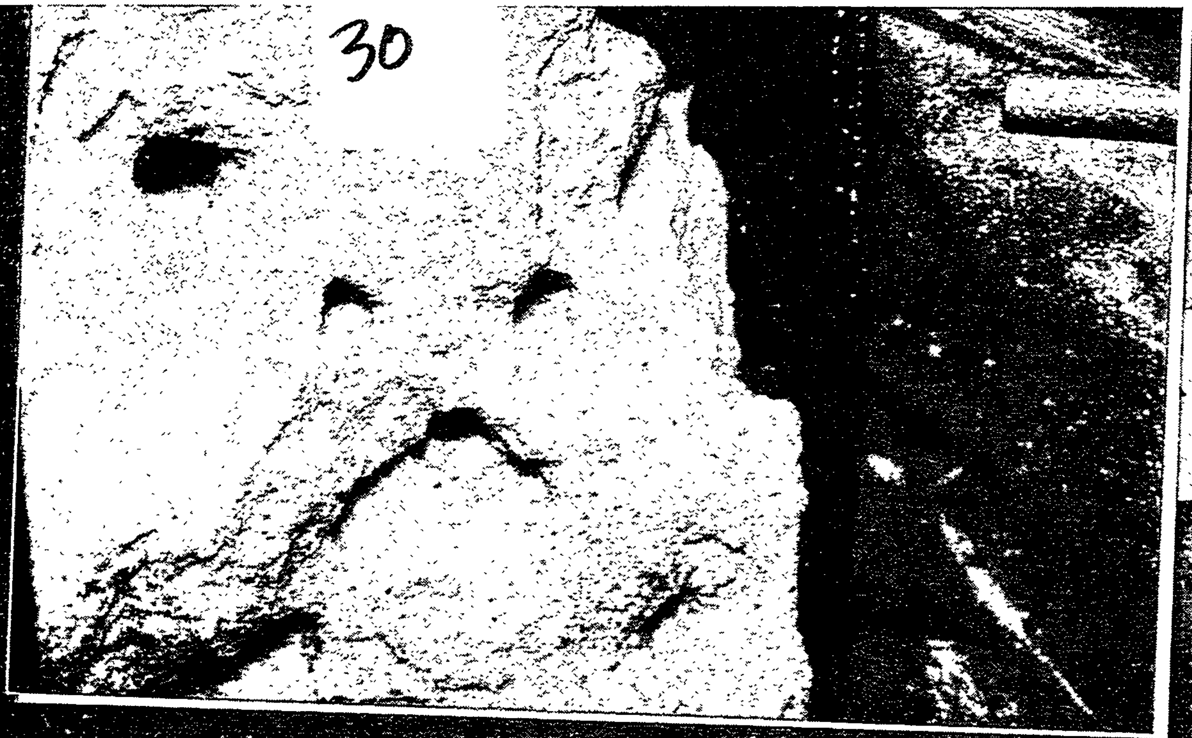
2"







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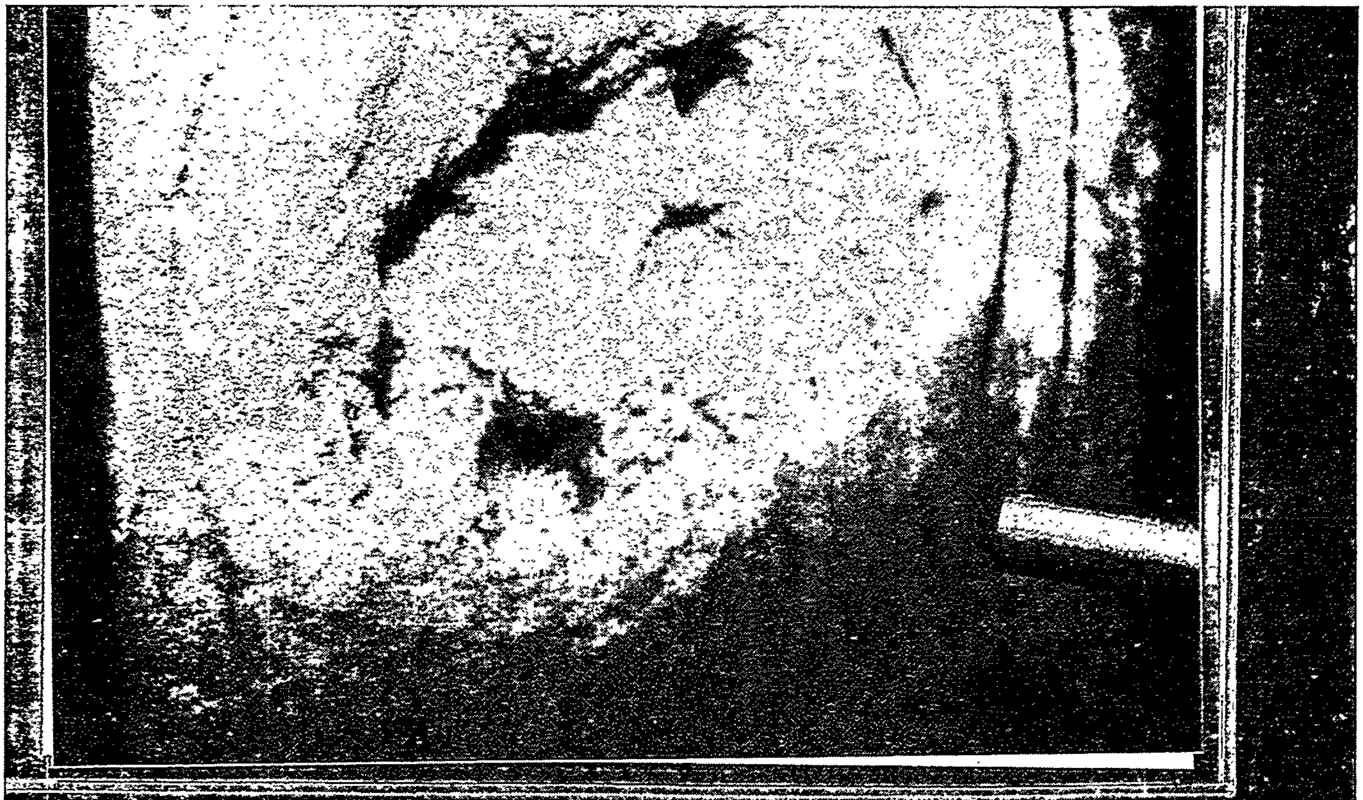
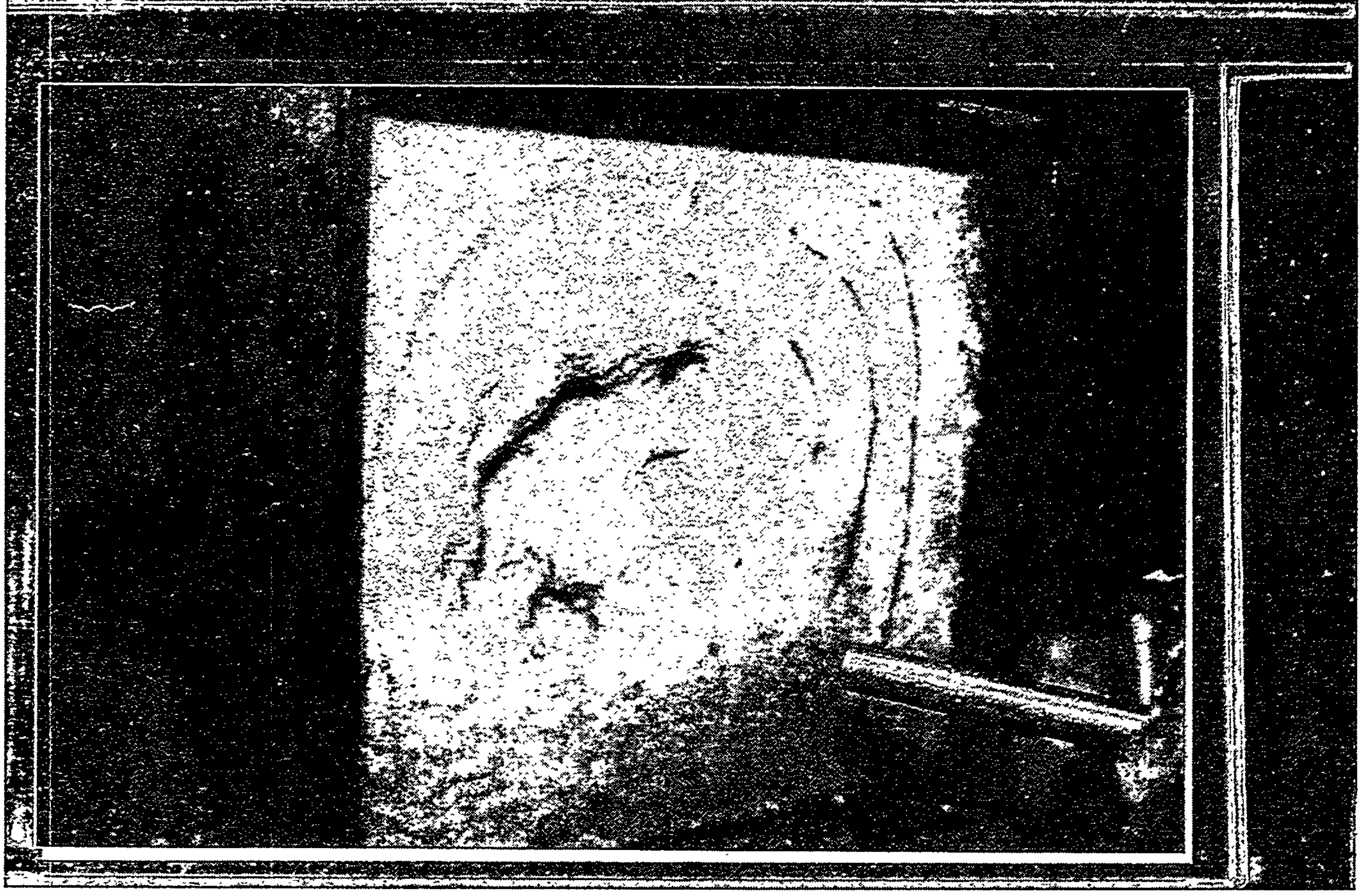
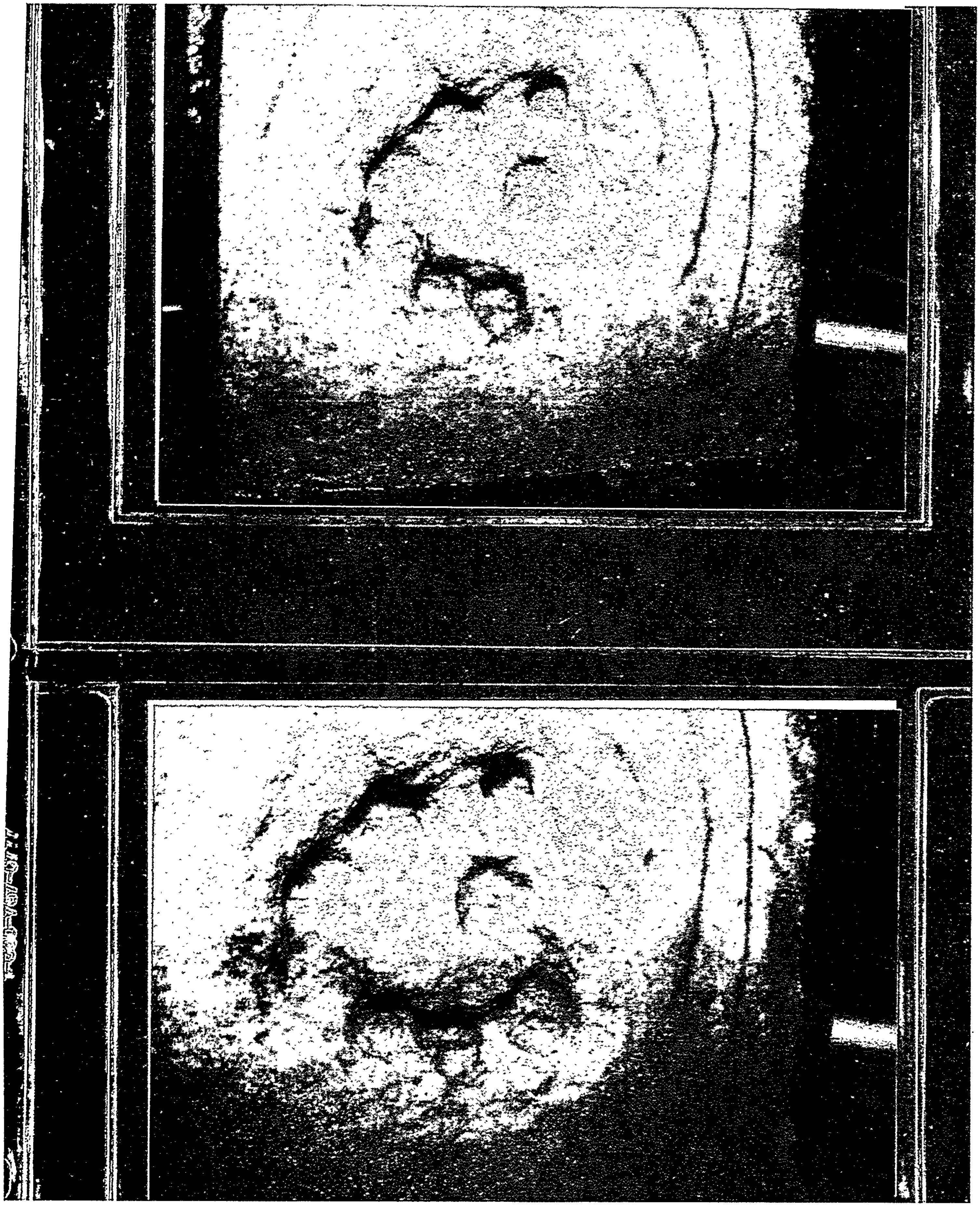
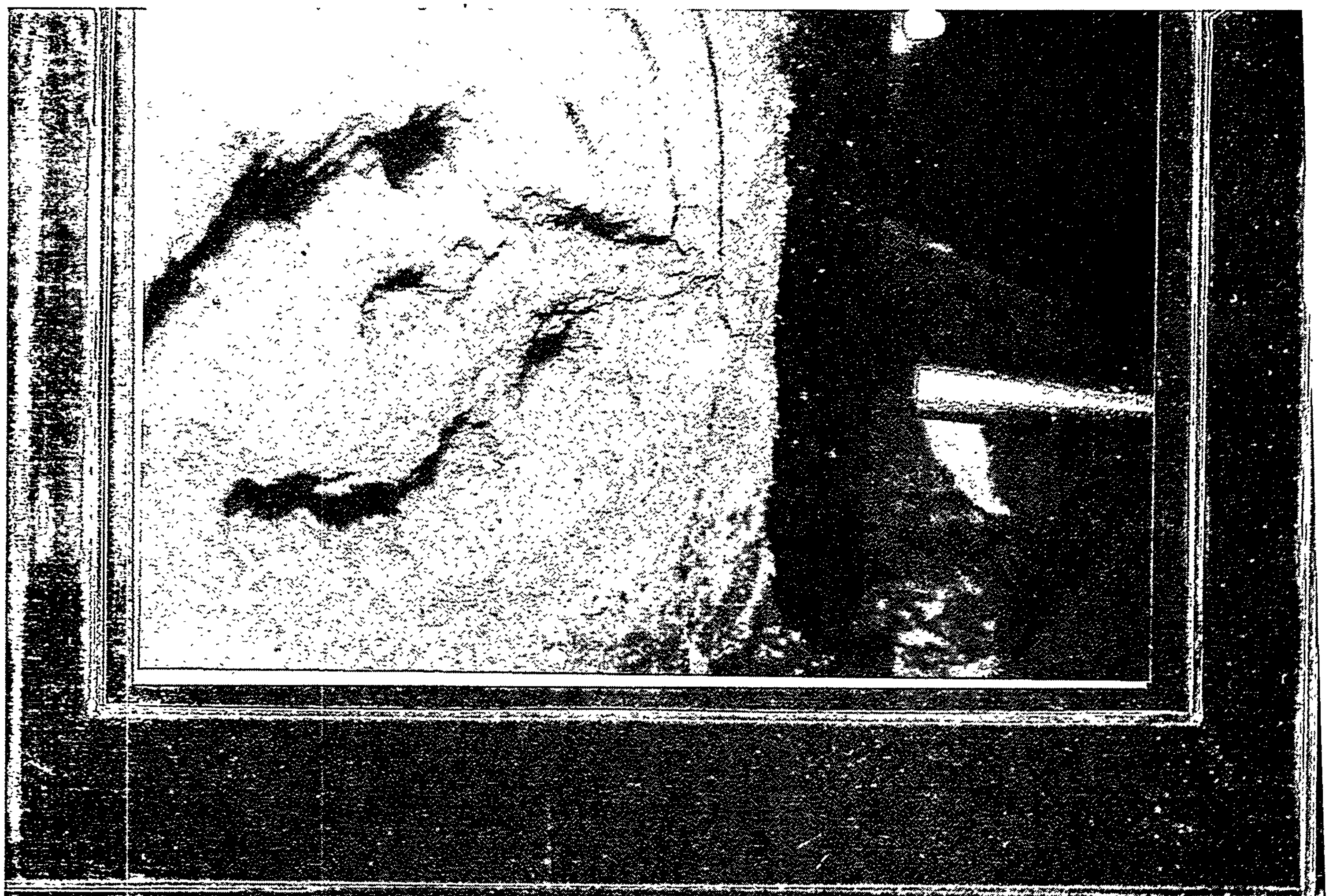
31

32



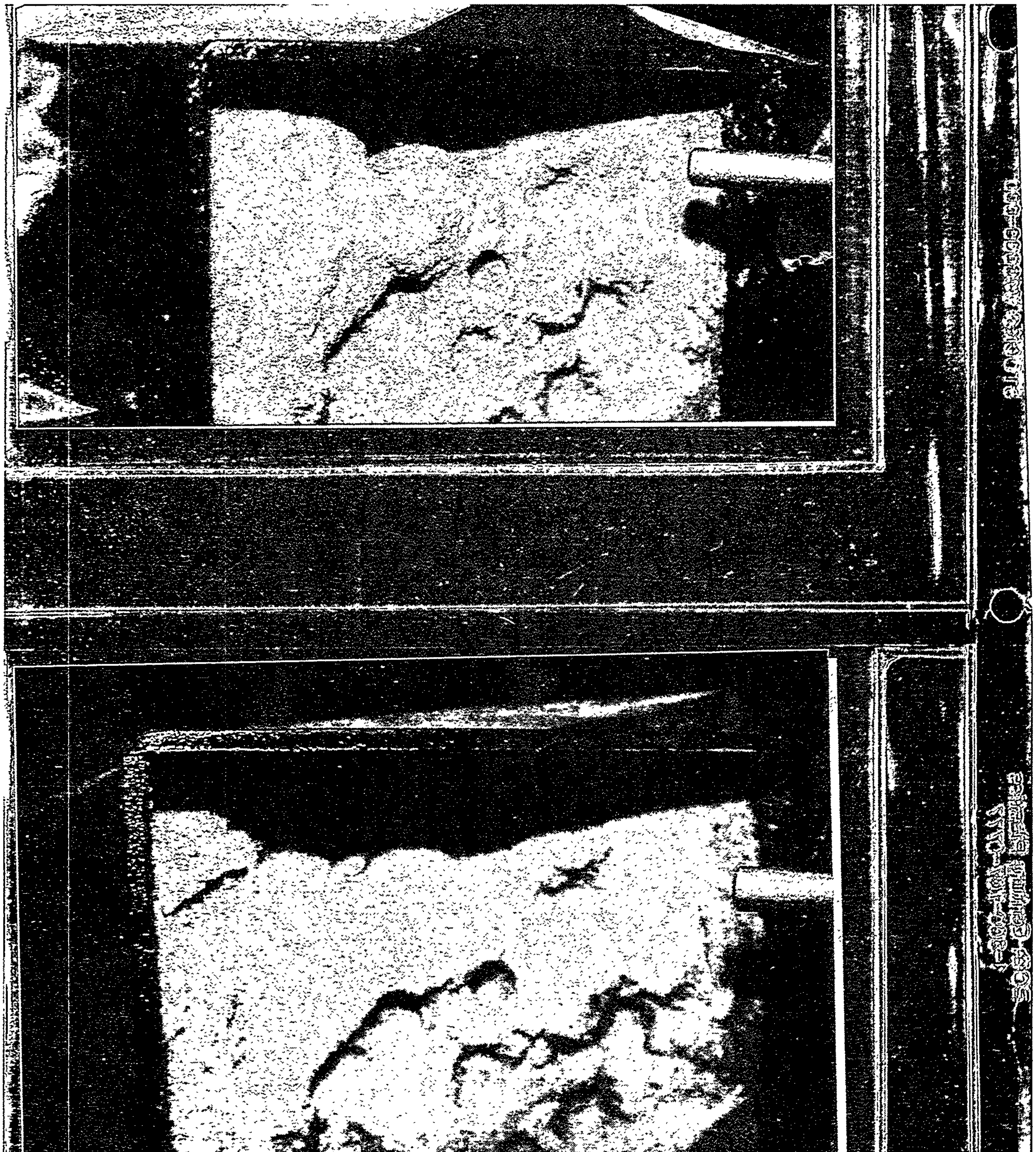


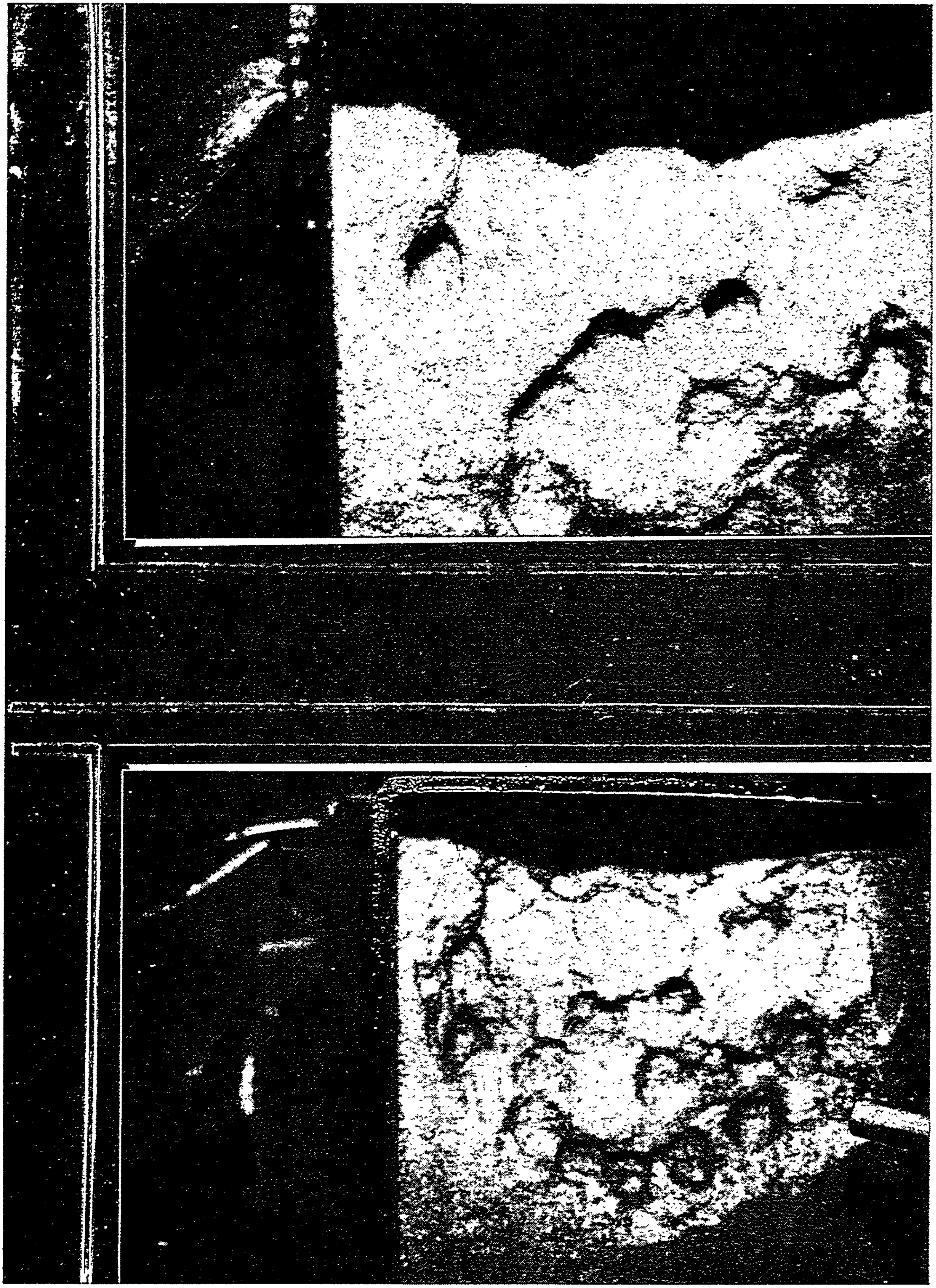


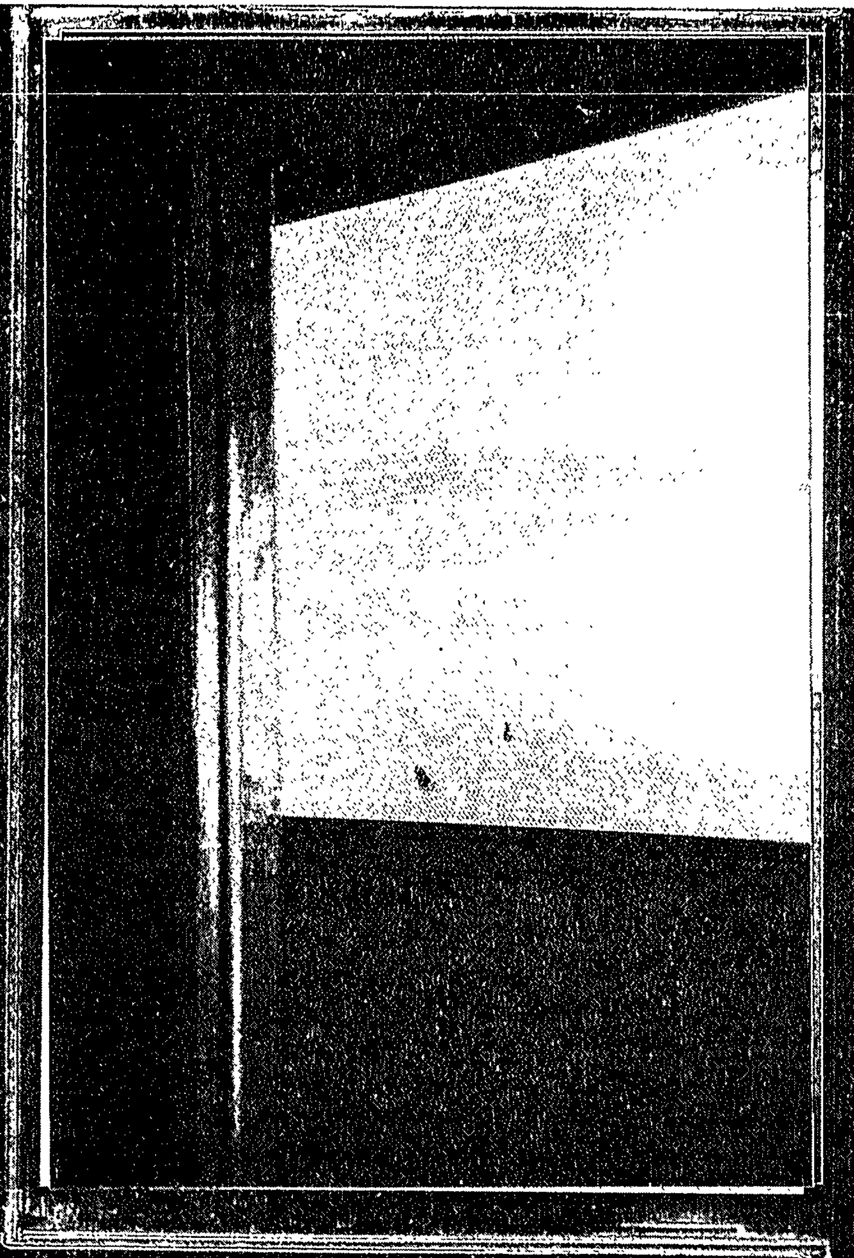


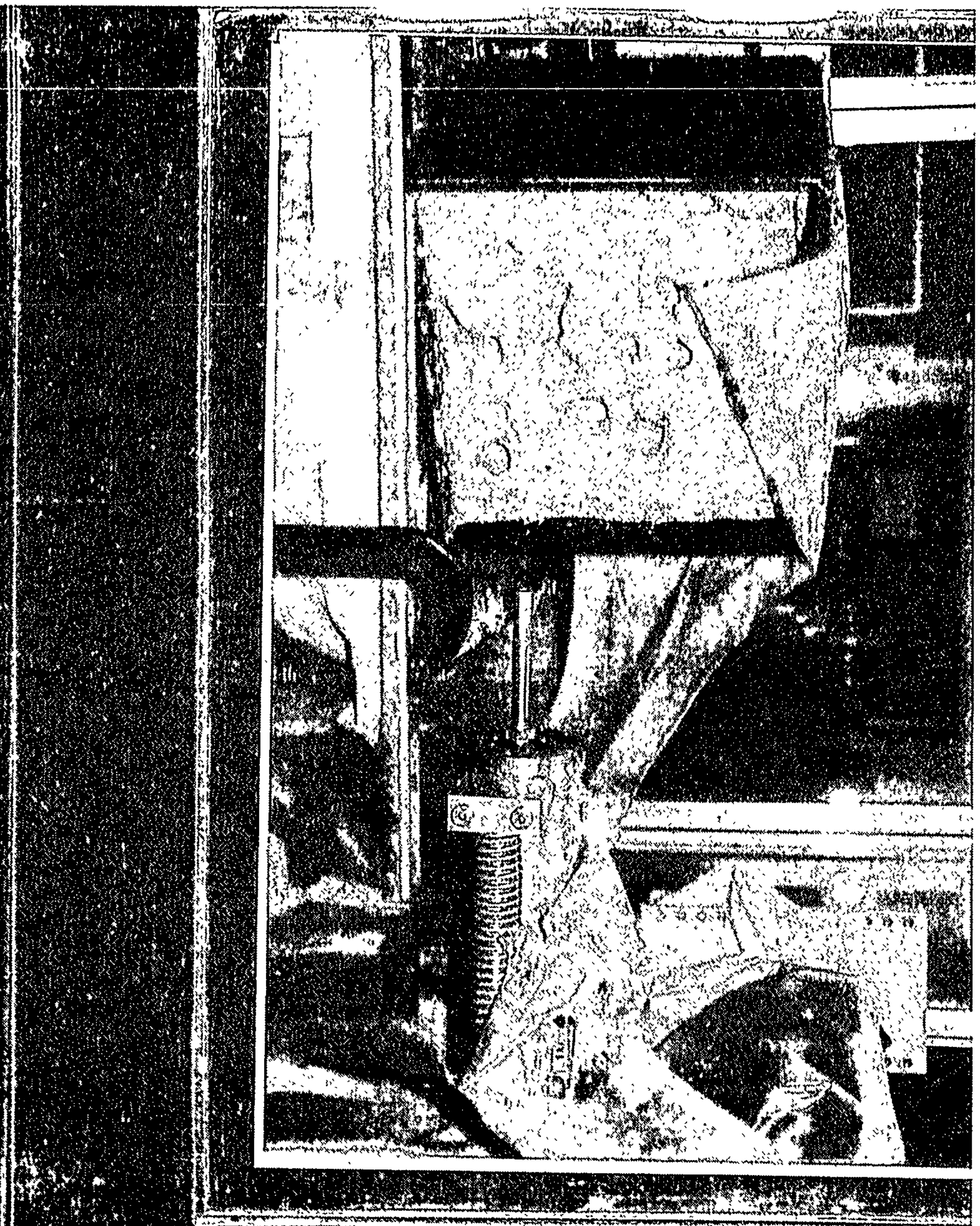
20th Century Plastics
1-800-767-0777

STOCK# 738000-06C







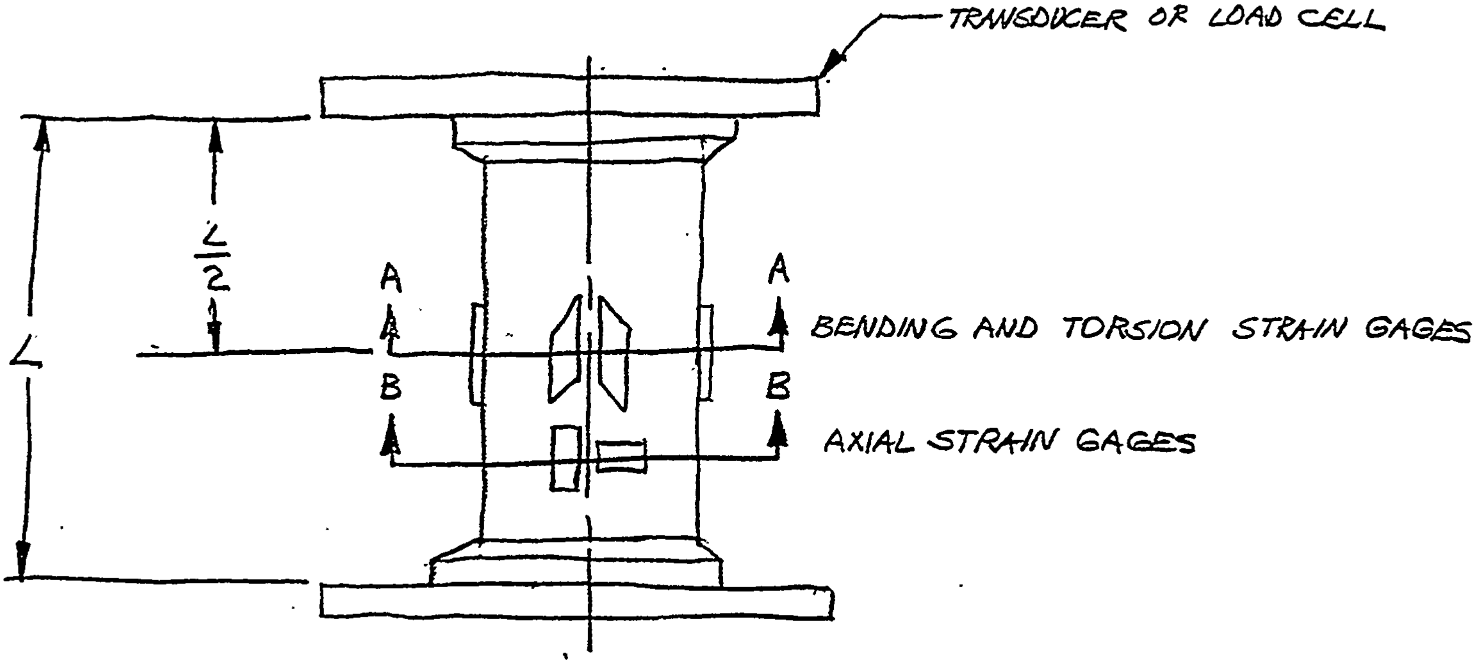


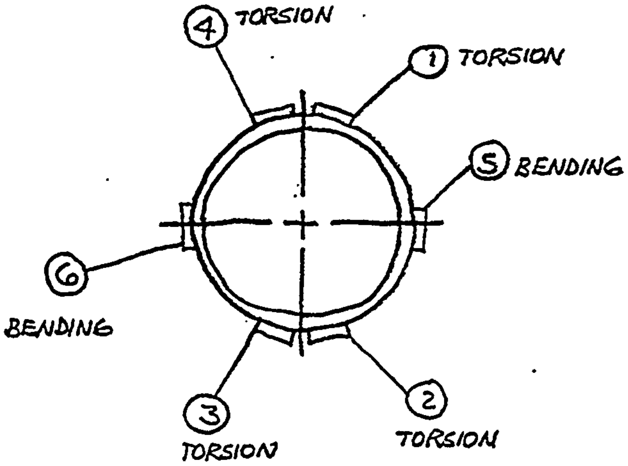
ATTACHMENT 13

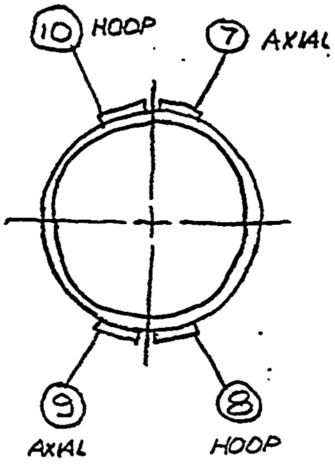
THREE-WAY TRANSDUCER

THIS TRANSDUCER WILL MEASURE THREE TYPES OF STRAIN:

(1). BENDING, (2). AXIAL, (3) TORSION.







SECTION AA

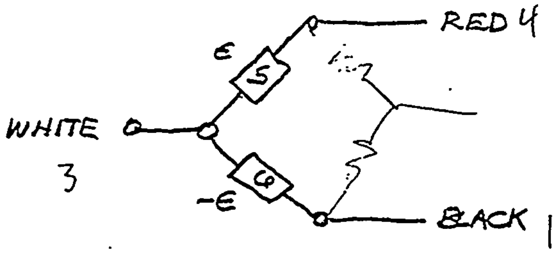
SECTION BB

BS
5/10/93

THREE-WAY TRANSDUCER

(1). BENDING STRAIN.

STRAIN GAGE: CEA-06-250UW-350

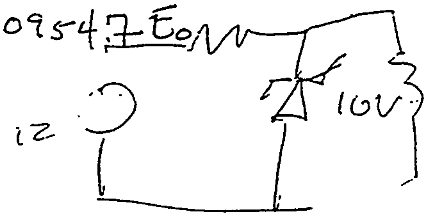


HALF BRIDGE

$$E_0 = E_{IN}\frac{(K)\epsilon}{2} \quad ①$$

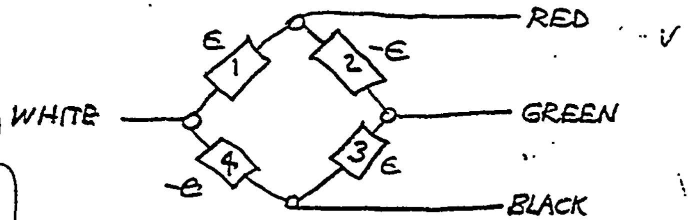
$$\epsilon = \frac{2E_0}{K E_{in}} = \frac{2}{(10.0)(2.095)} E_0$$

$$\epsilon = 0.09547 E_0$$



(2). TORSION STRAIN.

STRAIN GAGE: CEA-06-187UV-350



FULL BRIDGE

$$E_0 = E_{IN}(K)\epsilon \quad ①$$

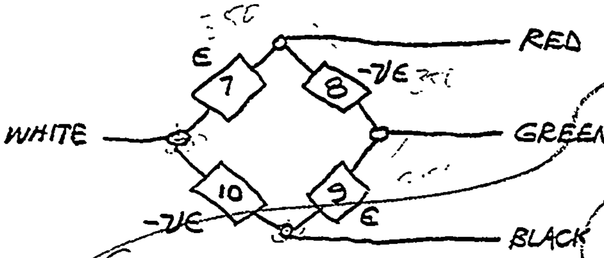
$$\epsilon = \frac{E_0}{K E_{in}} = \frac{1}{(2.085)(10.4)} E_0$$

$$\epsilon = 0.04656 E_0$$

(3). AXIAL STRAIN.

STRAIN GAGE: CEA-06-250UT-350

ν = 0.265 Cast steel
0.287 Cold. Rolled Steel
0.305 18-8 Stainless Stee
0.283-0.292 all other steel



FULL BRIDGE

$$E_0 = E_{IN}\frac{(K)\epsilon(1+\nu)}{2} \quad ①$$

ν = Poisson's Ratio

[illegible] / 1500 = 245 Ω

$$\epsilon = \frac{2E_0}{K(1+\nu)E_{in}} = \frac{2}{(2.09)(\quad)(10.3)} E_0$$

$$\epsilon = 0.04645 E_0$$

① E_0 = BRIDGE OUTPUT (VOLT)
E_{IN} = BRIDGE EXCITATION (VOLT)
K = GAGE FACTOR OR SENSITIVITY
ϵ = STRAIN (INCH/INCH)

BS
5/10,

THREE - WAY TRANSDUCER

1. ADHESIVE: AE-10. CURE 2 HRS. AT 120°F (GLUE LINE TEMPERATURE).
2. MOISTURE PROOFING: W-1 WAX WITH M-COAT F.
3. WIRE: WHITE "ENDEVCO" WIRE. ABOUT 3 ft. LONG. REMOVE GREEN WIRE FOR BENDING STRAIN GAGE (NUMBER 1).

   CAN USE NICHROME STRAPS TO SECURE CABLE TO TRANSDUCER.

   LABEL CABLE WITH 1, 2 AND 3.
4. INDICATE BENDING DIRECTION ON TRANSDUCER.
5. OUTSIDE DIAMETER = 1.340 INCH

   INSIDE DIAMETER = 1.250 INCH
6. COLOR CODE

   RED (+) EXCITATION
   BLACK (-) EXCITATION
   GREEN (+) OUTPUT
   WHITE (-) OUTPUT

ACCOUNT NUMBER: 5807-43

BS
5/10/93

SENSOR DATA
ENGINEERING MEASUREMENTS SECTION
BUILDING 231 ROOM 1441 EXTENSION 2-8839

REQUESTER : MAYNARD HOLIDAY

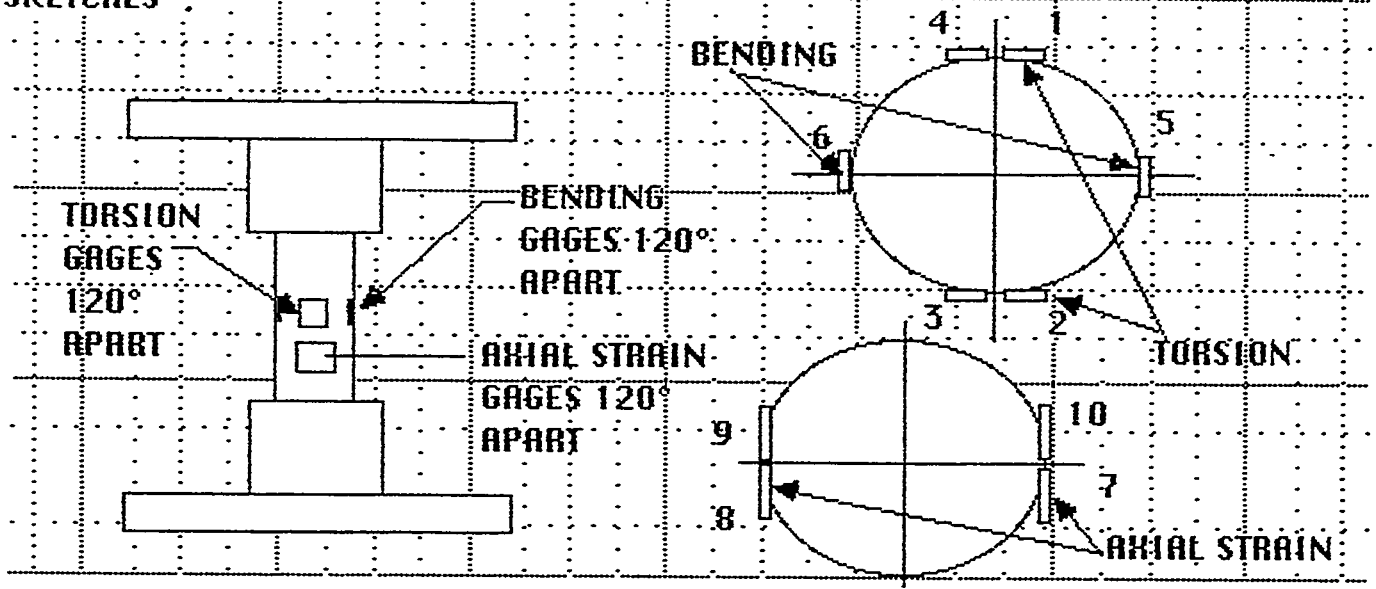
EXTENSION :

COMPLETED BY MARY ROSS

DATE COMPLETED 5-14-93

ACCOUNT NO. 5807-43

SKETCHES



APPLICATION DETAILS

SENSITIVITY FACTOR : *SEE BELOW

BENDING: CEA-06-250UW-350

TORSION: CEA-06-187UV-350

SENSOR: STRAIN: CEA-06-250UT-350

NOM. RES. : *SEE BELOW

LOT NO. : * SEE BELOW

SOLDER : 361A-20R

RES. TO GRND. : > 20 K m Ω

ADHESIVE & ADHESIVE CURE : AE-10 2HR @ 60 ° C W/CLAMP

WIRE TYPE & SIZE : 30 AWG ENDEVCO WIRE 3FT. LONG

WIRE CODE : BENDING: 3 WIRE 1/2 BRIDGE, TORSION & STRAIN: FULL BRIDGE

RECOMMENDED BRIDGE EXCITION : MV / V OUTPUT :

MOISTURE PROOFING : W-1 WAX AND M-COAT F

SURFACE PREPERATION : CSM-1, GRIT BLAST, NEUTRALIZER.

REMARKS : BENDING: 350.0 ± 0.3% G/F: 2.095 ± 0.5% LOT #: R-A56AD43

TORSION: 350.0 ± 0.4% G/F: 2.065 ± 0.5% LOT #: R-A56AD47

STRAIN: 350.0 ± 0.4% G/F: 2.09± 1.0% LOT #: R-A56AD67

BENDING STRAIN GAGES

ENGINEERING DATA SHEET

THE INFORMATION APPEARING ON THIS SHEET HAS BEEN COMPILED SPECIFICALLY FOR THE GAGES CONTAINED IN THIS PACKAGE. THIS FORM IS PRODUCED WITH ADVANCED EQUIPMENT & PROCEDURES WHICH PERMIT COMPREHENSIVE QUALITY ASSURANCE VERIFICATION OF ALL DATA SUPPLIED HEREIN. SHOULD ANY QUESTIONS ARISE RELATIVE TO THESE GAGES, PLEASE MENTION GAGE TYPE, BATCH NUMBER, AND LOT NUMBER.
H001

PON	Check	Final QA
S63513	JF	MM .64

Micro-Measurements
Division
Made in USA

MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

F007

CEA-06-250UW-350

CEA-06-250UW-350
TYPE

OPTION

5
QUANTITY

R-A56AD43
LOT NUMBER

350.0 ±0.3%
RESISTANCE IN OHMS AT 24°C

2.095 ±0.5%
GAGE FACTOR AT 24°C

(+0.3 ±0.2)%
K1

013120-3247
CODE

GENERAL INFORMATION: CEA-SERIES STRAIN GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: -100° to +400° F (-75° to +205° C) for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in. (3.2 mm) and larger; approximately 3% for gage lengths under 1/8 in. (3.2 mm).

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^5 cycles at ±1500μin/in (μm/m) using M-Line 361A solder.

CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletins B-127, B-130, and B-137 for installation procedures.

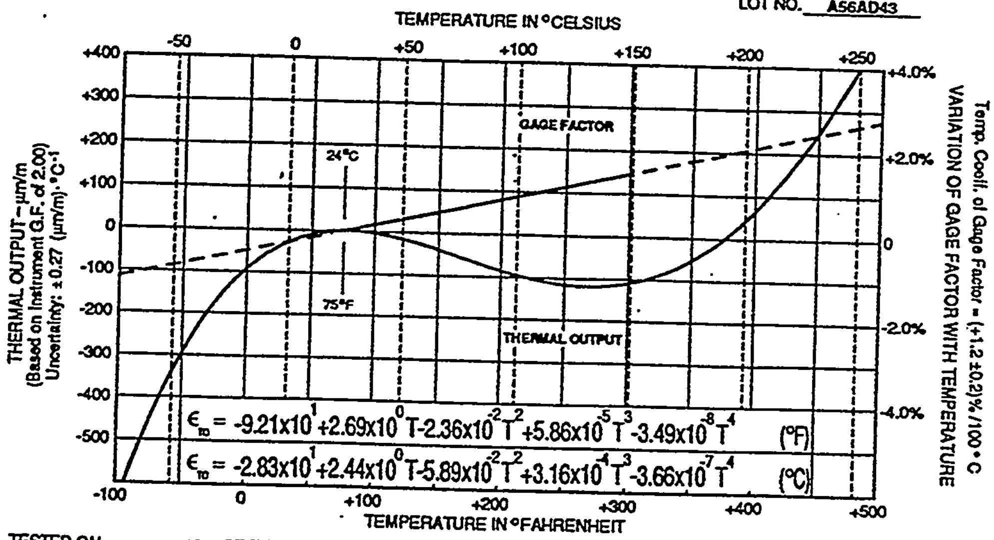
SOLDER: If operating temperature will not exceed +300° F (+150° C), M-Line solder 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder 450 (95-5) tin-antimony is satisfactory to +400° F (+205° C). Refer to M-M Catalog A-110 for further information on solders, and Tech Tip TT-609 for lead attachment techniques.

BACKING: The backing of CEA-Series gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

G045

THERMAL OUTPUT

LOT NO. A56AD43



$$\epsilon_{TO} = -9.21\times10^{1} + 2.69\times10^{0}T - 2.36\times10^{-2}T^{2} + 5.86\times10^{-5}T^{3} - 3.49\times10^{-8}T^{4} \quad (°F)$$

$$\epsilon_{TO} = -2.83\times10^{1} + 2.44\times10^{0}T - 5.89\times10^{-2}T^{2} + 3.16\times10^{-4}T^{3} - 3.66\times10^{-7}T^{4} \quad (°C)$$

TESTED ON: 1018 STEEL TEST PATTERN: 250BG CODE: 013016 ENG. GU

TORSION STRAIN GAGES

M-M

ENGINEERING DATA SHEET

THE INFORMATION APPEARING ON THIS SHEET HAS BEEN COMPILED SPECIFICALLY FOR THE GAGES CONTAINED IN THIS PACKAGE. THIS FORM IS PRODUCED WITH ADVANCED EQUIPMENT & PROCEDURES WHICH PERMIT COMPREHENSIVE QUALITY ASSURANCE VERIFICATION OF ALL DATA SUPPLIED HEREIN. SHOULD ANY QUESTIONS ARISE RELATIVE TO THESE GAGES, PLEASE MENTION GAGE TYPE, PON, AND LOT NUMBER.

H031

PON	Check	Final QA
S69876	JF	MM 42

M-M Micro-Measurements Division
Made in USA

MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

F007

CEA-06-187UV-350

CEA-06-187UV-350
TYPE

OPTION

5
QUANTITY

R-A56AD47
LOT NUMBER

350.0 ±0.4%
RESISTANCE IN OHMS AT 24°C

2.065 ±0.5%
GAGE FACTOR AT 24°C

(+0.6 ±0.2)%
Kt

022918-3189
CODE

GENERAL INFORMATION: CEA-SERIES STRAIN GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: -100° to +400° F (-75° to +205° C) for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in. (3.2 mm) and larger; approximately 3% for gage lengths under 1/8 in. (3.2 mm).

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^5 cycles at ±1500μin/in (μm/m) using M-Line 361A solder.

CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletins B-127, B-130, and B-137 for installation procedures.

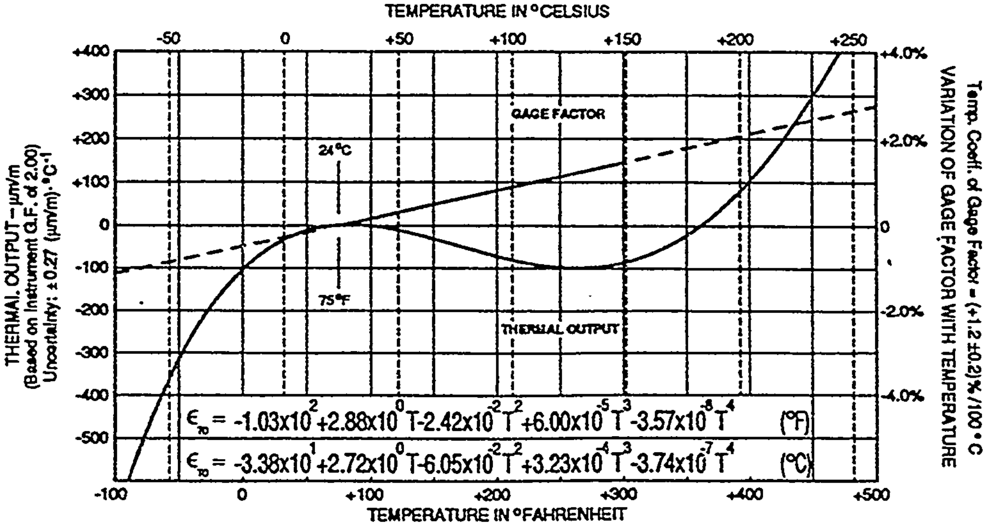
SOLDER: If operating temperature will not exceed +300° F (+150° C), M-Line solder 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder 450 (95-5) tin-antimony is satisfactory to +400° F (+205° C). Refer to M-M Catalog A-110 for further information on solders, and Tech Tip TT-609 for lead attachment techniques.

BACKING: The backing of CEA-Series gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

G045

THERMAL OUTPUT

LOT NO. A56AD47



TESTED ON: 1018 STEEL TEST PATTERN: 250BG CODE: 013318 ENG. GU

AXIAL LOAD STRAIN GAGES

ENGINEERING DATA SHEET

Final QA	Check	Batch
MM 84	JF	S74232

THE INFORMATION APPEARING ON THIS SHEET HAS BEEN COMPILED SPECIFICALLY FOR THE GAGES CONTAINED IN THIS PACKAGE. THIS FORM IS PRODUCED WITH ADVANCED EQUIPMENT & PROCEDURES WHICH PERMIT COMPREHENSIVE QUALITY ASSURANCE VERIFICATION OF ALL DATA SUPPLIED HEREIN. SHOULD ANY QUESTIONS ARISE RELATIVE TO THESE GAGES, PLEASE MENTION GAGE TYPE, BATCH, AND LOT NUMBER.

H001

Micro-Measurements Division
Made in USA

MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

F015

CEA-06-250UT-350

TYPE: CEA-06-250UT-350

OPTION:

QUANTITY: 5

LOT NUMBER: R-A56AD67

RESISTANCE IN OHMS AT 24°C: 350.0 ±0.4%

	GAGE FACTOR 24°C	TRANSVERSE SENSITIVITY 24°C
SECTION 1	2.085 ±0.5%	(+0.5 ±0.2)%
SECTION 2	2.095 ±0.5%	(+0.5 ±0.2)%
SECTION 3		
NOMINAL (All Sections)	2.09 ±1.0%	

CODE: 032911-3233

GENERAL INFORMATION: CEA-SERIES STRAIN GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: -100° to +400° F (-75° to +205° C) for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in. (3.2 mm) and larger; approximately 3% for gage lengths under 1/8 in. (3.2 mm).

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^6 cycles at ±1500μin/in (μm/m) using M-Line 361A solder.

CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletins B-127, B-130, and B-137 for installation procedures.

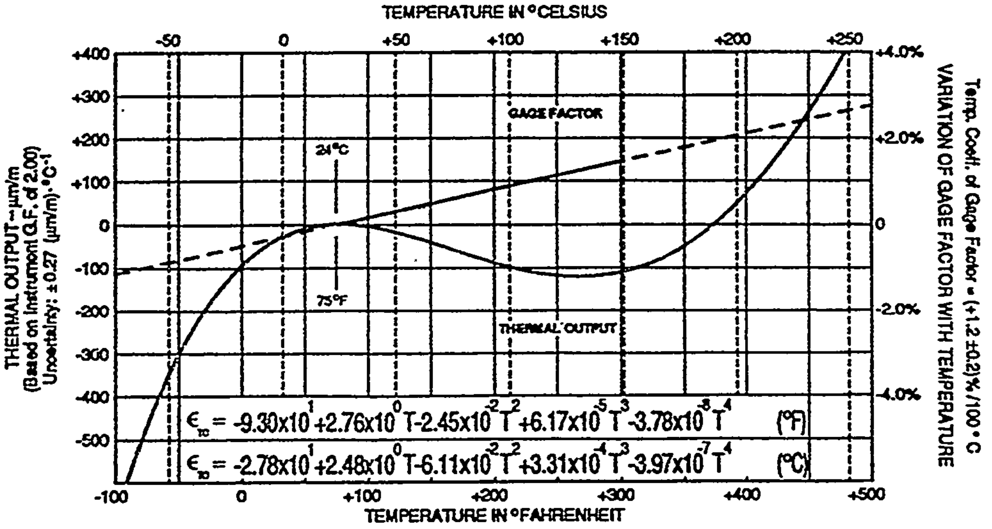
SOLDER: If operating temperature will not exceed +300° F (+150° C), M-Line solder 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder 450 (95-5) tin-antimony is satisfactory to +400° F (+205° C). Refer to M-M Catalog A-110 for further information on solders, and Tech Tip TT-609 for lead attachment techniques.

BACKING: The backing of CEA-Series gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

G045

THERMAL OUTPUT

LOT NO. A56AD67



TESTED ON: 1018 STEEL TEST PATTERN: 250BG CODE: 023115 ENG. GU

THREE WAY TRANSDUCER MAYNARD HOLIDAY MARY ROSS

5/14/93
5807-43

GAGE	>20KMΩ	OHMS	με
1 - ½ BRIDGE	✓	349	- 178
2 -			
R/B	✓	347	- 18
W/G		351	
3 -			
R/B	✓	349	129
G/W		349	

ATTACHMENT 14

Interdepartmental Letterhead

Mail Station L-346

Ext..: 4-6421

October 18, 1993

Ref. E.T. 5158

TO: Stan Baker

FROM: Linda S. Durbin / Reynold C. Lum

SUBJECT: Compression and Shear of K-Mag Fertilizer

This report is in response to your request to test K-Mag commercial fertilizer in compression and shear. The purpose of this test is to determine it's compressive and shear strength and to compare these values with those obtained by Battelle.

Compression Test

An Instron Model 1127 materials test machine was used to perform the tests. A total of four compression specimens were submitted for test and evaluation. The specimens were tested using a spherical seat to ensure proper alignment and even loading of the specimens. Three extensometers were placed on the specimen, 180 degrees apart, to obtain strain measurements. A gage length of 76.2 mm (3.0 inches) was used. The compressive strengths obtained were 20.7 MPa (3000 psi) for specimen number one and 21.4 MPa (3100 psi) for specimens numbered two, three, and four. These strengths do not meet the average compressive strength of 22.9 MPa (3320 psi) or the lowest strength of 22.2 MPa (3220 psi) obtained by Battelle.

Shear Test

An Instron Model 1127 materials test machine was used to perform the tests. A total of three shear specimens were submitted for test and evaluation. The specimens were tested using a specially machined double shear fixture. A spherical seat was used to ensure proper alignment and even loading of the specimens. The shear strengths obtained were 2.8 MPa (404 psi), 3.2 MPa (463 psi), and 4.5 MPa (649 psi) for specimens one, two, and three respectively. These strengths do not meet the average shear strength of 5.1 MPa (740 psi) obtained by Battelle however, specimen number three exceeds their lowest strength of 4.0 MPa (580 psi).

Included with this report are plots of Stress versus Average Strain for all compression tests performed and plots of Stress versus Crosshead Deflection for all shear tests performed.

Linda S. Durbin

Linda S. Durbin
Materials Test and Evaluation Group
Materials Engineering and Mechanics Section
Engineering Sciences Division

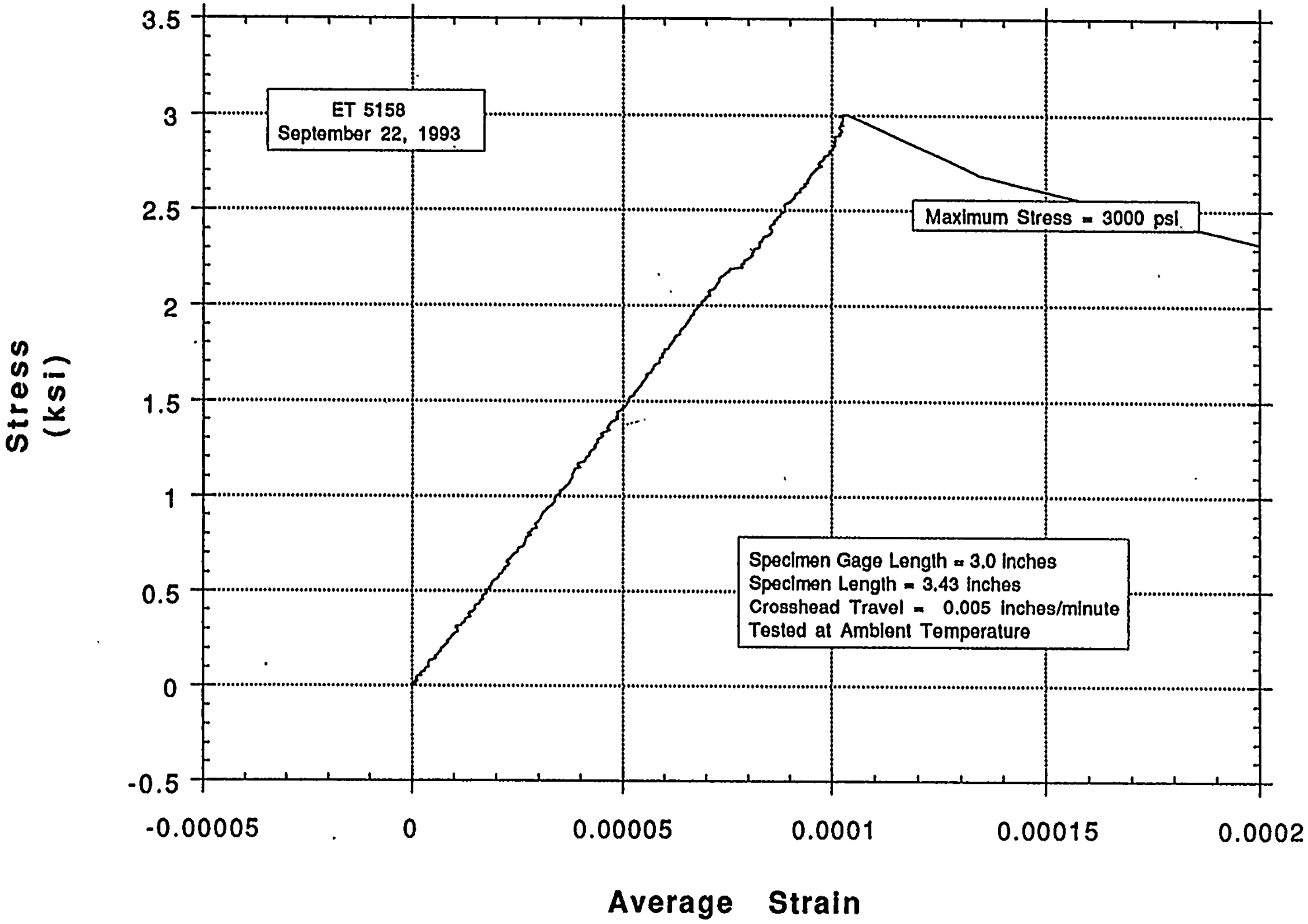
Reynold Lum Jr

Reynold Craig Lum
Materials Test and Evaluation Group
Materials Engineering and Mechanics Section
Engineering Sciences Division

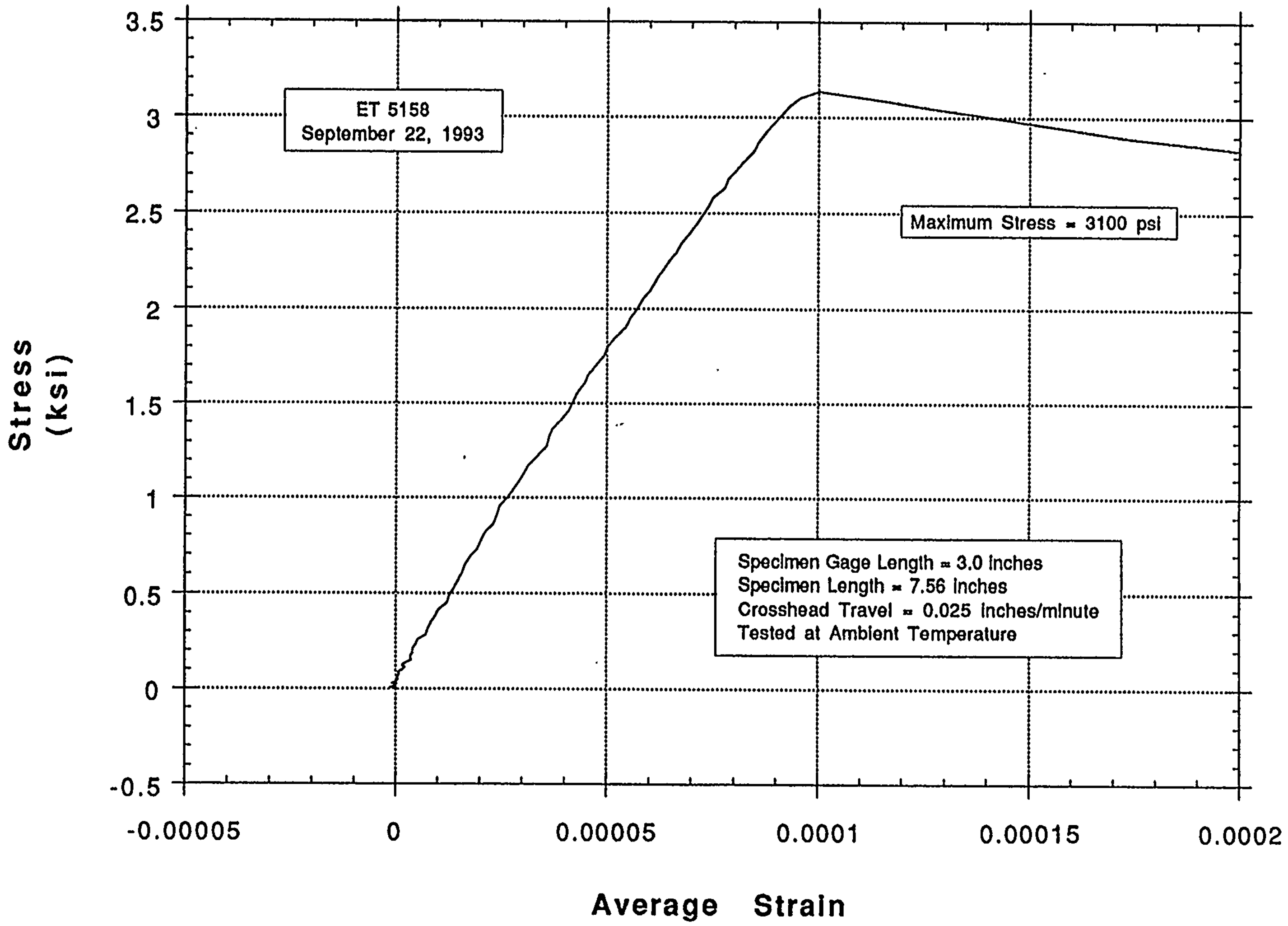
cc:		
	D. Lassila	L-342
	T. Oravetz	L-346
	R. Vandervoort	L-342
	G. Yanes	L-346
	MTE section file	

University of California
Lawrence Livermore
National Laboratory

Compression of K-MAG
Specimen #1



Compression of K-MAG
Specimen #2

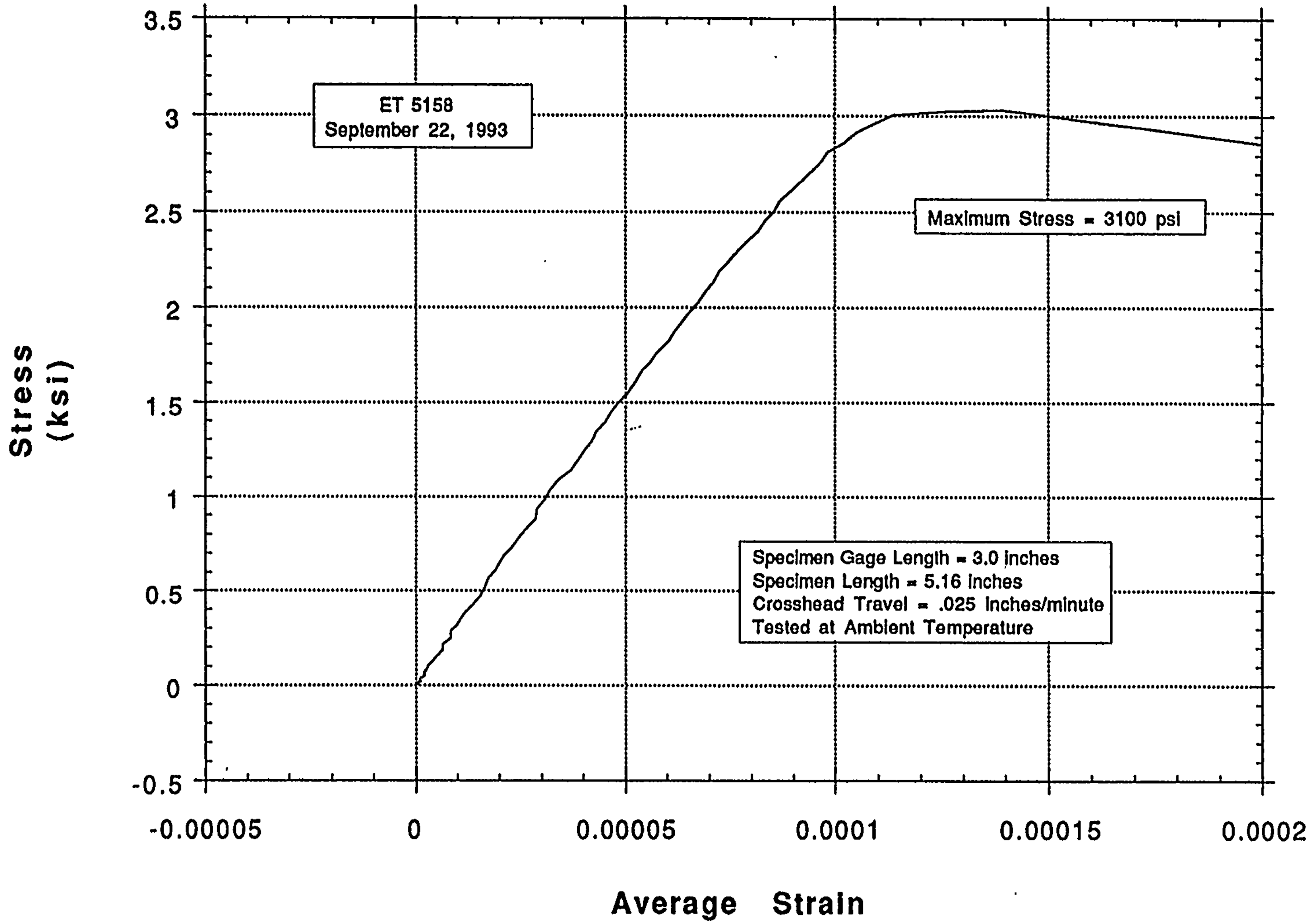


ET 5158
September 22, 1993

Maximum Stress = 3100 psi

Specimen Gage Length = 3.0 Inches
Specimen Length = 7.56 Inches
Crosshead Travel = 0.025 Inches/minute
Tested at Ambient Temperature

Compression of K-MAG
Specimen #3

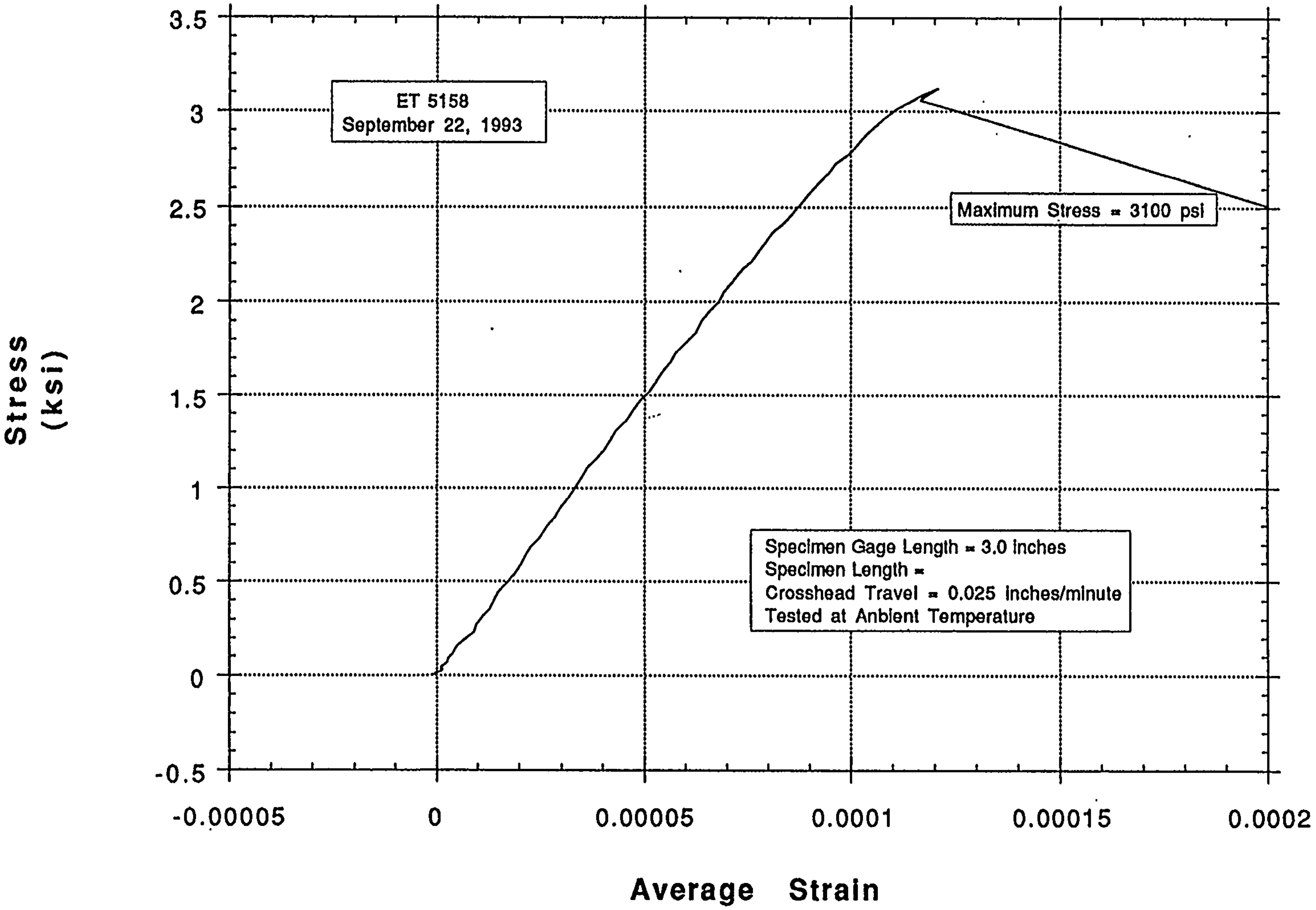


ET 5158
September 22, 1993

Maximum Stress = 3100 psi

Specimen Gage Length = 3.0 inches
Specimen Length = 5.16 inches
Crosshead Travel = .025 inches/minute
Tested at Ambient Temperature

Compression of K-MAG
Specimen #4



ATTACHMENT 15

Interdepartmental Letterhead

Mail Station L-346

Ext..: 4-6421

Ref. E.T. **5158**

October 18, 1993

TO: Stan Baker

FROM: Linda S. Durbin / Reynold C. Lum

SUBJECT: Compression and Shear of K-Mag Fertilizer

This report is in response to your request to test K-Mag commercial fertilizer in compression and shear. The purpose of this test is to determine it's compressive and shear strength and to compare these values with those obtained by Battelle.

Compression Test

An Instron Model 1127 materials test machine was used to perform the tests. A total of four compression specimens were submitted for test and evaluation. The specimens were tested using a spherical seat to ensure proper alignment and even loading of the specimens. Three extensometers were placed on the specimen, 180 degrees apart, to obtain strain measurements. A gage length of 76.2 mm (3.0 inches) was used. The compressive strengths obtained were 20.7 MPa (3000 psi) for specimen number one and 21.4 MPa (3100 psi) for specimens numbered two, three, and four. These strengths do not meet the average compressive strength of 22.9 MPa (3320 psi) or the lowest strength of 22.2 MPa (3220 psi) obtained by Battelle.

Shear Test

An Instron Model 1127 materials test machine was used to perform the tests. A total of three shear specimens were submitted for test and evaluation. The specimens were tested using a specially machined double shear fixture. A spherical seat was used to ensure proper alignment and even loading of the specimens. The shear strengths obtained were 2.8 MPa (404 psi), 3.2 MPa (463 psi), and 4.5 MPa (649 psi) for specimens one, two, and three respectively. These strengths do not meet the average shear strength of 5.1 MPa (740 psi) obtained by Battelle however, specimen number three exceeds their lowest strength of 4.0 MPa (580 psi).

Included with this report are plots of Stress versus Average Strain for all compression tests performed and plots of Stress versus Crosshead Deflection for all shear tests performed.

Linda S. Durbin

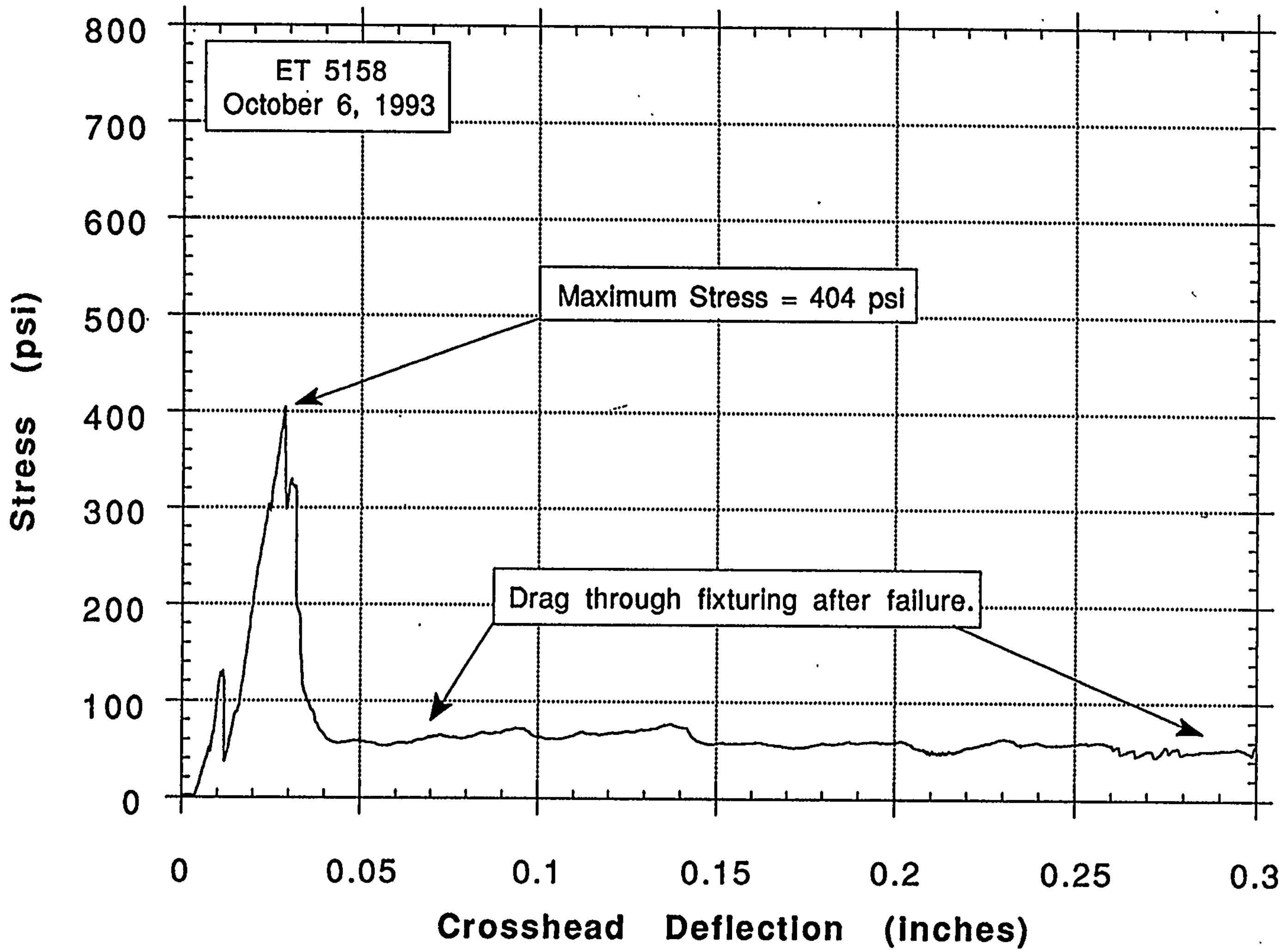
Linda S. Durbin
Materials Test and Evaluation Group
Materials Engineering and Mechanics Section
Engineering Sciences Division

Reynold Lum Jr

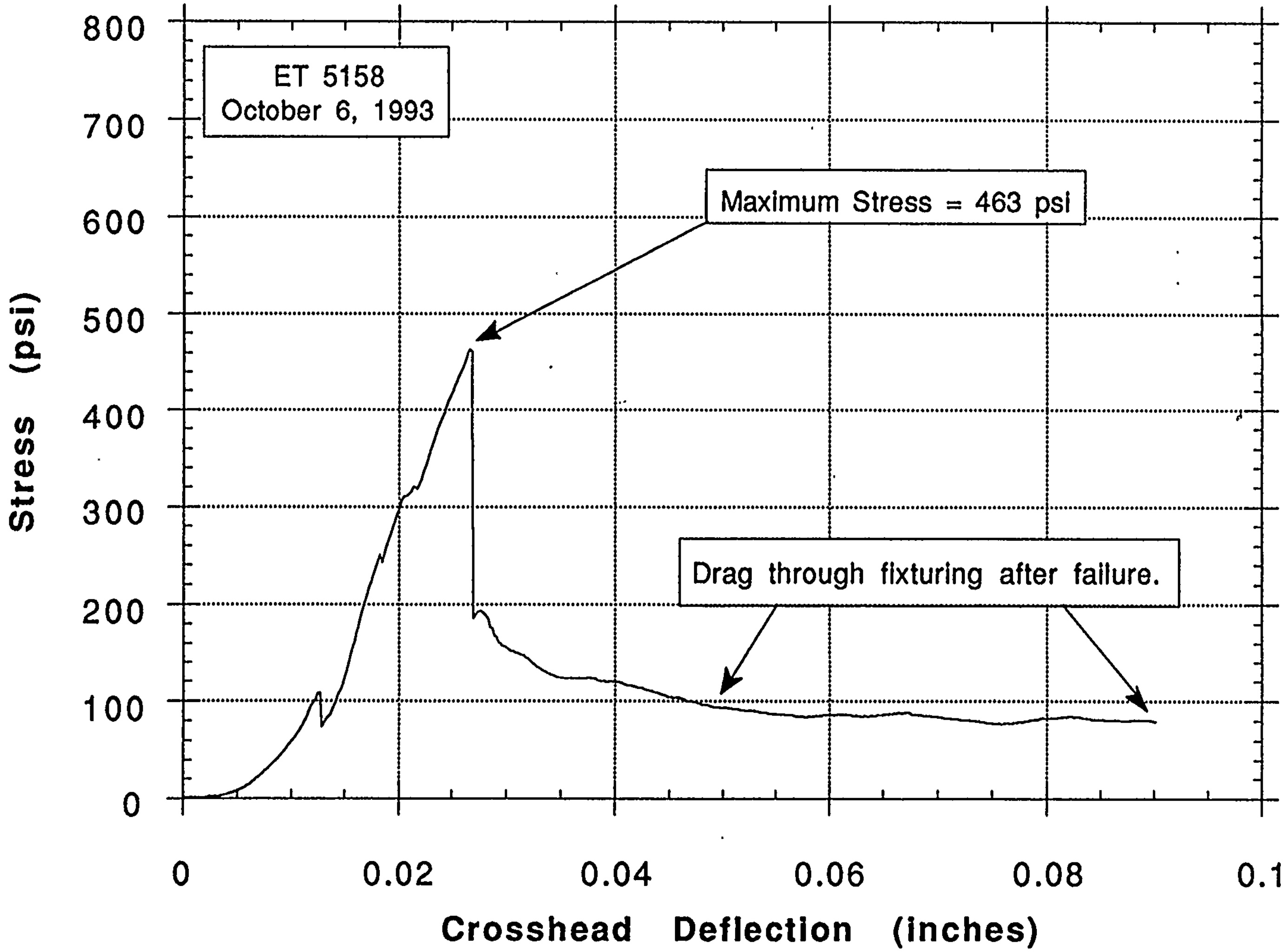
Reynold Craig Lum
Materials Test and Evaluation Group
Materials Engineering and Mechanics Section
Engineering Sciences Division

cc:	D. Lassila	L-342
	T. Oravetz	L-346
	R. Vandervoort	L-342
	G. Yanes	L-346
	MTE section file	

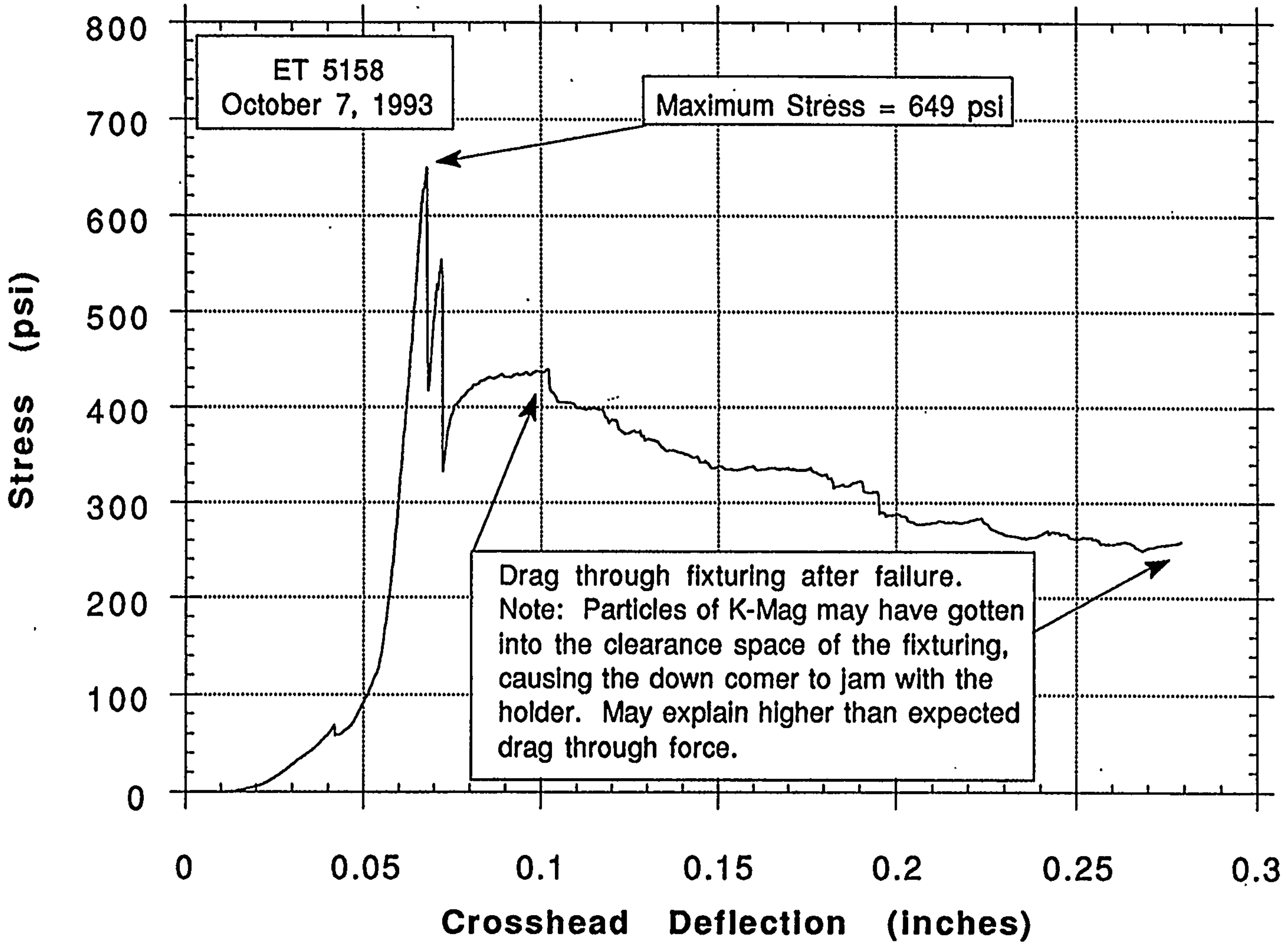
Shear of K-MAG
Specimen # 1



Shear of K-MAG
Specimen # 2



Shear of K-MAG
Specimen # 3



ET 5158
October 7, 1993

Maximum Stress = 649 psi

Drag through fixturing after failure. Note: Particles of K-Mag may have gotten into the clearance space of the fixturing, causing the down comer to jam with the holder. May explain higher than expected drag through force.

ATTACHMENT 16

EST Technical Communication No. 370

HYDRAULIC IMPACT END EFFECTOR
ADVANCED DEVELOPMENT
TEST PROCEDURE

June 1993

Prepared for
LAWRENCE LIVERMORE NATIONAL LABORATORIES
SUBCONTRACT NO. B244759

QUEST INTEGRATED, INC.
21414 - 68th Avenue South
Kent, Washington 98032

1.0 INTRODUCTION

This test procedure addresses the continued development of a Hydraulic Impact End Effector System (HIEE). This system was formerly developed and tested for Lawrence Livermore National Laboratories (LLNL) by QUEST Integrated, Inc., (QUEST) under purchase order No. B199069. Figure 1 illustrates the HIEE. The end effector is designed to dislodge and fragment adherent wastes from the single-shell tanks at the Hanford Reservation near Richland, Washington. The end effector accomplishes this task by discharging small-volume water blasts at high velocity.

2.0 STATEMENT OF WORK

During the previous work, testing indicated that the performance of the HIEE may be improved through minor modifications to the method of operation. The work to be performed, under the current contract #B244759, between QUEST and LLNL is to conduct tests to further investigate possible improvements in the performance of the HIEE. This document states the specific test procedures to be adhered to in this investigation.

The tests, as outlined in this procedure, are for the purpose of investigating the performance improvement of the HIEE. While these tests are a part of the optimization process, it is not expected that the adherent waste removal process will be fully optimized at the conclusion of this work. The tests are expected to identify means to improve the efficiency of the process through modifying the HIEE and its operating procedure.

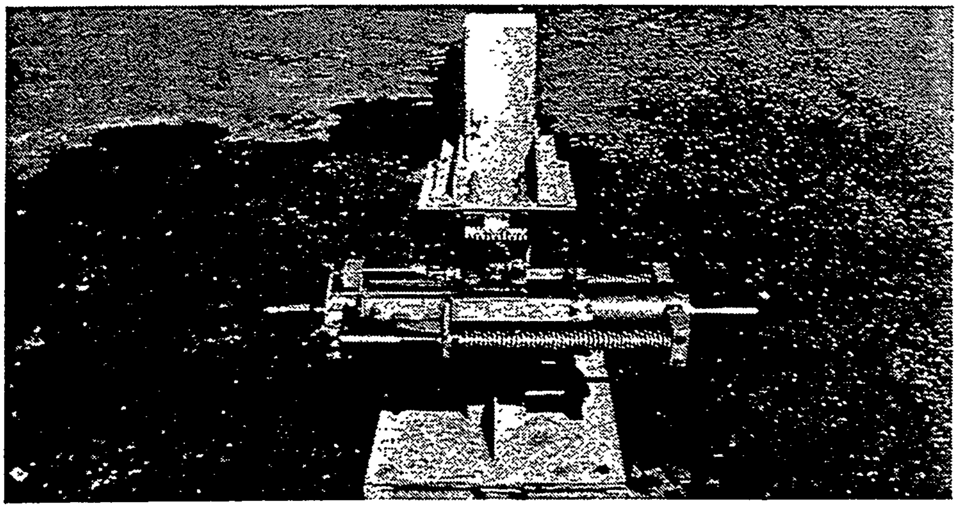


Figure 1. Hydraulic Impact End Effector

3.0 OBJECTIVE

The objective of this test procedure is to conduct waste material fragmentation tests to investigate material process improvement through the test items described in Section 4 , Test Description.

4.0 TEST DESCRIPTION

4.1 Test Items

1. **55,000 psi Charge Pressure Effects:** Greater impact energies can be obtained by increasing the charge pressure of the water discharged by the HIEE. The designed charge pressure for the HIEE is 40,000 psi. In this item, the performance effects of raising the pressure to 55,000 psi will be tested. Tests will also be conducted at 40,000 psi to provide a performance baseline.
2. **Outlet Geometry Effects:** Effector performance may be effected by the geometry of the water slug. The water slug geometry designed for the HIEE is cylindrical. In this item, three different geometries will be tested to determine their effect on process performance.
3. **Fluid Containment Effects:** The HIEE process of building up hydraulic pressure in fissures in material is crucial to material fragmentation. Previously, the HIEE process consisted of surface blasting the material. Process improvement may be obtained by containing the discharged water volume within the material. In this item, the performance effects of discharging the HIEE inside holes drilled in the material will be examined. Tests will be conducted in both an open hole and a hole with the end sealed between the HIEE and the material.
4. **Excavation Pattern Effects:** Fragmentation of material occurs by the propagation of fissure lines to free faces. The previous HIEE process consisted of impacting against a flat surface. Process improvement may be realized by impacting against a surface with multiple free faces around the impact zone. This item will test the performance effects and the feasibility of propagating multiple free-face impact areas. -
5. **Rubble Size Control Technique:** The size of the rubble produced by the HIEE fragmentation process is important to the overall operation efficiency. Rubble must be smaller than 2 inches in diameter to be easily transported away from the test/work site. It is anticipated that proper fragmentation patterns will produce rubble in this size range. This item will test the effect of the fragmentation pattern on the rubble size.

4.2 Test Facilities and Equipment

The tests will be conducted at QUEST Integrated, Inc., (QUEST) located at 21414 68th Avenue South, Kent, Washington. All testing will be performed in the ultrahigh-pressure (UHP) laboratory utilizing equipment at QUEST with the exception of an 8,000 lb. weight scale. Utilization of any non-resident equipment other than the stated exception and/or calibration of any equipment is beyond the scope of this contract and is not to be inferred by this test procedure. Calibration of any specific instrument may be provided by LLNL. QUEST will send any instrument that needs to be calibrated to LLNL for calibration.

Information describing the exact equipment used for each test will be recorded at the time the test is conducted. This information will include item type, manufacturer, and operating range. Tests will be conducted utilizing the following equipment:

1. **Hydraulic Impact Tool**

   To conduct all tests, QUEST will use a hydraulic impact tool, resident at QUEST, that is capable of 55,000 psi charge pressures. This tool is larger than the HIEE developed for LLNL, therefore, volume displacing blanks will be manufactured and installed. These blanks will reduce the charge volume of the impact tool to duplicate that of the HIEE.

2. **UHP Power Unit**

Several UHP power units are available for charging the impact tool. Flow rates and pressures are variable with the maximum ranges of 5 gpm and 55,000 psi respectively.

3. **UHP Gauge**

   A UHP power unit will be monitored by the use of UHP gauges with operating ranges of up to 100,000 psi.

4. **Weight Scale**

   Weights of the dislodged fragmented material and/or test samples will measured on weight scales. QUEST does not own a scale with an 8000 lb. capacity, therefore, a scale will be rented.

4.3 Test Samples

Samples for the end effector discharge tests will consist of a cured salt cake mixture that simulates the salt cake in the Hanford tanks. The formula for this mixture will be obtained from LLNL prior to producing any samples. The samples will consist of a minimum of one (1) 8,000 lb. sample, two (2) 2,000 lb. samples, and twenty (20) 1 cu. ft. samples. The samples will be used for specific tests as outlined in the Test Description section.

4.4 Test Descriptions

Each test will be performed in an area designated for Hydraulic Impact End Effector testing. The area shall have access to a UHP water supply and provide easy access for sample and end effector placement. The area shall provide mounts for the sample and the end effector. The area will be segregated by the use of permanent or temporary wall structures to provide containment of all fragmented sample material. Each test will be visually monitored using video tape recording and photography. All tests will follow a general procedure with additional procedures specific to a given test. The general procedure for each test is as follows:

1. Weigh sample and record weight
2. Determine and mark the location for impact
3. Place sample in test area and position impact tool at the marked impact location
4. Photographically record test area
5. Charge tool to charge pressure and record charge pressure
6. Focus videotape on area and begin recording
7. Discharge end effector
8. Stop video recording
9. Photographically record test area
10. Weigh remaining sample and record weight
11. Gather any fragments of over 2 inches in diameter. Measure and record dimension and weight of fragments.
12. Photographically record fragments

Specific tests for each test item are as follows:

1. **55,000 psi Charge Pressure Tests**

   Charge pressure tests will be conducted to test the effect of raising the impact tool's charge pressure to 55,000 psi. To establish a base line for all tests, tests will first be conducted at the HIEE design pressure of 40,000 psi. This will consist of four impacts at 40,000 psi charge pressure. Each impact will be made on a individual 1 cu. ft. sample. Each impact will be made with a nozzle tip to material standoff distance of 2 inches (previously used in HIEE testing). Following these impacts the 55,000 psi test will conducted. This test will consist of four impacts at 55,000 psi charge pressure. Each impact will be made on an individual 1 cu. ft. sample. Each impact will be made with a nozzle tip to material standoff distance of 2 inches.

2. **Outlet Geometry Tests**

   Three different outlet geometries will be tested to determine the effect of outlet geometry. The designs for the geometries will be provided to LLNL prior to the performance of any test. Each geometry will be tested by four impacts. Each impact will be made on an individual 1 cu. ft. sample. The impacts will be made with a nozzle to material standoff distance of 2 inches and a charge pressure of 40,000 psi.

3. **Fluid Containment Test**

   Fluid containment tests will be conducted to determine the effect of containing the discharge fluid within the material. Two fluid containment concepts will be tested. The first concept will be a blind unsealed hole. This will consist of drilling a hole to the depth of the nozzle length (1 ft.). The nozzle tip will be located at the bottom of this hole and the impact tool discharged at 40,000 psi. The second concept will test a blind sealed hole. A seal for sealing the outer diameter of the nozzle to the hole wall will be designed and manufactured. Testing will then consist of drilling a hole as previously stated, placing the impact tool nozzle and seal in the hole, and discharging the tool at 40,000 psi. Each concept will be tested by four impacts. The impacts will be made in a 2000 lb. sample.

4. **Excavation Pattern Test**

   Tests will be performed to evaluate the effects of impacting an area that has multiple free faces within close proximity. A successive impact pattern will be designed with a view to propagating multiple free face areas. The pattern will be provided to LLNL prior to the performance of the test. The test of this pattern will consist of a minimum of twelve impacts at a charge pressure of 40,000 psi and a standoff distance of 2 inches. The test will be conducted on the 8,000 lb. sample. For this test, sample weights will not be recorded after each impact but before and after completing the pattern to obtain the summation effect of the multiple impacts.

5. **Ruble Size Control Test**

   A test will be performed to evaluate the effect of fragmentation pattern on ruble size. A successive impact pattern will be designed with a view to minimizing ruble size. The pattern will be provided to LLNL prior to the performance of the test. The test will consist of a minimum of twelve impacts based on this pattern. Impacts will be made at a charge pressure of 40,000 psi and a standoff distance of 2 inches. The test will be conducted on a 2,000 lb. sample.

4.6 Test Performance Schedule

Each test will consist of a minimum number of hydraulic impacts. This number may be increased if deemed necessary during any particular test. Wherever possible, tests will be performed concurrently to minimize test setup and operation time. The minimum number of discharge impacts for each test and a sequence of events is as follows. The same sequence number indicates concurrent performance.

Test Item	No. of Impacts	Performance Sequence
1	8	1
2	12	1
3	8	2
4	12	3
5	12	3

4.7 Data

The data of interest for each test will be recorded on a preprinted data sheet, a video tape, and photographed. A sample data sheet is shown in Figure 2. Each data sheet will include time, date, and name of test technician performing the test. Data to be recorded includes:

1. Weight of sample prior to test
2. Weight of sample following the test
3. Size and weight of fragments over 2 inches in diameter
4. Charge pressure
5. Comments on problems encountered and/or suggestions for improvements in end effector design or operating procedure
6. Video tape recording of each discharge impact
9. Photographs of test area before and after tests

5.0 SAFETY

All testing shall be conducted in a manner to ensure the safety of operating personnel and test observers. The test area will be segregated and posted with signs warning that impact tool testing is being conducted.

6.0 QUALITY ASSURANCE

The quality of the testing conducted will be assured by strict adherence to this test procedure. All testing will be supervised by the project engineer or project manager for compliance with this document.

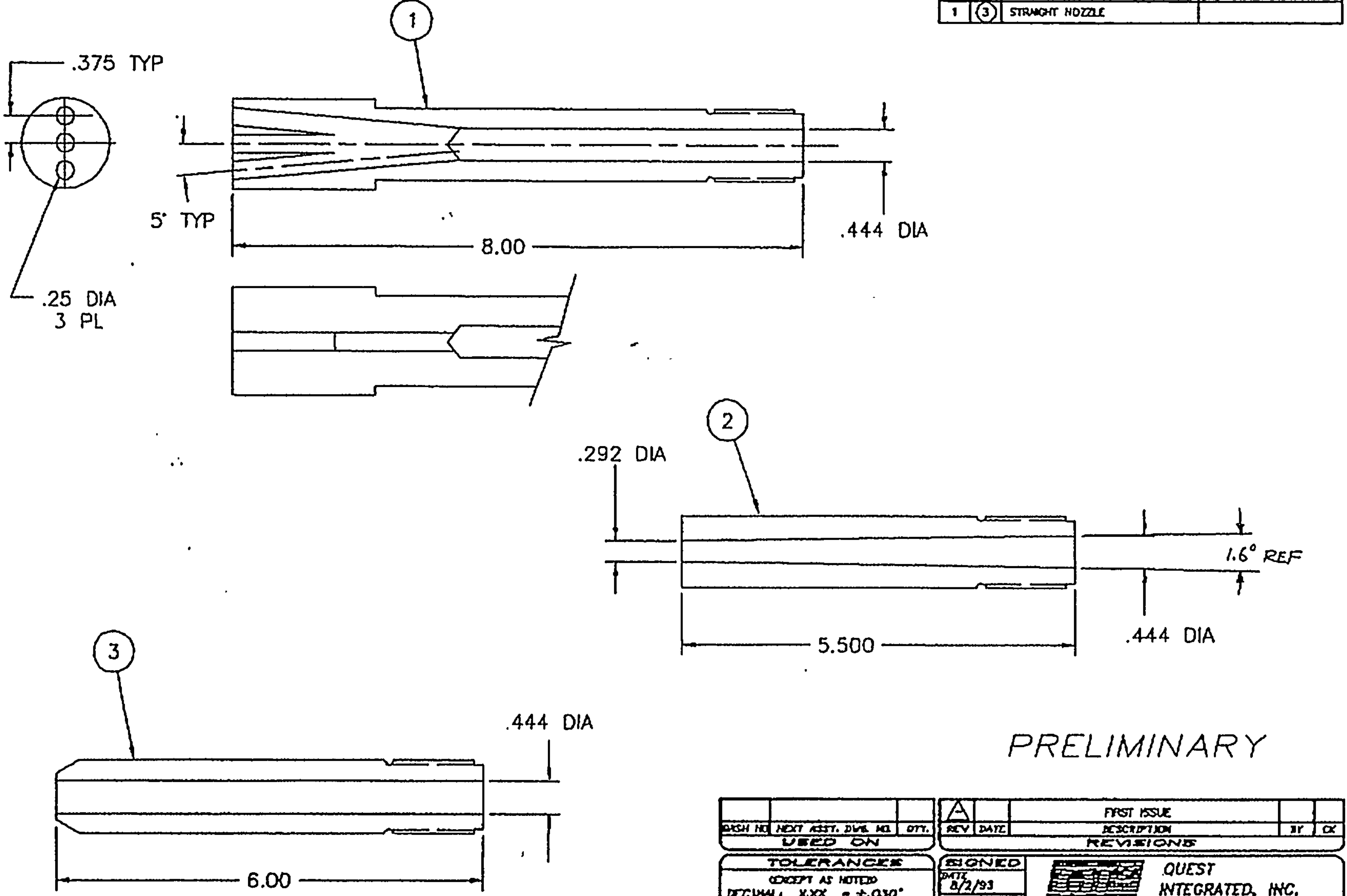
7.0 TEST RESULTS

Upon completion of all testing, a report will be issued to LLNL within 30 days. The report will contain as the following information:

1. A description of each test, including an explanation of performance method and data recorded
2. Drawings and/or sketches of test unit and test area
3. A list of instruments, type of equipment, and operating range
4. Photographs of test area and results following each discharge test
5. Copy of test procedure
6. Copies of data sheets
7. Data summary
8. A copy of the video tape recorded during all tests

ATTACHMENT 17

QTY	ITEM	DESCRIPTION	SPECIFICATION
PARTS LIST			
1	①	DIVERGENT NOZZLE	
1	②	CONVERGENT NOZZLE	
1	③	STRAIGHT NOZZLE	



PRELIMINARY

DASH NO.	NEXT ASST. DWG. NO.	QTY.

USED ON

REV	DATE	DESCRIPTION	BY	CK
A		FIRST ISSUE		

REVISIONS

TOLERANCES
EXCEPT AS NOTED
DECIMAL X.XX = ±.030"
X.XXX = ±.010"
FRACTION X/X = ±1/16"
ANGLE X° = ±2°
ALL MACHINED SURFACES 125√
ALL DIMENSIONS ARE INCHES
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ⌀.
BREAK ALL SHARP EDGES.

SIGNED
DATE 8/2/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE
3 NOZZLES
EFFECT

SCALE 1:2
DRAWING NUMBER A66985 REV— SH

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MAKE QTY.	CHARGE NO.	ENGR EXT.
DATE REC'D.	QUALITY PLAN NO.	EST. HOURS
MACHINIST		ACTUAL HOURS

SHOP INSTRUCTIONS

ATTACHMENT 18

HYDRAULIC END EFFECTOR

Performed by: Holden/Miles

IMPACT TESTS IN SIMULATED SALT CAKE

Date: 8/11/93

Type of test: Baseline 40 KSI; 2" standoff; long nozzle

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
1	136	X	X	X	2	40k	X	X	X	136	*(1)	neg.	neg.	neg.	n/a
2	135-3/4	X	X	X	2	40k	X	X	X	135-3/4	*(2)	neg.	neg.	neg.	n/a
3	135-1/4	X	X	X	2	40k	X	X	X	128-1/4	9	5-1/4	1-3/4	7	X
4	131-1/4	X	X	X	2	40k	X	X	X	131-1/4	*(3)	neg.	neg.	neg.	n/a

COMMENTS:

*(1) No substantial fragments. Crater at impact site 1.5 x 4 x 1-1/2" deep.

*(2) No substantial fragments. Crater at impact site 1-3/8 x 1-1/2 x 3/8" deep.

*(3) No substantial fragments. Crater at impact site 1-1/2 x 1-3/4 x 3/8" deep.

HYDRAULIC END EFFECTOR

Performed by: Holden/Miles

IMPACT TESTS IN SIMULATED SALT CAKE

Date: 8/12/93

Type of test: 55 KSI; 2" standoff; long nozzle

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
5	134-3/4	X	X	X	2	53k	X	X	X	134-3/4	*(1)	neg.	neg.	neg.	n/a
6	135-1/4	X	X	X	2	54k	X	X	X	135-1/4	*(2)	neg.	neg.	neg.	n/a
7	130	X	X	X	2	54k	X	X	X	112-3/4	9-1/4 *(3)	16-1/4	1	17-1/4	X
8	126-1/4	X	X *(4)	X	2	55k	X	X	X	119	6-7/8 *(5)	6-3/4	7-1/4	neg.	X
9	124	X	X *(6)	X	2	55k	X	X	X	124	*(7)	neg.	neg.	neg.	n/a

COMMENTS:

*(1) No substantial fragments. Crater 1-1/2 x 2 x 3/4" deep. Spalled area 2-1/2 across.

*(2) No substantial fragments. Crater 1-5/8 x 2-3/4 x 1-1/8" deep.

*(3) Crater 1-1/2 x 2 x 4" deep from original surface.

*(4) Tool position was moved about 3" after dripping water made hole in block during a delay.

*(5) Crater 1-1/2 x 2-3/4 x 2-7/8" deep from original surface.

*(6) Positioned adjacent to vertical saw-cut edge 2-1/4" deep.

*(7) No substantial fragments. Crater 1-1/2" dia x 1" deep.

HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by: Holden/Miles

Date: 8/25/93

Type of test: 55 KSI; 2" standoff; diverging nozzle

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
10	135-3/4	X	X	X	2	54k	X	X	X	72-3/4 *(1)	12" side	59-1/4	3-3/4	63	X
11	137-3/4	X	X	X	2	55k	X	X	X	48 *(2,3)	12" side	86	3-3/4	89-3/4	X
12	128-3/4	X	X	X	2	54k	X	X	X	128 *(4)	3-1/8	n/a	3/4	3/4	X
13	135-1/2	X	X	X	2	53k	X	X	X	135-1/2 *(5)	n/a	n/a	neg.	neg.	n/a

COMMENTS:

*(1) Crater 1-1/2 x 2 x 3-3/4 deep when large frags reassembled. Spalled area 7" across.

*(2) "Sample weight" is of largest fragment.

*(3) Crater 1/2 x 2 x 5-1/2" deep from original surface. Spalled area 8" across.

*(4) No substantial fragments. Crater 1-1/2 dia x 1-3/4" deep. Spalled area 6" across.

*(5) No substantial fragments. Crater 1-1/4 x 2 x 1-3/4" deep. Spalled area 5" across.

HYDRAULIC END EFFECTOR

Performed by: Holden/Miles

IMPACT TESTS IN SIMULATED SALT CAKE

Date: 8/26/93

Type of test: 55 KSI; 2" standoff; 3-hole nozzle

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
14	125-1/4	X	X	X	2	55k	X	X	X	70 *(1,2)	12" side	52-1/2	2-3/4	55-1/4	X
15	129-1/4	X	X	X	2	55k	X	X	X	129 *(3)	n/a	n/a	1/4	1/4	X
16	128-1/4	X	X	X	2	55k	X	X	X	128-1/2 *(4)	neg.	n/a	neg.	neg.	n/a
17	127-1/4	X	X	X	2	55k	X	X	X	70-1/4 *(5,6)	12" side	55-1/2	1-1/2	57	X

COMMENTS:

*(1) Sample split nearly in half. "Sample weight" is of largest piece.

*(2) Crater 3/8 x 1-3/4 x 4" deep. Spalled area 4" across.

*(3) No substantial fragments. Crater 1-1/2 x 2-1/4 x 3-1/4" deep from original surface. Spalled area 7" across.

*(4) No substantial fragments. Crater 3/4 x 2 x 2-3/4" deep from original surface. Spalled area 3-1/2" across.

*(5) Sample split nearly in half. "Sample weight" is of largest piece.

*(6) Crater 1 x 2-1/2 x 2-1/2" deep. Spalled area 3-1/2 - 5" across.

HYDRAULIC END EFFECTOR

Performed by: Holden/Miles

IMPACT TESTS IN SIMULATED SALT CAKE

Date: 8/27/93

Type of test: 55 KSI; 2" standoff; converging nozzle

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
18	131-1/4	X	X	X	2	55k	X	X	X	70-3/4 *(1)	10	56-1/2	4	60-1/2	X
19	126-1/2	X	X	X	2	55k	X	X	X	61-1/4 *(2)	9	61-3/4	3-1/2	64-1/4	X
20	131-1/4	X	X	X	2	55k	X	X	X	130-3/4 *(3)	neg.	neg.	1/2	1/2	n/a
21	135-3/4	X	X	X	2	56k	X	X	X	107-1/4 *(4)	12 side	27-1/4	27-1/4	28-1/2	X

COMMENTS:

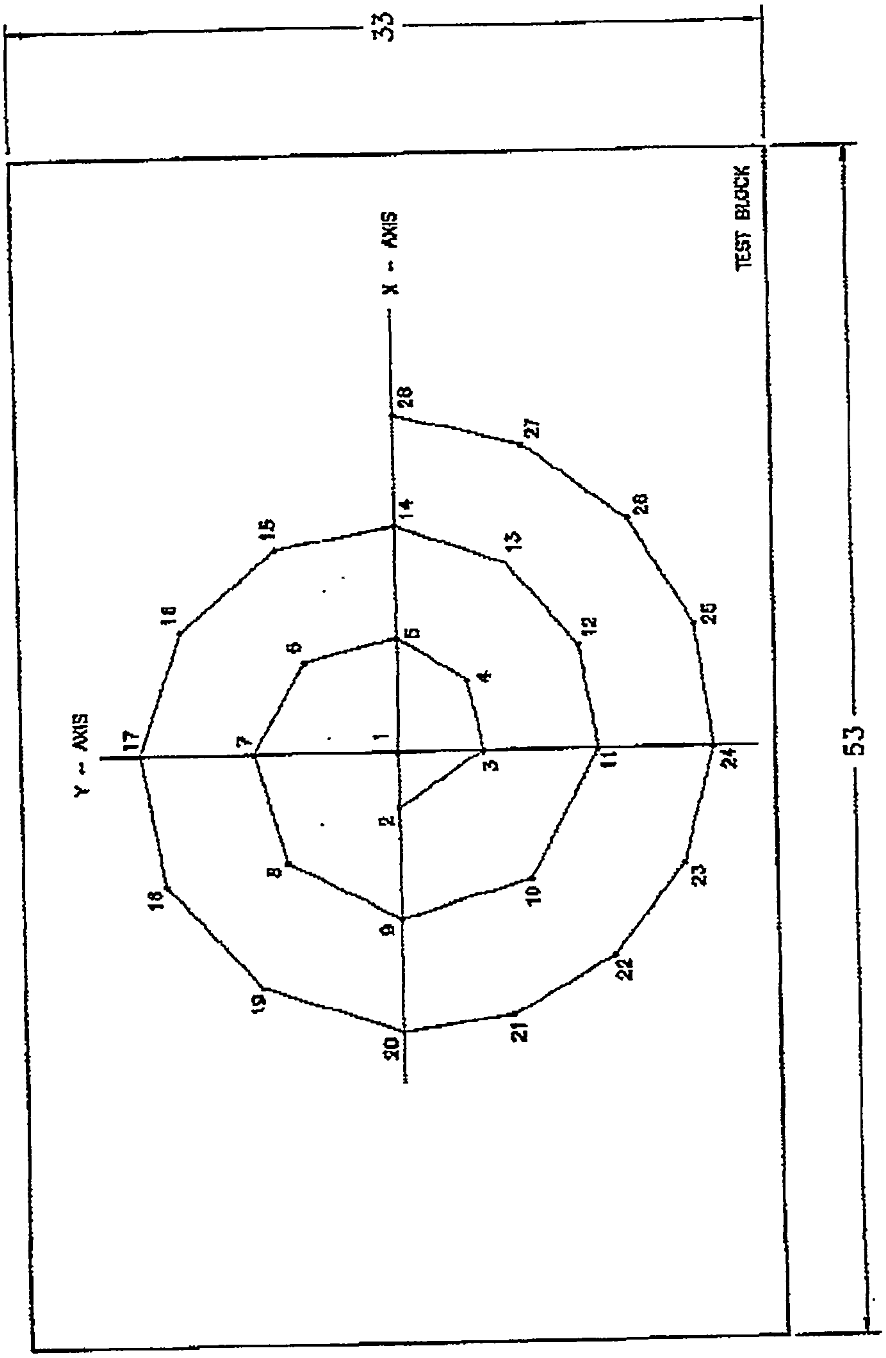
*(1) Crater 1-5/8 dia x 4-1/2" deep from original surface. Spalled area 8-10" across.

*(2) Crater 1-1/2 x 2 x 3-3/4" deep from original surface. Spalled area 7-9" across.

*(3) No substantial fragments. Crater 3/4 x 1 x 2-3/4" deep. Spalled area 3-4" across.

*(4) Crater 1-3/4 dia x 2" deep from original surface. Spalled area "6" across.

ATTACHMENT 19



SIGNED
DATE 8-21-93
DRAWN BY HILES
ENGINEER
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE
TEST PATTERN
EFFECT SK3006

SCALE 1:8
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ATTACHMENT 20

QUEST Technical Report No. 601

HYDRAULIC IMPACT END EFFECTOR ADVANCED DEVELOPMENT

Final Report

R. C. Lilley, R. L. C. Holden, and P. J. Miles

November 1993

Prepared for
LAWRENCE LIVERMORE NATIONAL LABORATORIES
Under Contract No. B244759

Limited Distribution

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QUEST INTEGRATED, INC.
21414 - 68th Avenue South
Kent, Washington 98032
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EXECUTIVE SUMMARY

One of the tools being developed for dislodging and fragmenting the hard salt cake waste in the single-shell nuclear waste tanks at the Hanford Reservation near Richland, Washington, is the hydraulic impact end effector (HIEE). This tool operates by discharging 11 cubic inches of water at ultrahigh pressures to fragment and dislodge nuclear waste material. The HIEE was previously designed, built, and initially tested for Lawrence Livermore National Laboratories. This program is the advanced development of the HIEE to further investigate its waste material fragmentation abilities and to determine more-effective waste material removal operation procedures. The results of the advanced development tests for the HIEE have shown that increased fragmentation of the waste material can be achieved by increasing the charge pressures of 40,000 psi to 55,000 psi and through implementing different operating procedures.

It is believed that two of the major factors involved in material fragmentation are the size of the material and the impact energy of the water slug fired from the HIEE. The material's ability to fracture appears to be also dependent on the distance a fracture or crack line has to travel to a free surface. Thus, larger material is more difficult to fracture than smaller material. Discharge pressures of 40,000 psi resulted in little penetration or fracturing of the material. When the discharge pressures were increased to 55,000 psi, however, the size and depth of the fractures increased. The use of different HIEE nozzle geometries resulted in greater material fragmentation, thus indicating that nozzle geometry has a significant effect on material fragmentation. When the HIEE material fragmentation operating method was changed from surface shots to discharging the HIEE into predrilled holes, the material fragmentation increased an order of magnitude. Since surface shots tend to create craters, a multi-shot operation procedure, along with an advance nozzle design, was used to drill (crater) deep holes into large-sized material. This procedure successfully resulted in rubblizing a 600-pound block into smaller-sized pieces of material without the use of any additional equipment.

As a result of this advanced development program, the HIEE has demonstrated that it can quickly fragmentate salt cake material into small-sized, easily removable fragments. The HIEE has also demonstrated that its material fragmentation ability can be substantially increased through the use of different nozzle geometries and operation procedures.

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1. INTRODUCTION

This report summarizes the results of the hydraulic impact end effector (HIEE) advanced development program, contract number B244759, conducted for Lawrence Livermore National Laboratories (LLNL). This program is part of the continuing development of the HIEE that was built and tested for LLNL under contract number B199069. This work was conducted from May 14 to October 20, 1993 at the facilities of QUEST Integrated, Inc., in Kent, Washington.

The HIEE is being developed as one option to dislodge and fragment hard salt cake wastes in the single-shell nuclear waste tanks at the Hanford Reservation near Richland, Washington. The HIEE operates by discharging a small volume of water (11 cubic inches) at very high velocities (up to Mach 4). These high-energy discharges are used to fracture the waste material in Hanford's nuclear waste tanks. The hydraulic impact tool used in this program is shown in Figure 1. Figure 2 shows a schematic HIEE system used during the tests described in this report.

In the prior program it was determined that:

- Higher charge pressures increased the salt cake fracture capability of the HIEE.
- A standoff distance (the distance between the nozzle tip and material surface) between 0 and 12 inches did not affect tool performance.
- Repeated shots at the same target tended to drill a hole into the sample, and insertion of the tool's nozzle into a target hole may increase the material's fracture ability.
- Splitting the outlet flow may increase the spalling of the material around the impact area.

As a result, the primary emphasis in this contract was to further investigate:

- The effect of charge pressures on the ability of the HIEE to fracture salt cake.
- The effect of various nozzle geometries on the HIEE's ability to fracture salt cake.
- The effect of discharging the HIEE into predrilled sealed and unsealed holes on the tool's ability to fracture salt cake.
- The excavation capability of the HIEE when fired in a predetermined pattern.
- The ability of the HIEE to rubblize large-sized salt cake fragments into small-sized fragments.

The key accomplishments gained during this program determined:

1. Higher charge pressures increase the HIEE's ability to fracture salt cake.
2. Nozzle geometry has a significant affect on material fragmentation.
3. Large volumes of waste can be easily fractured by inserting the HIEE into predrilled holes.
4. Material excavation is more effective when the HIEE is discharged into shallow predrilled holes.
5. Large-sized fragments can be easily converted to small-sized rubble through repeated surface shots.

It is believed that two of the major factors involved in material fragmentation are the size of the material and the impact energy of the water slug fired from the HIEE. The material's ability to fracture appears to be dependent on the distance a fracture or crack line has to travel to a free surface. Thus, larger material is more difficult to fracture than smaller material. A discharge of the HIEE at 40,000 psi onto the surface resulted in little penetration or fracturing. This is due to the water slug being diverted away from the impact area by the sheer mass of the simulant. When the discharge pressure was increased to 55,000 psi, however, the size and depth of the crater increased, along with the size of the fragments.

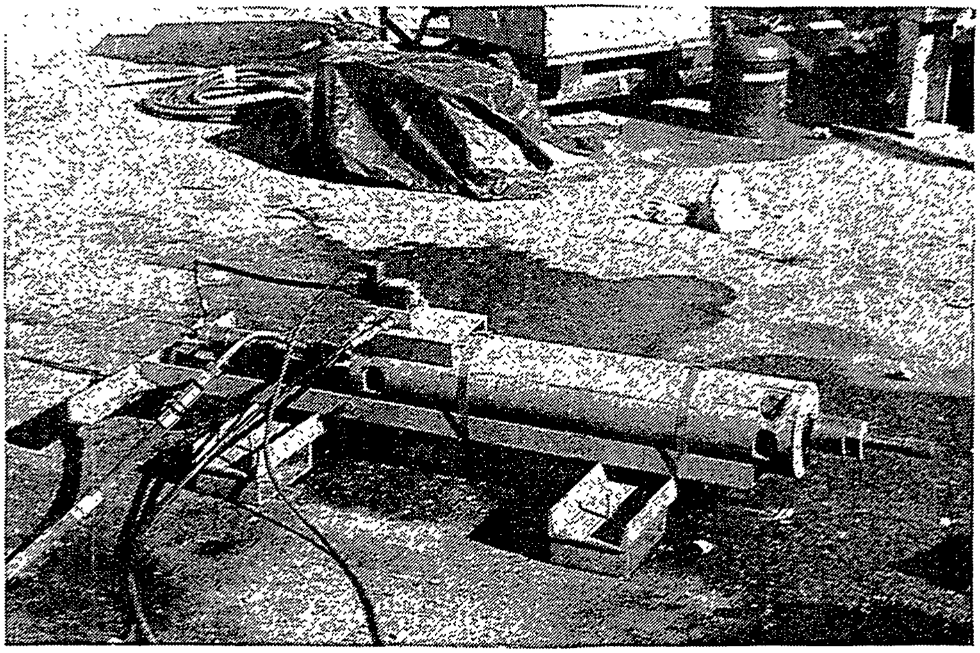


Figure 1. Hydraulic Impact Tool

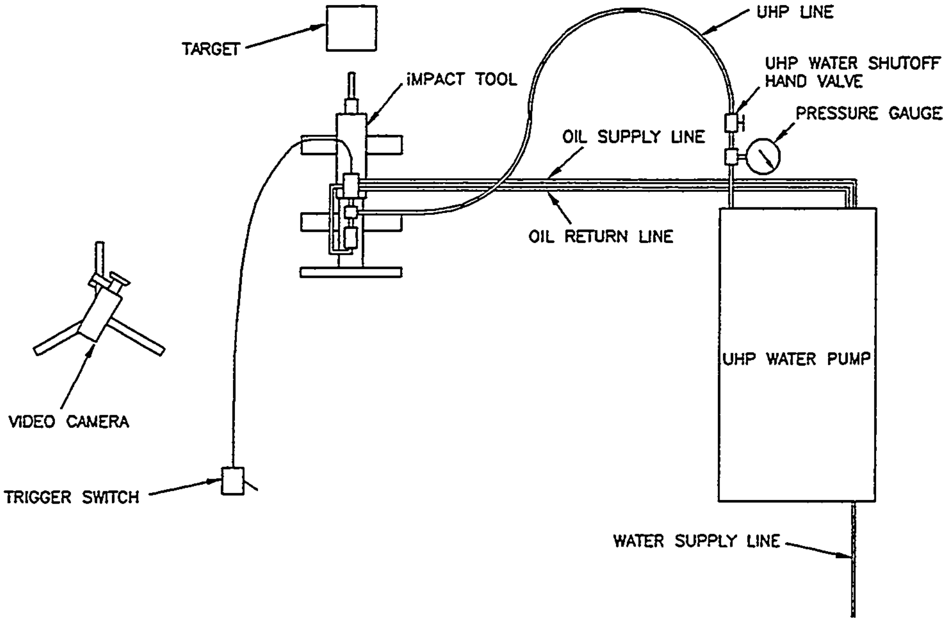


Figure 2. HIEE Configuration Schematic

Nozzle geometry was shown to have a significant effect on the HIEE's ability to fracture salt cake. Three different nozzle geometries were tested: one to concentrate the size of the water slug to a smaller area for deeper fragmentation, another to increase its impact area for greater spalling, and a third to develop a "chisel" effect to create a fracture line that will cleave the material. Each of these nozzles showed increased fracture capability with the HIEE.

Discharging the HIEE into a predrilled hole constrains the water flow in the hole to create significant shear stresses. It is believed these stresses will generate deep fracture lines. Two different methods were used to constrain the water within a hole. One method involved sealing the nozzle inside the hole with a nylon seal, and in the other, the nozzle was inserted into a hole that was slightly larger than it in diameter. Results have shown that very deep fracture lines were created, and very large-sized salt cake simulant samples were quite easily fragmented.

Surface shots tend to create craters rather than fracture the material. Therefore, a multi-shot spiral pattern was used to merge the fracture lines between consecutive shots. This is believed to result in higher material removal rates. Two different tests were used to evaluate this method. The first one consisted of only surface shots and the other of firing into shallow, predrilled holes. The surface shot method yielded no advantage to material excavation. This is probably due to the shot-to-shot distance being too far apart. However, firing into the predrilled holes resulted in significant removal of small-sized fragments, with fracture lines propagating from shot to shot.

Using the advantages of the results of the previous tests with regard to nozzle geometry, surface shot cratering, and water containment, large-sized fragments were easily rubblized. Since surface shots tend to create craters, multiple shots into the same area were used to create deep holes. Continued shots into these holes created greater internal stresses and deeper fracture lines. The in-line, three-hole nozzle was used to enhance a primary fracture plane. A 20-inch-thick sample was split in half with as little as two shots. The results of this method have shown that large-sized material can quickly and easily be rubblized into small-sized fragments.

As a result of this development effort, the effectiveness of the HIEE can be greatly enhanced. QUEST recommends that continued development be pursued to determine the most efficient salt cake removal method for the single-shell storage tank application.

Development should include:

1. Further investigation of the effects of nozzle geometry.
2. Further investigation into multi-shot hole development and predrilled holes for large-scale material fragmentation.
3. A fragmentation ability investigation of the simulant while constraining its free surfaces.
4. Further investigation into excavation patterns and methods.

The subsequent sections of this report present detailed descriptions of the approach and results of this investigative program.

2. OBJECTIVES

The specific objectives of the program were to:

1. Investigate the effect of charge pressure on the HIEE's ability to fracture the salt cake material.
2. Investigate the effect of nozzle geometry on the HIEE's ability to fracture the material.
3. Investigate the effect on material fragmentation when firing the HIEE within sealed and unsealed holes.
4. Investigate the effect of multi-shot excavation patterns to increase material removal rates.
5. Investigate a material rubblization operation procedure.

3. TEST DESCRIPTION

3.1 Test Plan

Five different test procedures were used to evaluate these objectives:

1. **55,000 psi Charge Pressure Effects:** A series of tests were conducted to evaluate the effect of water pressure on removal rates and particle sizes. Pressures of 40,000 psi and 55,000 psi were used.
2. **Outlet Geometry Effects:** This test evaluated the fragmentation performance by altering the geometry of the water pulse coming out of the HIEE. Three different nozzle designs were developed to vary the characteristics and energies of the pulse. These designs consisted of diverging, converging, and an in-line, three-hole, "chisel-shaped" geometries.
3. **Fluid Containment Effects:** This test examined the effectiveness of containing the hydraulic pressure in small volumes, such as in cracks or holes. Specifically, holes were drilled in the salt cake simulant and the HIEE was discharged into them, both with and without seals.
4. **Excavation Pattern Effects:** This test evaluated the material removal rate by the interaction of successive shots in a pattern. The objective is to develop internal cracks in the adherent waste that will propagate between shots to greatly enhance the amount of material that will be removed. Tests were conducted to evaluate the effect of excavation patterns.
5. **Rubblization Destruction Tests:** This test evaluated the ability of the HIEE to take large-sized rubble and fracture it into smaller-sized fragments that are more compatible with anticipated conveyance methods.

3.2 Test Facilities

The tests were conducted at the facilities at QUEST. All testing was performed in the ultrahigh-pressure (UHP) laboratory utilizing equipment resident at QUEST.

3.3 Test Equipment

The following equipment were utilized in conducting these tests:

1. Hydraulic Impact Tool. The tests were conducted utilizing QUEST's Hydraulic Impact Tool that is capable of 55,000-psi charge pressures. A volume displacement blank was manufactured and installed to reduce the charge volume of this tool to match the HIEE previously delivered to LLNL.

2. UHP Power Unit. Two different UHP power units were used (depending on availability) for charging the impact tool. The flow rates and pressures are variable, with a maximum range of 5 gpm and 55,000 psi respectively.
3. UHP Gauge. The UHP power unit was monitored by using UHP gauges with operating ranges of up to 80,000 psi. The gauge was calibrated by a dead-weight tester.
4. Weight Scale. The weights of the tests samples and material fragments were measured on QUEST's weight scales and on a 4,000-pound scale that was rented from an outside source.
5. Cameras. A 35-mm camera and video recorder were used to record the results of the tests.
6. Hand Drill. An electric hand drill using a 1-inch-diameter twist drill bit and a 1-3/4-inch rock drill bit was used for predrilling holes into the tests samples.

3.4 Tests Samples

The samples used for the end effector discharge tests consisted of a cured salt cake mixture that simulates the salt cake in the Hanford tanks. The formula for this mixture consisted of fine-grained sulfur potassium magnesium (k-mag) fertilizer that was prepared in a small concrete mixer with a ratio 50 pounds of fertilizer to one gallon of water. The samples were cast in plastic-lined boxes and cured for a minimum of one week before being used in testing. This recipe was furnished by Mr. Monte Elmore of Pacific Northwest Laboratories as a representative test simulant for hard salt cake waste. The fine-grained sulfur k-mag fertilizer was purchased from Western Agricultural Chemical of Houston, Texas, and is described as "feed" grade. The particles are of a crushed angular shape with an approximate size of 1/16 inch in diameter.

The samples consisted of one 8,000-pound sample, two 3,000-pound (approximately a cubic yard in size) samples, and twenty 1-cubic-foot (approximately 135 pounds) samples.

3.5 Test Description

Each test was performed in an area designated for the hydraulic impact end effector testing. The area had a UHP water supply and easy access for sample and end effector placement. Each test was monitored visually using a video camera and a 35-mm camera. (A videotape of the test results is included.) The general procedure for each test is as follows:

1. Weigh sample and record its weight.
2. Determine and mark the test location for impact.
3. Place the sample in the test area and position the impact tool at the marked location.
4. Photograph the area prior to each shot.
5. Charge the tool and record the charge pressure.
6. Begin recording with the video camera.
7. Discharge the impact tool.
8. Stop the video camera from recording.
9. Photograph the test area.
10. Weigh the remaining sample and record its weight.
11. Gather all the fragments and record their weights and sizes.
12. Photograph the fragments.

The specific tests for each test item follow.

3.5.1 Charge Pressure Tests

The charge pressure tests were conducted to test the effect of raising the impact tool's charge pressure to 55,000 psi. To establish a baseline for all the tests, four trials were first conducted at the HIEE design pressure of 40,000 psi. Each impact was made on an individual 1-cubic-foot sample with a standoff distance of 2 inches. Following these impacts, an identical set of four trials was conducted at 55,000 psi. The impact tool's orientation was vertical and firing downward in both cases.

3.5.2 Outlet Geometry Tests

Three different outlet geometries were designed and tested to determine the effect of the nozzle outlet geometry. The geometries are explained in detail in Section 4.2. Each nozzle was tested with four impacts, each on a single 1-cubic-foot sample. The impacts were made with a nozzle-to-material standoff distance of 2 inches and a charge pressure of 55,000 psi. The impact tool was firing downward and the orientation was vertical.

3.5.3 Fluid Containment Test

The fluid containment tests were conducted to determine the effects of containing the discharge fluid within the material. Two fluid containment concepts were tested. The first series evaluated the use of blind, unsealed holes drilled to depths of 10, 6, and 3 inches. The nozzle tip was located at the bottom of each hole and the impact tool's discharge pressure was 55,000 psi. The second test series evaluated blind, sealed holes. The seal between the outer diameter of the nozzle and the hole wall is discussed in Section 4.1. A series of 1-3/4-inch-diameter holes drilled to depths of 3, 6, and 9 inches was evaluated. The nozzle and seal of the impact tool were inserted into the hole, and the HIEE was discharged at 55,000 psi. Each concept was tested with three impacts on a 3,000-pound sample.

3.5.4 Excavation Pattern Test

A spiral impact pattern was used to observe propagation of fractures between free faces. These tests patterns consisted of two series of twenty eight impacts at a charge pressure of 55,000 psi. The first series were made with a nozzle-to-material standoff distance of 2 inches. The second series were conducted with the nozzle fully inserted in 1-inch-diameter by 1-inch-deep holes. These tests were conducted on the 8,000-pound sample. For these tests, the fragment weights were recorded after completing the pattern to determine the cumulative effect of the multiple impacts.

3.5.5 Rubblization Destruction Test

Tests were performed to evaluate the effect of fragmenting larger-sized rubble into smaller-sized fragments. This test consisted of a minimum of 12 impacts. Impacts were made at a charge pressure of 55,000 psi and a standoff distance between 0 to 6 inches. The tests were conducted on one of the large fragments from a previous test.

4. TEST RESULTS

4.1 Charge Pressure Effects

Eight tests were conducted, four at 40,000 psi and four at 55,000 psi, with each test conducted on a single 1-cubic-foot sample. Table 1 shows the results of the 40,000-psi charge pressure tests, and Table 2 shows the results of the 55,000-psi charge pressure tests. With the 40,000-psi case, only one out of the four samples was fragmented. Two of the four samples, however, were fractured in the 55,000-psi case. The main difference in the results between the two charge pressures was the size of the spalled area and the depth of the crater. With the 40,000-psi charge pressure, the spalled areas were around 1-5/8 inch in diameter and the crater depth was about 3/8 inch. The 55,000-psi charge created a spalled area of around 2-5/8 inch in diameter, with an average crater depth of 1 inch. On the samples that did break apart, the total fragment weight with the 40,000-psi charge was 7 pounds, and with the 55,000-psi charge the average fragment weight was 12-1/4 pounds. With both of these cases, the weight of the fragments under 2 inches in diameter was under 2 pounds, but the 55,000-psi tests had a greater amount of large-sized fragments. In Test #1, the crater results are outside the norm. In Test #9, the sample had a 3-inch-square cut out of one of the edges. The nozzle was aimed at this edge. The results of this shot are found in Table 2. In Tables 1 through 4, "neg." represents any material fragments that were negligible in size and weight.

Table 1. 40,000-psi Charge Test Results

Test No.	Sample weight before test (lb)	Sample weight after test (lb)	Weight of fragments over 2 in. (lb)	Weight of fragments under 2 in. (lb)	Total fragment weight (lb)	Crater depth (in.)	Spalled area, inches in diameter
1	136	136	-	neg.	neg.	1.5	4
2	135.75	135.75	-	neg.	neg.	3/8	1.5
3	135.25	128.25	5.25	1.75	7	-	-
4	131.25	131.25	-	neg.	neg.	3/8	1.75

Table 2. 55,000-psi Charge Test Results

Test No.	Sample weight before test (lb)	Sample weight after test (lb)	Weight of fragments over 2 in. (lb)	Weight of fragments under 2 in. (lb)	Total fragment weight (lb)	Crater depth (in.)	Spalled area, inches in diameter
5	134.75	134.75	-	neg.	neg.	0.75	2.5
6	135.25	135.25	-	neg.	neg.	1.125	2.75
7	130	112.75	16.25	1.0	17.25	4	2
8	126.25	119	6.75	1/8	7.25	2.875	2.75
9	124	124	-	neg.	neg.	1	1.5

Figure 3 shows what a typical 1-cubic-foot test sample looks like before testing. The color of this material is between pink and orange. Figure 4 shows a typical crater in a sample that did not fracture. Figures 5 and 6 show the fractured results in Tests #3 and #7 respectively.

4.2 Outlet Geometry Effects

The three different types of nozzles tested were a converging nozzle, a diverging nozzle, and a three-hole, in-line nozzle. The purpose of the converging nozzle was to increase the velocity of the water slug that is being fired by linearly decreasing the bore diameter along the nozzle length, as illustrated in Figure 7. It is believed that greater water slug velocity results in a greater shock energy.

With the diverging nozzle, the diameter of the bore linearly increases along the barrel length to decrease the water slug velocity and to give it a greater diametrical size when it impacts the simulant. This geometry is shown in Figure 8.

The three-hole, in-line nozzle has three smaller bores with the same total cross-sectional area as with the standard straight bore nozzle. The center bore lies concentric with the center line of the nozzle and the two other bores are angled outward at 5 degrees from the center bore. This configuration is shown in Figure 9. This nozzle produces an impact line (chisel effect) to create fracture lines or fissures that would cleave the test samples.

All tests conducted with these nozzles used charge pressures of 55,000 psi. Four tests were conducted with each nozzle.

4.2.1 Diverging Nozzle

The results for this test can be found in Table 3. Two out of the four samples were severely fragmented, with the fragments' weight totaling approximately half of the original sample weight. The spalled areas for all four shots were at least 5 inches in diameter. The majority of the fragments' weight was in large pieces, with about 4 pounds of fragments under 2 inches in diameter. The crater depth for the nonfragmented tests was approximately 1-3/4 inch compared to 3-3/4 to 5-1/4 inch for the fragmented samples. The total fragment weight when using this nozzle was typically in excess of four times the fragments' weight when using the standard straight bore nozzle. Figures 10 and 11 show the fractured results of Tests #10 and #11 respectively.

Table 3. Diverging Nozzle Test Results

Test No.	Sample weight before test (lb)	Sample weight after test (lb)	Weight of fragments over 2 in. (lb)	Weight of fragments under 2 in. (lb)	Total fragment weight (lb)	Crater depth (in.)	Spalled area, inches in diameter
10	135.75	72.75	59.25	3.75	63	3.75	7
11	137.75	48	86	3.75	89.75	5.25	8
12	128.75	128	-	0.75	0.75	1.75	6
13	135.5	135.5	-	neg.	neg.	1.75	5

Figure 3. Typical 1-Cubic-Foot Test Sample

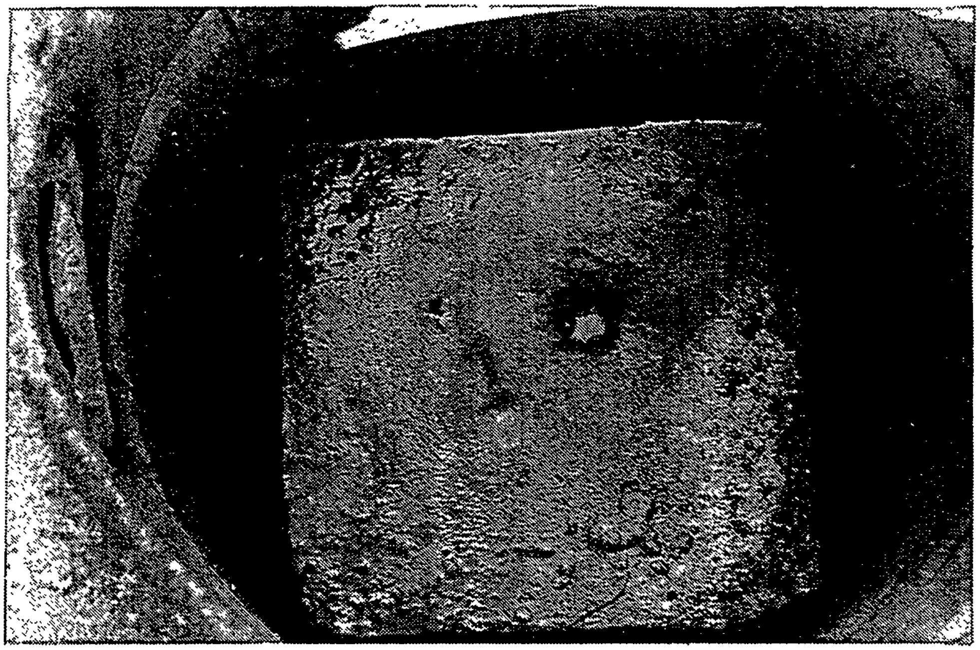


Figure 4. Typical Crater In a Nonfractured Test Sample

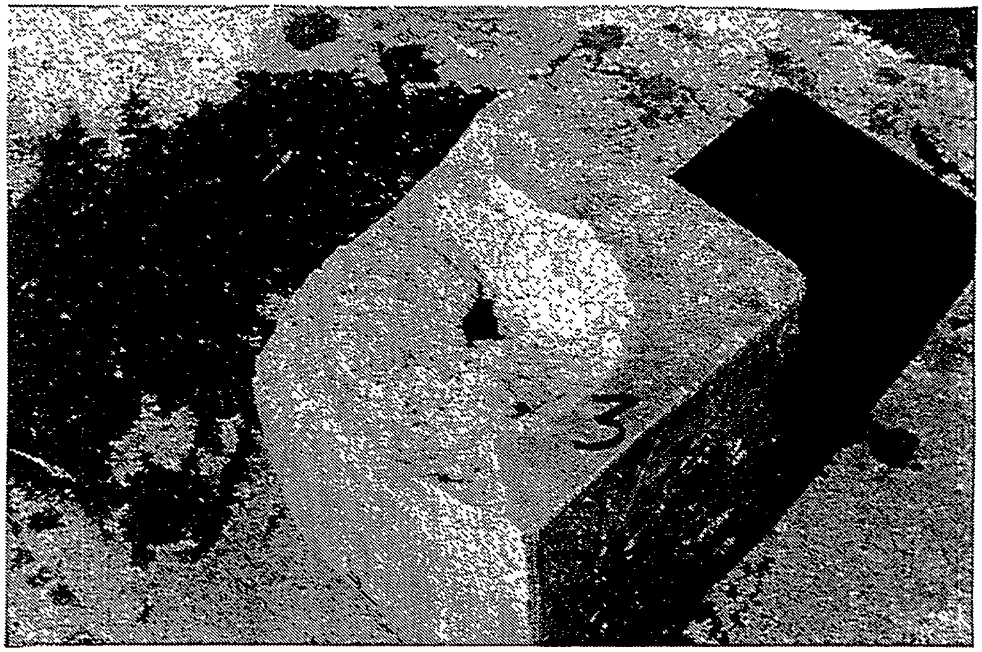


Figure 5. Fractured Results In Test #3

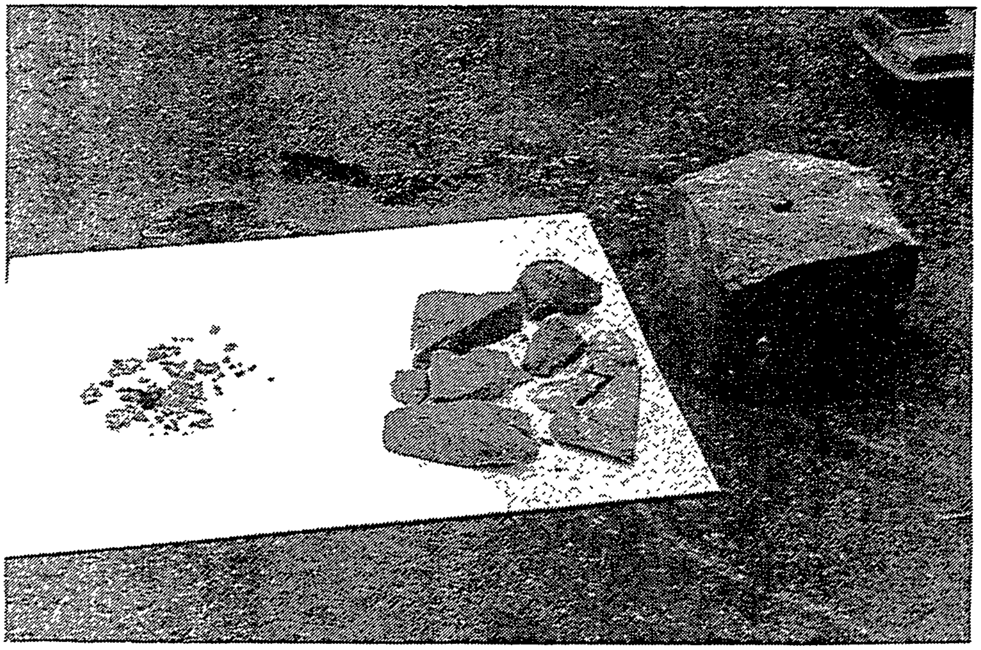


Figure 6. Fractured Results In Test #7

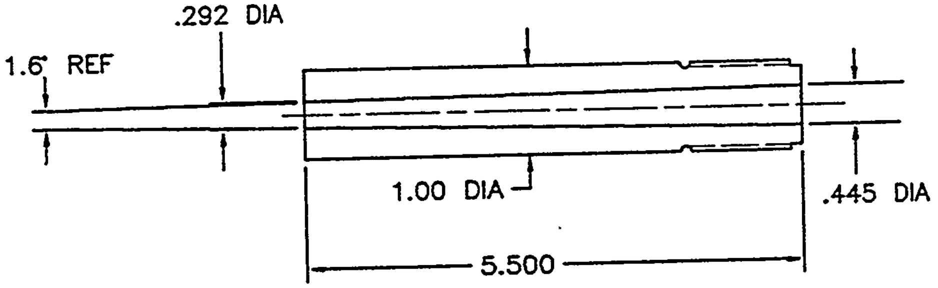


Figure 7. Converging Nozzle

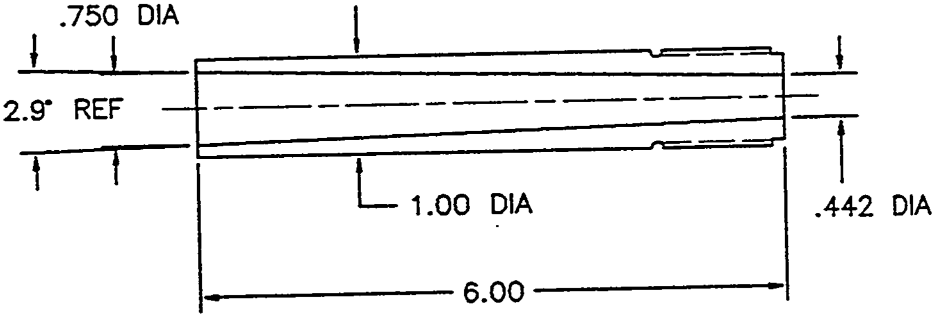


Figure 8. Diverging Nozzle

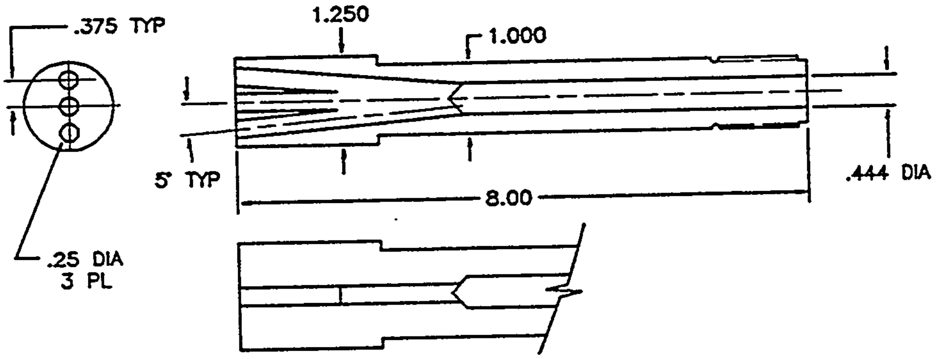


Figure 9. Three-Hole, In-Line Nozzle

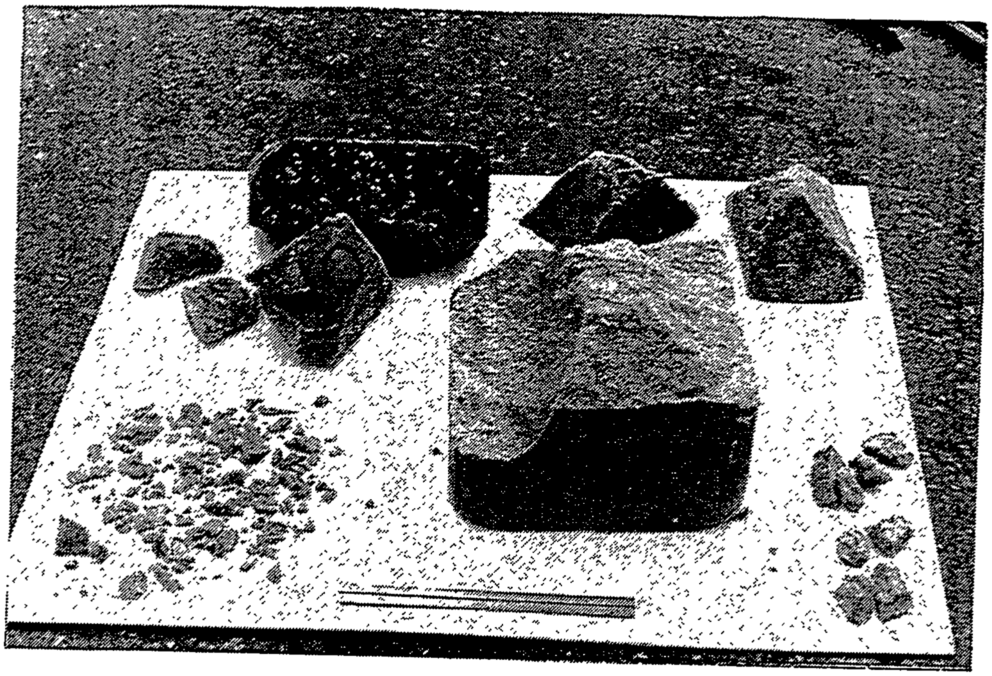


Figure 10. Fractured Results In Test #10

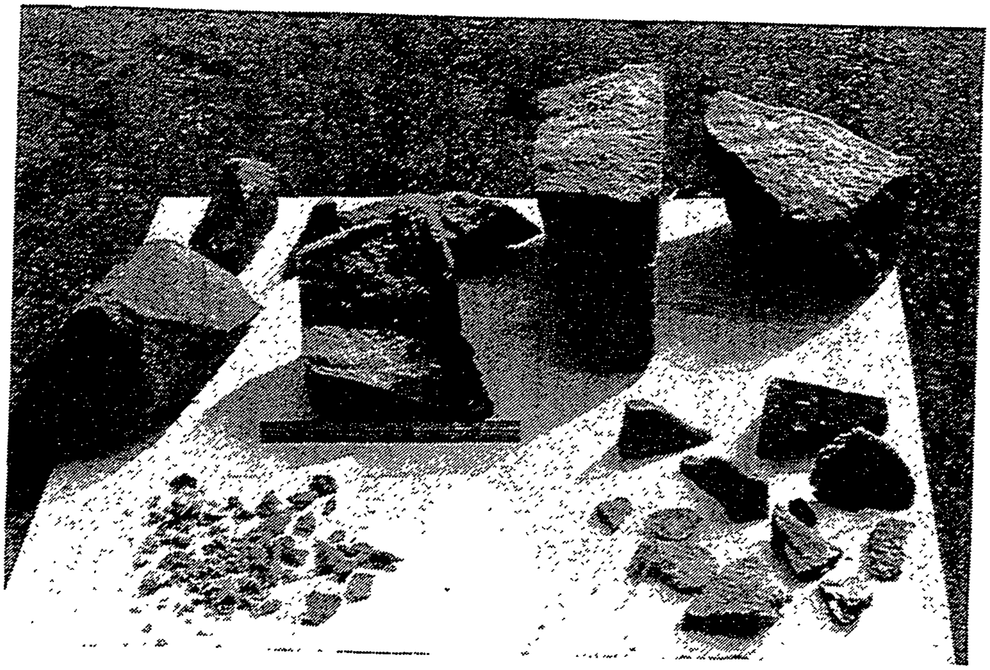


Figure 11. Fractured Results In Test #11

4.2.2 Three-Hole, In-Line Nozzle

Two out of the four samples were split in half. In both of these cases, the primary crack line was coincident with the three-hole orientation or "chisel edge." These results are shown in Figures 12 and 13. In the two samples that did not fracture, the craters that were formed was rectangular in shape and were 2-3/4 to 3-3/4 inches deep. The orientation of these craters also lined up with the "chisel edge," as shown in Figure 14. Table 4 contains the results of this test.

Table 4. Three-Hole, In-Line Nozzle Test Results

Test No.	Sample weight before test (lb)	Sample weight after test (lb)	Weight of fragments over 2 in. (lb)	Weight of fragments under 2 in. (lb)	Total fragment weight (lb)	Crater depth (in.)	Spalled area, inches in diameter
14	125.25	70	52.5	2.75	55.25	4	4
15	129.25	129	-	0.25	0.25	3.25	7
16	128.25	128.5	-	neg.	neg.	2.75	3.5
17	127.25	70.25	55.5	1.5	57	2.5	3.5 - 5

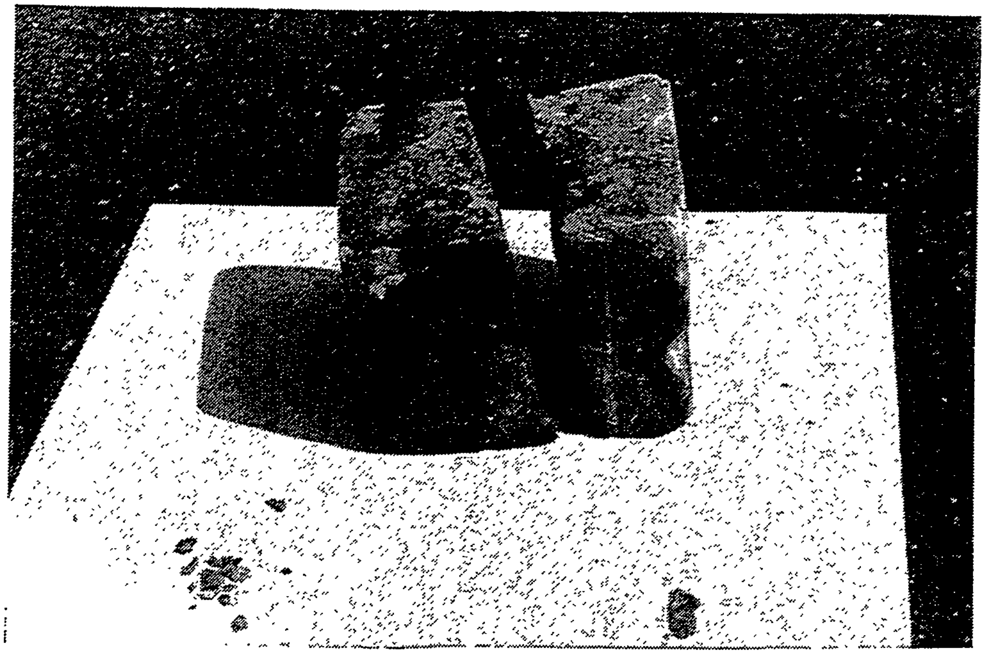


Figure 12. Fractured Results In Test #14

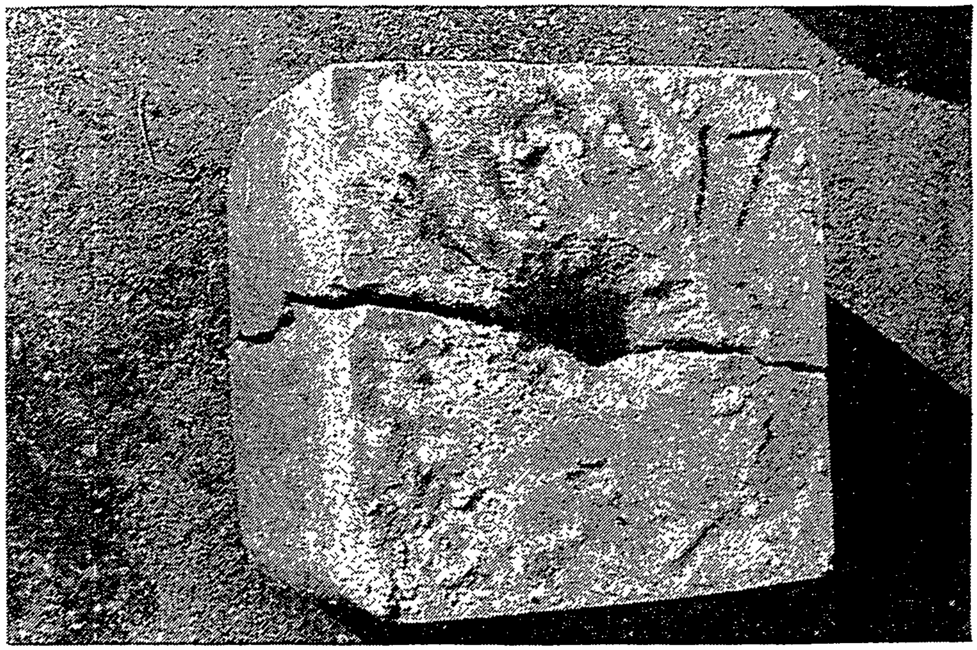


Figure 13. Fractured Results In Test #17

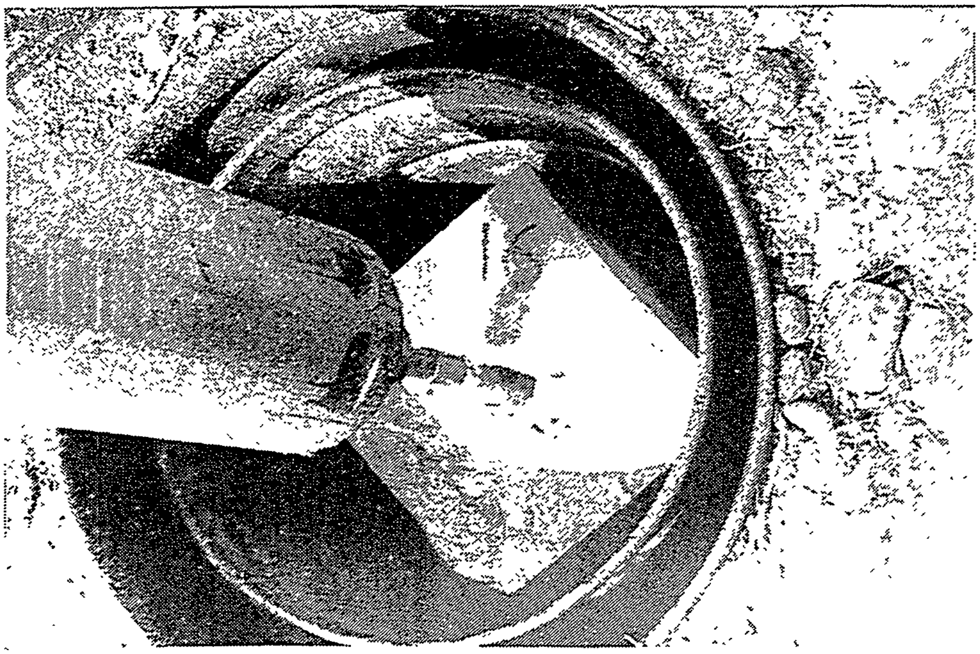


Figure 14. Crater Results In Test #16

4.2.3 *Converging Nozzle*

Three out of the four samples were severely fragmented, with two of the tests having a total fragment weight of nearly half of the original sample weight and the other about a quarter of the weight. The spalled areas ranged from 3 to 10 inches across, and crater depths range from 2 to 4-1/4 inches. The weight of the small fragments was similar to the weight achieved by the diverging nozzle. Table 5 summarizes the results of these tests. Figures 15 through 18 show the fractured results of these tests. The total fragment weight with the converging nozzle is two to four times that when using the standard straight bore nozzle; the crater depths are twice as deep and the spalled areas are two to five times greater.

Table 5. Converging Nozzle Test Results

Test No.	Sample weight before test (lb)	Sample weight after test (lb)	Weight of fragments over 2 in. (lb)	Weight of fragments under 2 in. (lb)	Total fragment weight (lb)	Crater depth (in.)	Spalled area, inches in diameter
18	131.25	70.75	56.5	4	60.5	4.25	8 - 10
19	126.5	61.25	61.75	3.5	64.25	3.75	7 - 9
20	131.25	130.75	-	0.5	0.5	2.75	3-4
21	135.75	107.25	27.25	1.25	28.5	2	6

4.3 Fluid Containment Effects

This test evaluated two methods for fluid containment. In both methods holes were drilled at various depths into a 3,000-pound sample approximately a cubic yard in size. The original HIEE nozzle was used with these tests. The first series of tests was conducted with no seals around the nozzle inside 1-inch-diameter predrilled holes. For the second series of tests, a 1-3/4-inch-diameter hole was drilled. A two-piece, 1-3/4-inch-diameter nylon conical seal was placed around the nozzle and two locking rings were placed at both ends of the seal. A tightening ring was placed behind the seal and tightened after the nozzle was inserted into the hole so that the two nylon seals would mesh together and expand in diameter, thus creating a seal between the nozzle and the predrilled hole. This configuration is illustrated in Figure 19.

4.3.1 *Test With No Seals*

In each of these tests, the sample broke apart in a few large pieces. Some of the pieces were in excess of 100 pounds. Larger-sized fragments were created with deeper holes. Table 6 contains the results for this test. Figures 20 through 24 show the fractured samples. In Test #22 the nozzle was inserted only 8 inches, but for the rest of the tests the nozzle was fully inserted.

4.3.2 *Test With Seals*

The sample broke into large pieces during these tests. In this case, the number of fragments was less than with the no-seal case (usually only two pieces), but the fragment size was larger. Test #29 had only two fragments with weights of 575 and 625 pounds. Table 7 shows the results of these tests, and Figures 25 through 27 show the fractured results.

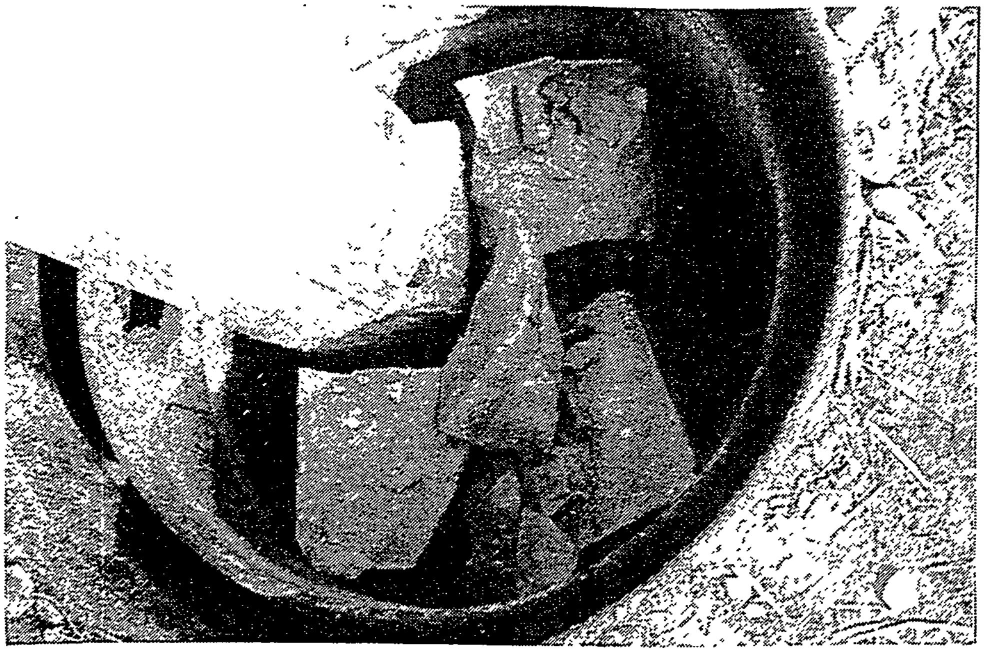


Figure 15. Fractured Results In Test #18

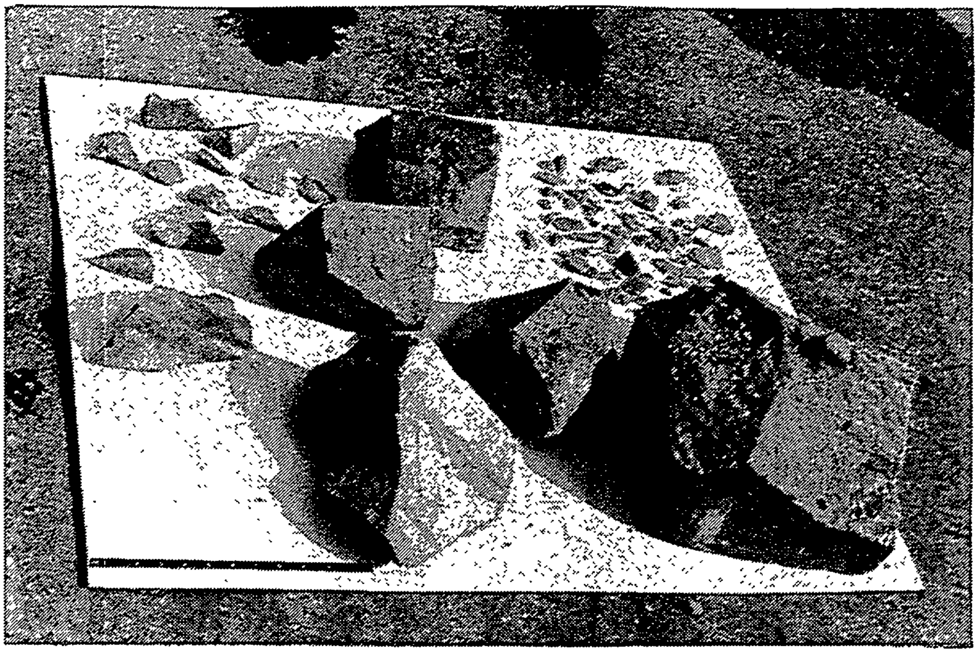


Figure 16. Fractured Results In Test #18

Figure 17. Fractured Results In Test #19

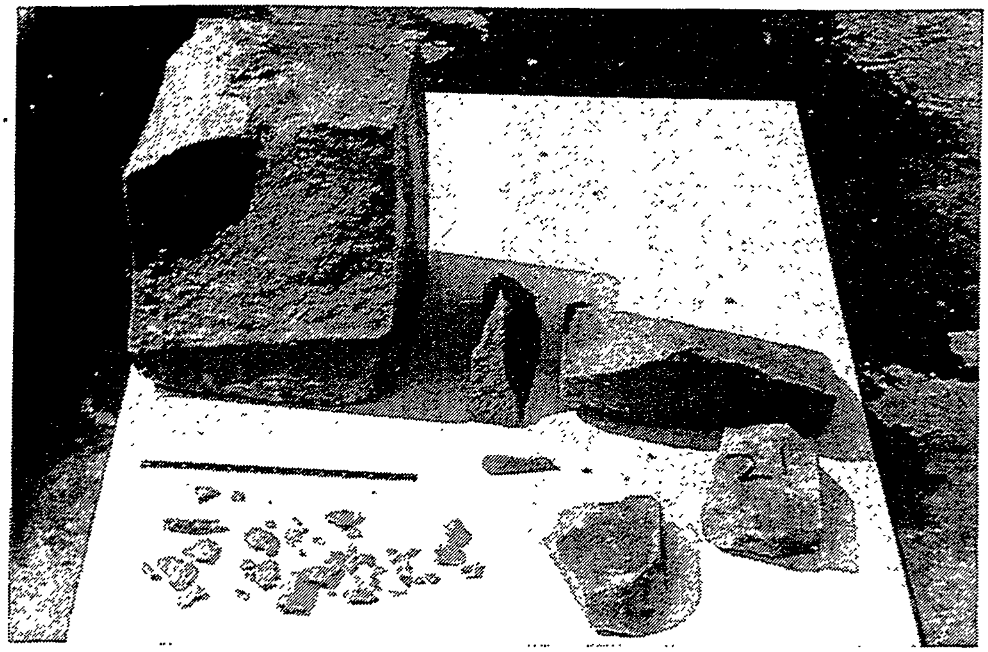


Figure 18. Fractured Results In Test #21

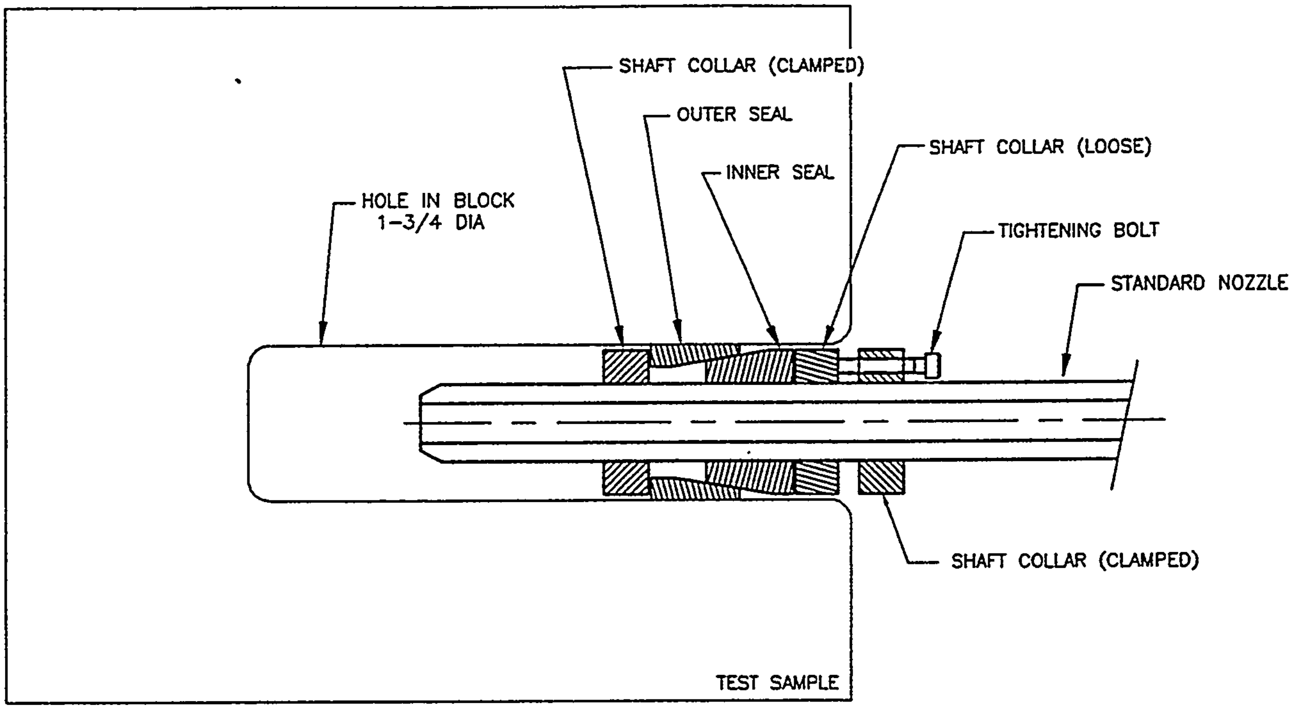


Figure 19. Fluid Containment Seal

Table 6. Blind Hole With No Seal Test Results

Test No.	Hole depth (in.)	Sample weight before test (lb)	Sample weight after test (lb)	Total fragment weight (lb)
22	10.5	3,000	2,475	505
23	6	2,475	2,150	303.5
24	3	2,150	1,585	569.5 [1]
25	3	1,585	1,507	133.25
26	1	[2]	[2]	257.75

1. A 353-pound fragment's fracture line was mostly created in Test #23.

2. Not measured.

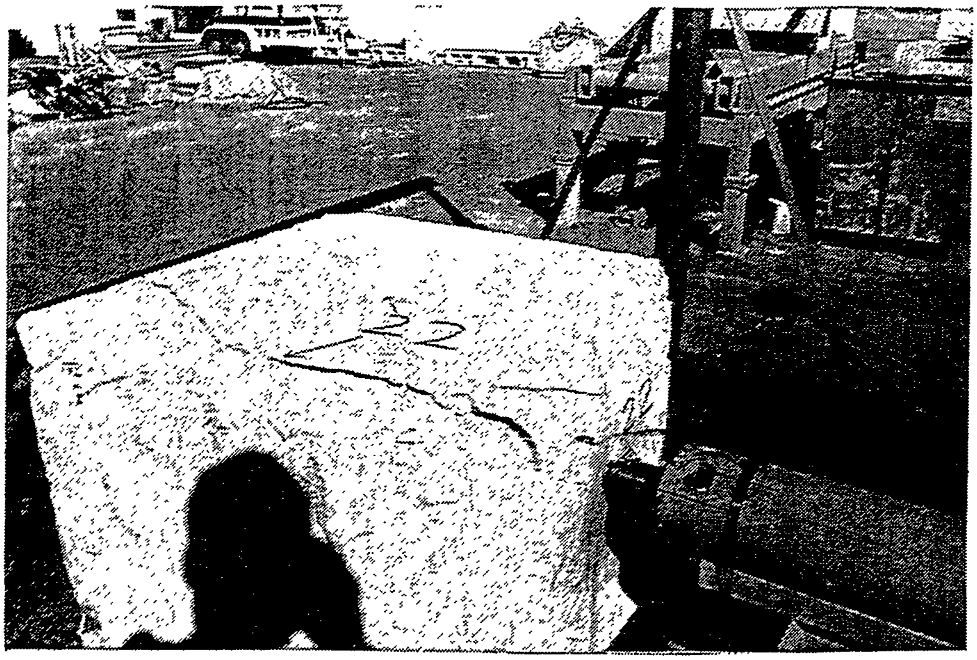


Figure 20. Fractured Results In Test #22

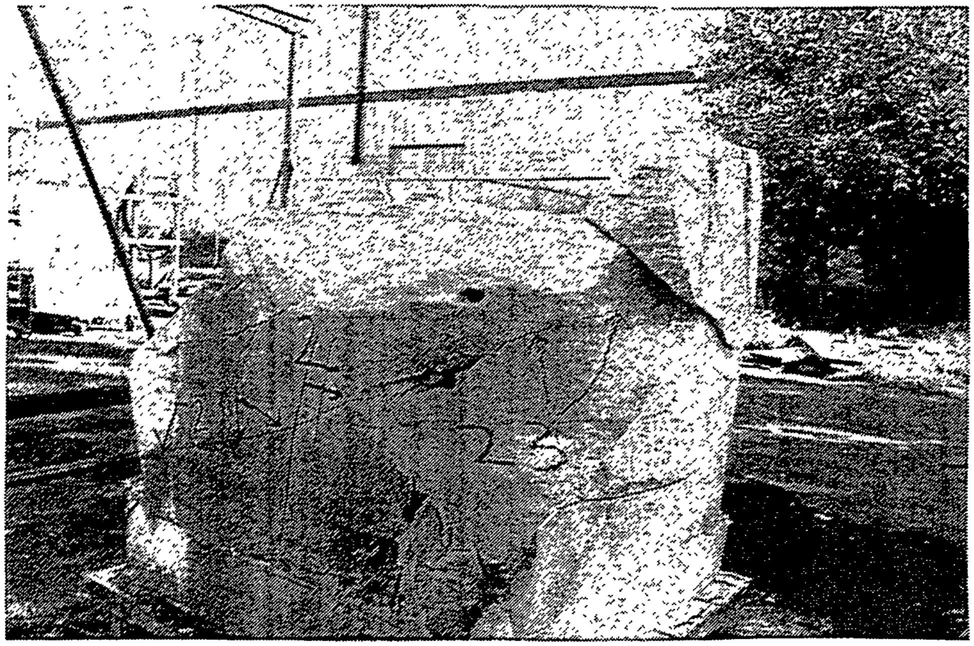


Figure 21. Fractured Results In Test #23

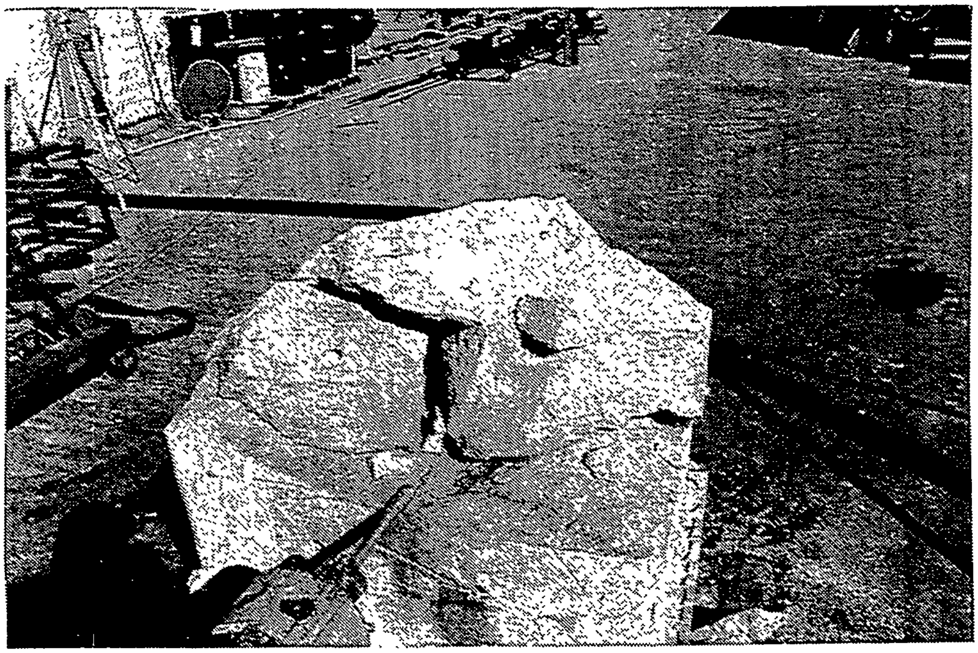


Figure 22. Fractured Results In Test #24

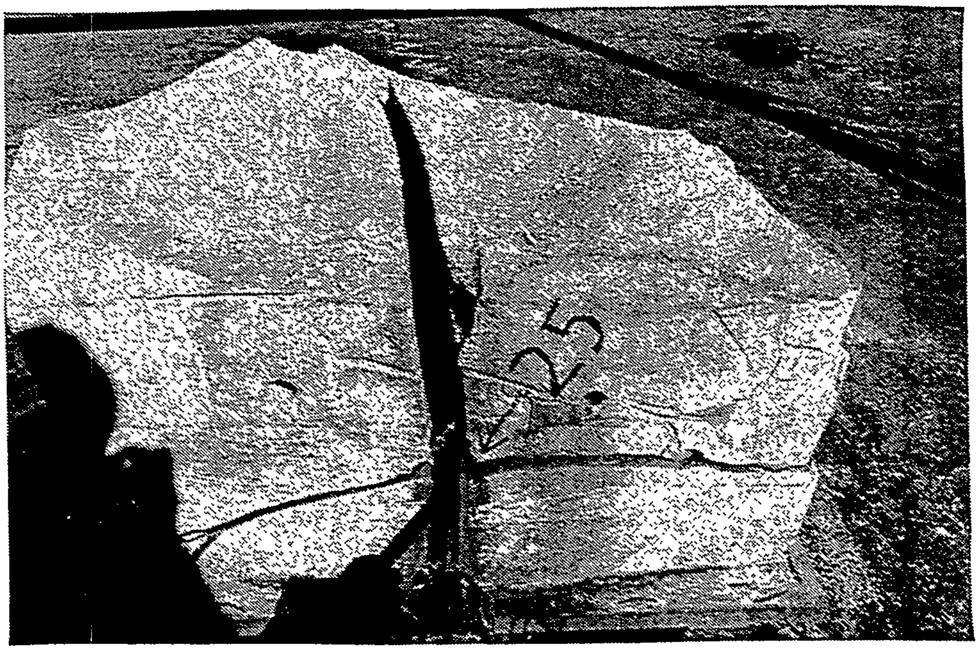


Figure 23. Fractured Results In Test #25

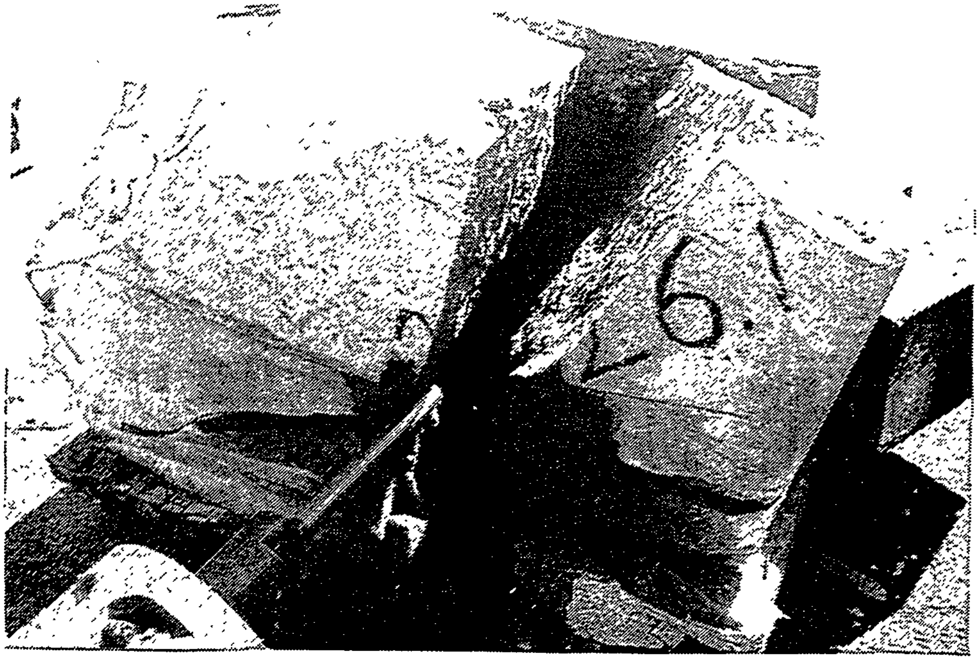


Figure 24. Fractured Results In Test #26

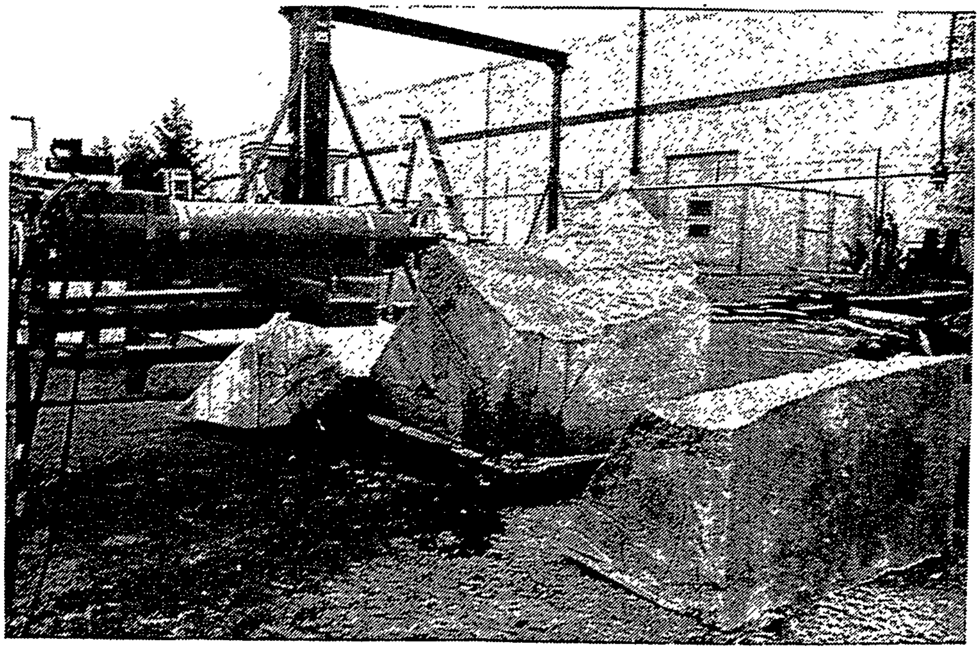


Figure 25. Fractured Results In Test #29

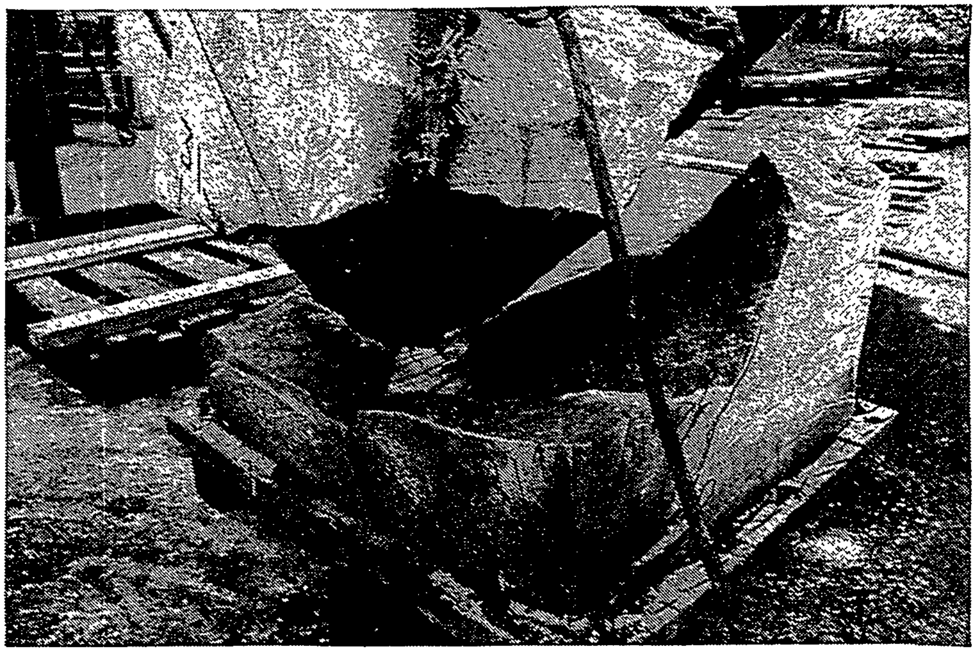


Figure 26. Fractured Results In Test #30 and #31

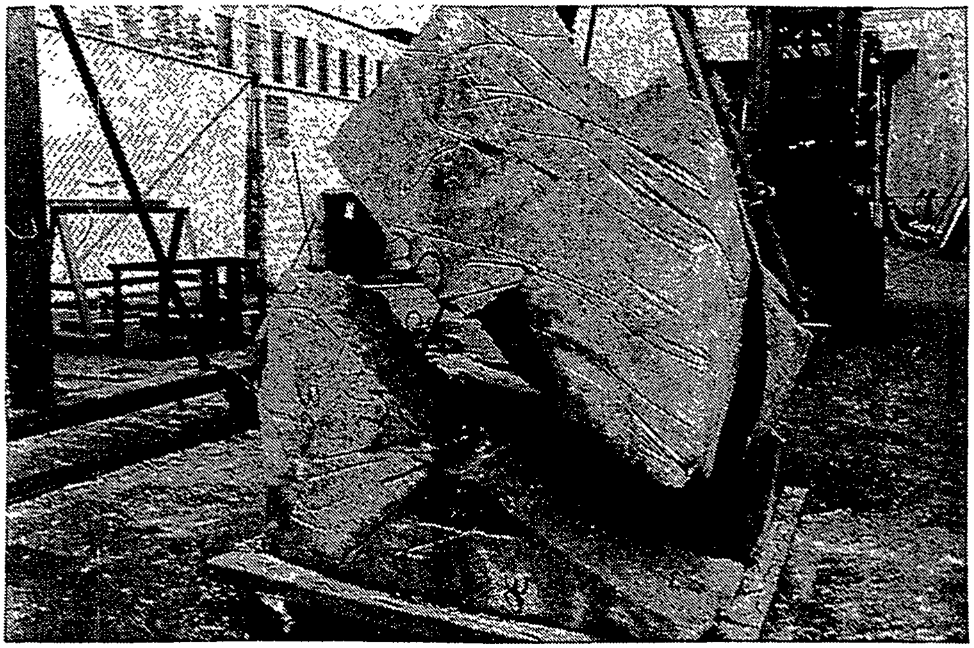


Figure 27. Fractured Results In Test #30 and #31

Table 7. Blind Hole with Seals Test Results

Test No.	Hole depth (in.)	Barrel inserted (in.)	Sample weight before test (lb)	Sample weight after test (lb)	Total fragment weight (lb)
29	9.25	7.25	2,840	1,700	1,200
30	6	6	1,700	1234 [1,2]	266 [2]
31	3	2	1234 [2]	1,080	153.5

1. The block split down the middle.
2. Approximate weights.

4.4 Excavation Pattern Test

The typical result of a surface impact test is that a small crater is created. With the small-sized samples, fracturing does not always occur. The inclination to fracture is partially based on the distance between the firing location and free surface edges and/or crack lines. When firing at large surfaces, these free surface edges and cracks are much further apart. The purpose of an excavation pattern is to create intermediate cracks and edges to improve the propagation of fractures.

The excavation pattern used was based on the geometry of an involute curve or spiral. The firing pattern started at the center of the 8,000-pound sample and spiraled outward in a counter-clockwise manner, as shown in Figure 28. After each revolution, the diameter of the curve increased by 5 inches. Two series of tests were conducted, each using the same involute pattern. The first was done with a 2-inch standoff distance between the barrel tip and material surface, and the other was done with the barrel inserted into 1-inch-deep drilled holes. There were 28 shots for each test.

4.4.1 Surface Test

This test was unsuccessful since each shot only created small craters. The first nine shots used the standard nozzle. The spalled areas from these impacts were approximately 2 inches in diameter, with crater depths from 1/4 to 1/2 inch. Shots 10 through 28 were made using the converging nozzle. The spalled areas then became 2 to 3-1/2 inches in diameter and the crater depths ranged from 1/2 to 2 inches. Due to the extremely small size of the fragments, they were unable to be collected. Fractures did not propagate between the shot locations. Figure 29 shows the results after the first 22 shots.

4.4.2 Hole Test

This test was very successful. Each shot created large spalled areas and removed material between it and the previous shots. The spalled areas ranged from 4 to 18 inches in diameter, and the crater depths ranged from 1-3/4 to 3-3/4 inches. Approximately 128 pounds of fragments were created with this procedure, with 28 pounds of fragments under 2 inches in diameter, and 22 pounds fragments between 2 and 4 inches. Several large fragments were created with the shots near the top and bottom of the test pattern. Figures 30 and 31 show the results after the fourth and fourteenth shots respectively. Figure 32 shows the fragmented pattern after the firing pattern was completed. Figures 33 through 35 show the 0 to 2 inch, 2 to 4 inch, and larger than 4-inch-diameter fragments respectively.

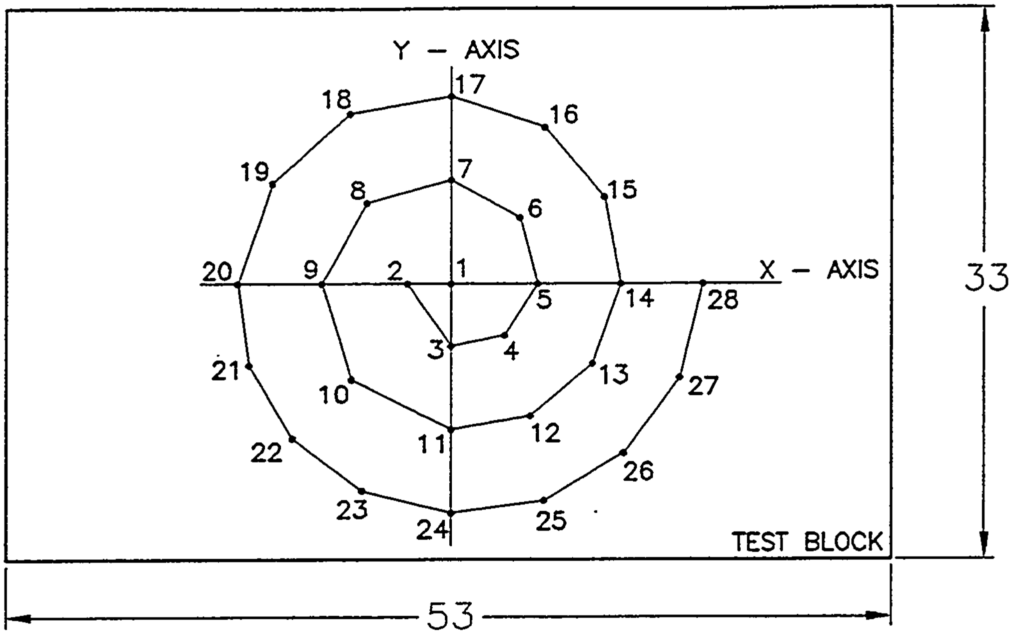


Figure 28. Excavation Pattern

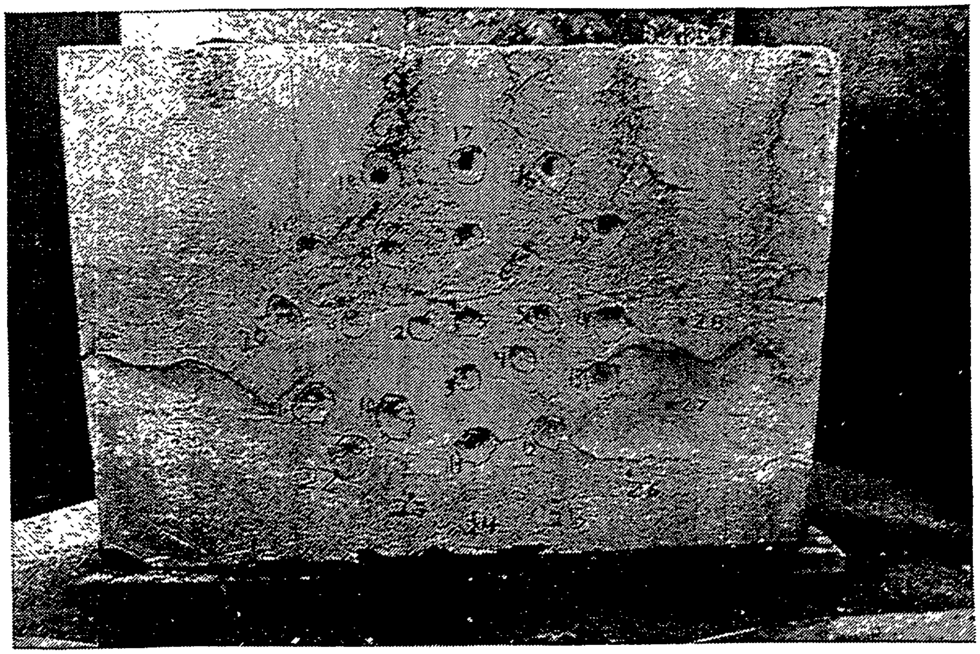


Figure 29. Excavation Pattern After the First 22 Shots

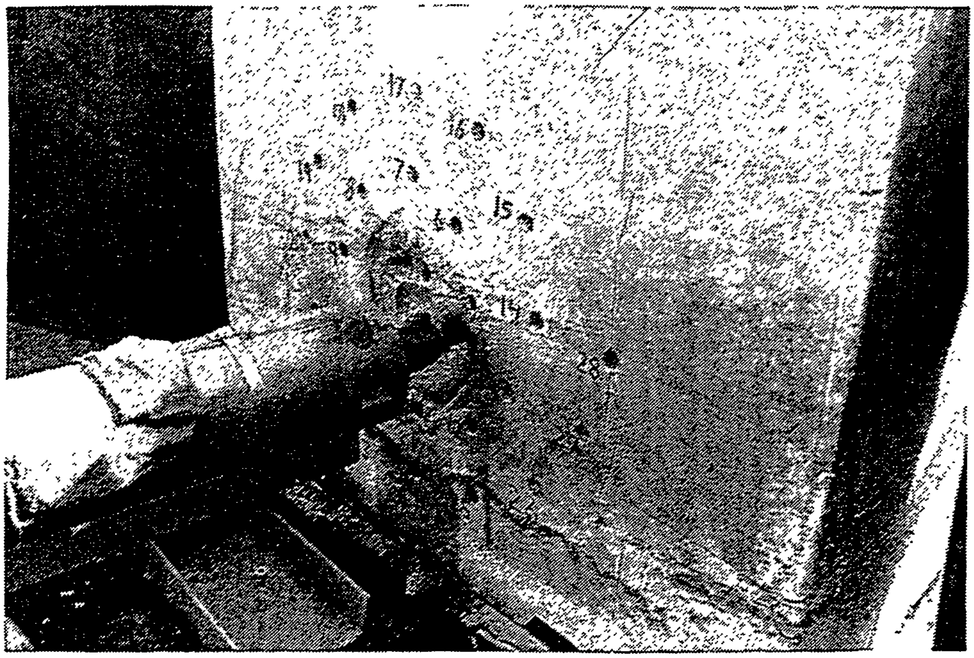


Figure 30. Excavation Pattern After the First Four Shots

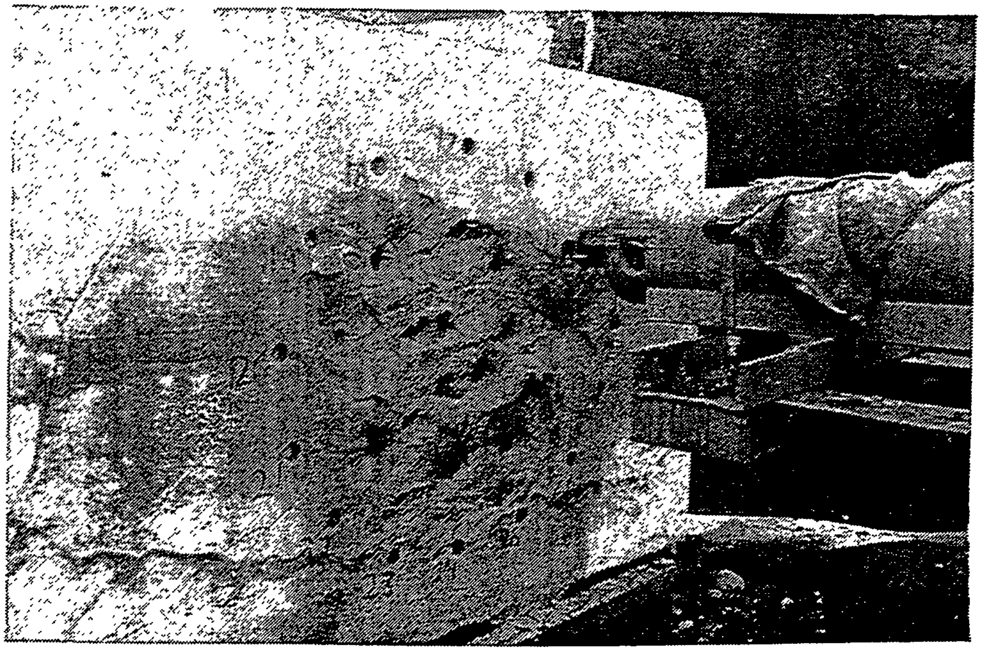


Figure 31. Excavation Pattern After the First 14 Shots

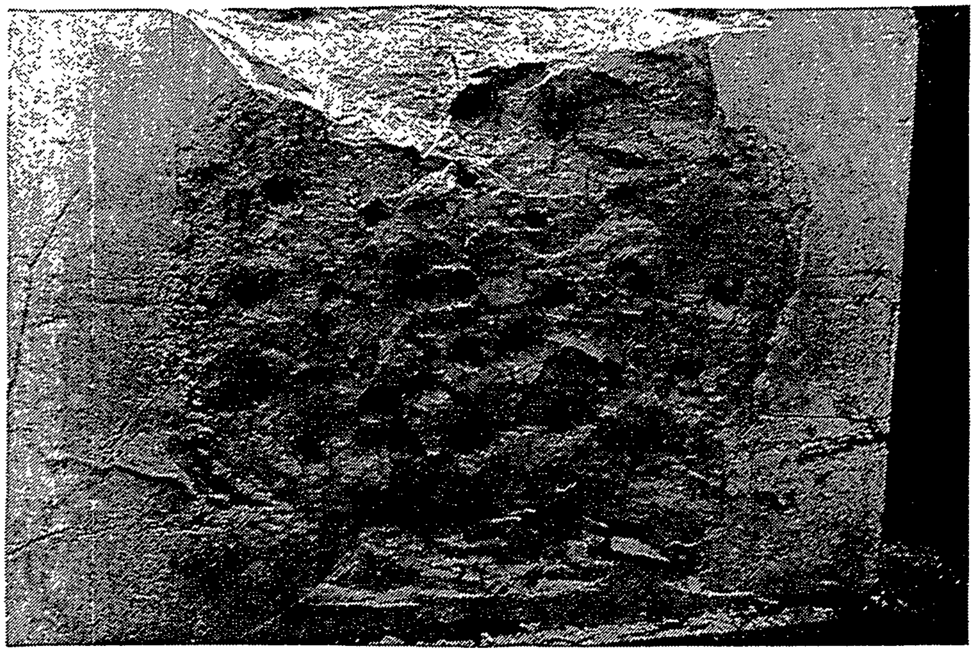


Figure 32. Excavation Pattern After All 28 Shots

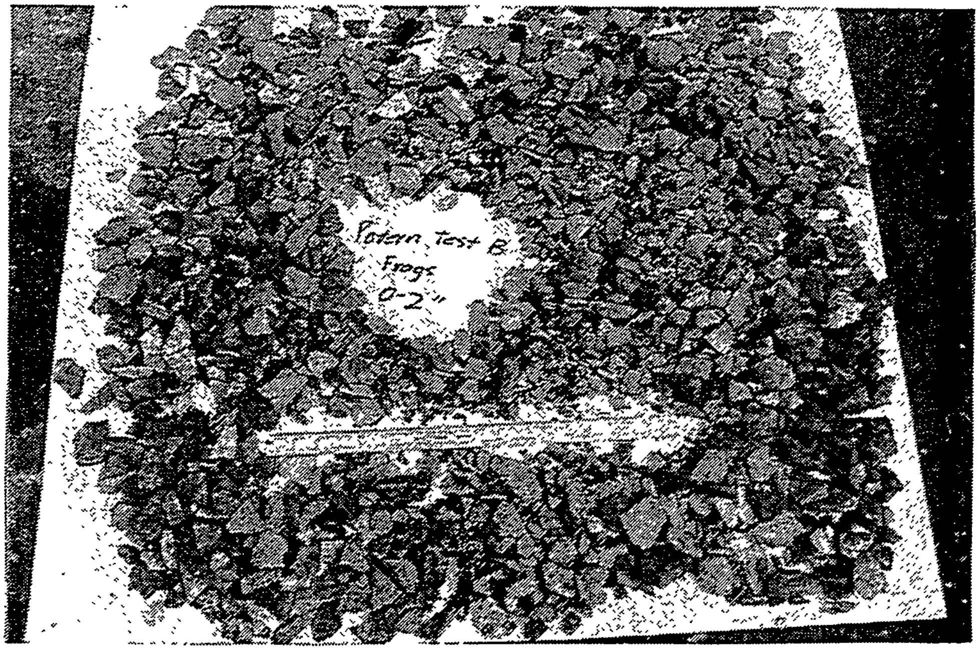


Figure 33. 0- to 2-Inch-Diameter Fragments from the Predrilled Hole Excavation Pattern Test

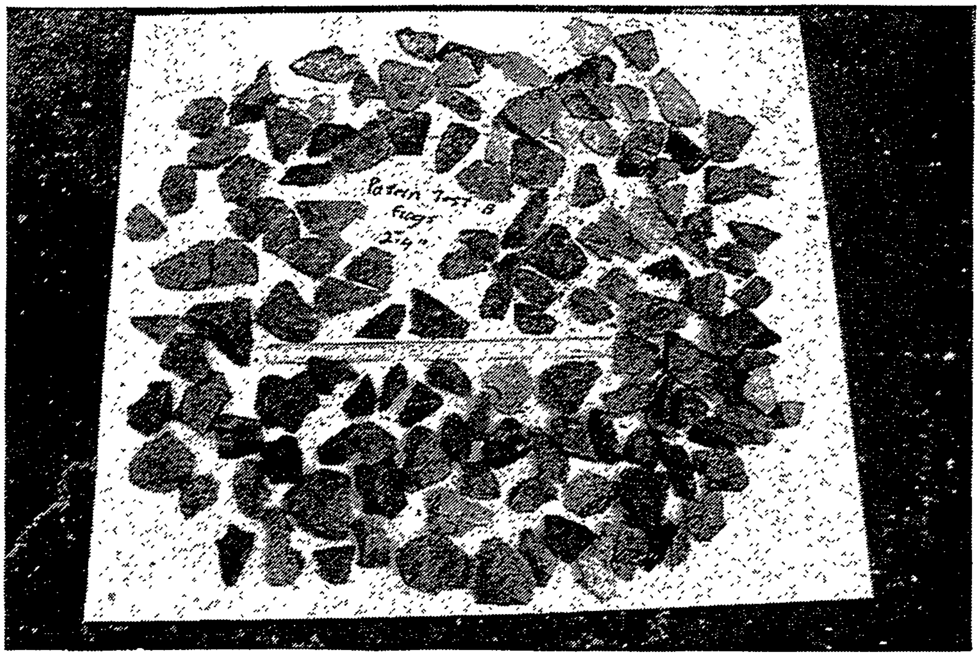


Figure 34. 2- to 4-Inch-Diameter Fragments from the Predrilled Hole Excavation Pattern Test

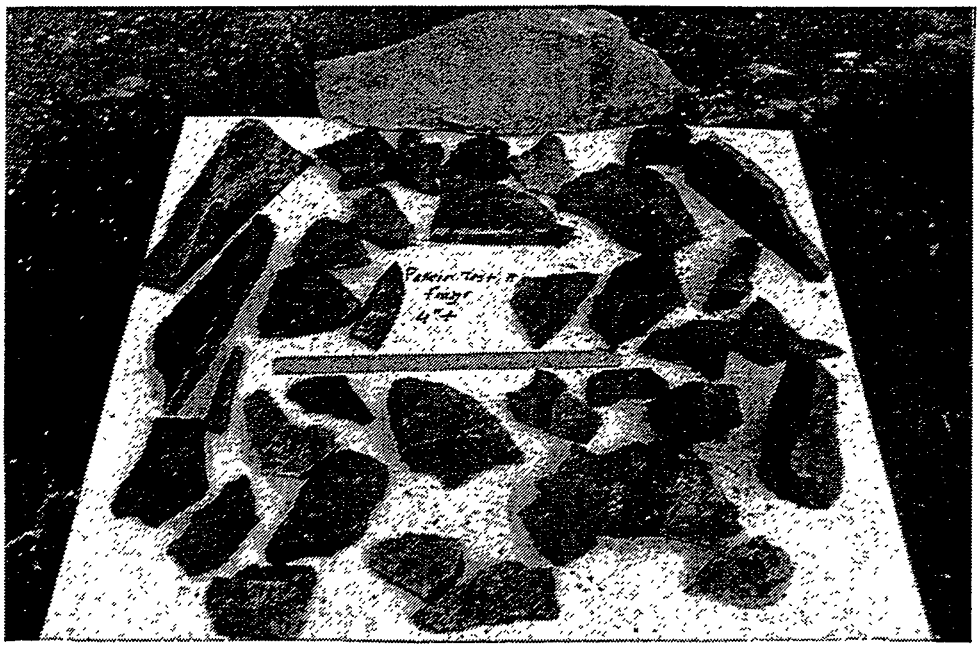


Figure 35. 4-Inch and Greater Diameter Fragments from the Excavation Pattern Test

4.5 Rubblization Tests

A 575-pound fragment from the first shot of the drilled hole-with-seal test was used for this test. Figure 36 shows the block used for this test and Figure 25 refers back to the test that created this block. The three-hole, in-line nozzle was used to further demonstrate its cleaving ability. The first three series of shots were used to quarter this block. For the first series, the nozzle was placed at the surface and approximately at the center of the block. A total of 13 shots were used to split this block in half. A second series of shots was aimed at the center of one of the fractured pieces (approximately 315 pounds). Two shots were used to split this sample. A third series was aimed at the center of the other half of the block leftover from the first series. A total of six shots were used to fracture this sample. The fracture line from the first two series was vertical, whereas it was horizontal in the third series. The nozzle's in-line orientation was vertical for these tests. The thickness of the block for the first three series was approximately 20 inches. A fourth series was used to cleave in half the largest fragment (approximately 150 pounds) from the third series. Again, six shots were used to split this sample. A large fragment from this series was split in half with two shots, and its largest fragment was split in half with two more shots. The largest fragment from the last shot was split in half with only one shot, and its largest fragment was split again with only one shot. At this point, the largest remaining fragment size was approximately five inches in diameter. A material weight breakdown from these 33 shots is shown in Table 8. Figure 37 shows the results of the first series after three shots. Figure 38 shows the fractured results after the completion of the second series. Figure 39 shows the fractured results from the third series and the beginning crater of the fourth series. Figure 40 shows the fractured results at the completion of the rubblization tests.

Table 8. Fragment Size-To-Weight Profile

Fragment Sizes (in.)	Fragment Weights (lb)
0 - 2	4 - 3/4
2 - 4	7 - 1/4
4 - 6	6 - 1/4
6 - 8	12
8 - 10	37 - 1/2
10 - 14	46 - 1/2
14 + (Individual fragment weights are shown here)	211 - 1/2 104 - 3/4 100 53

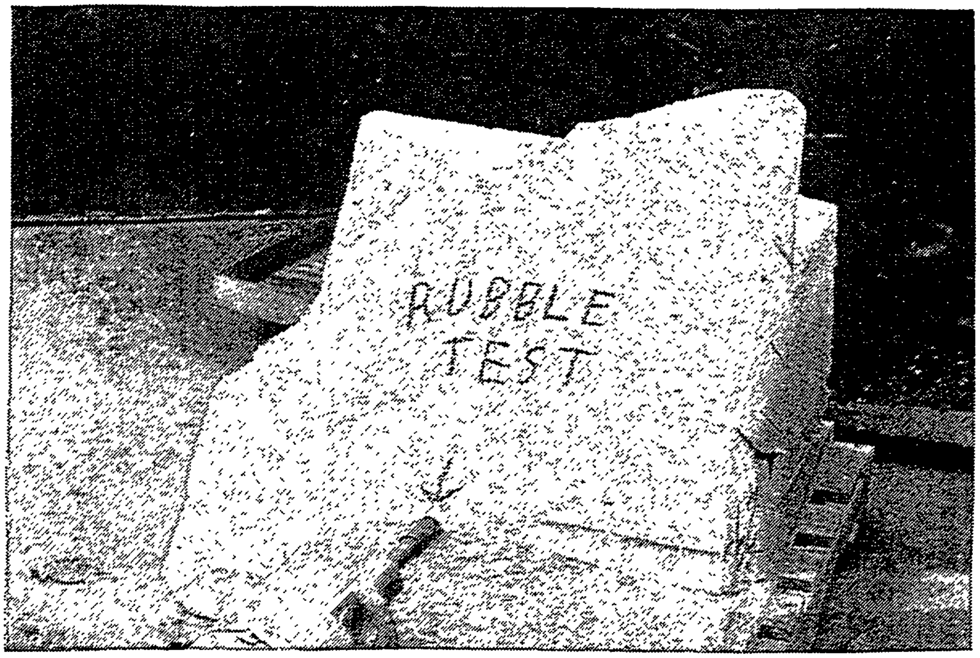


Figure 36. Rubble Test Block Prior to Testing

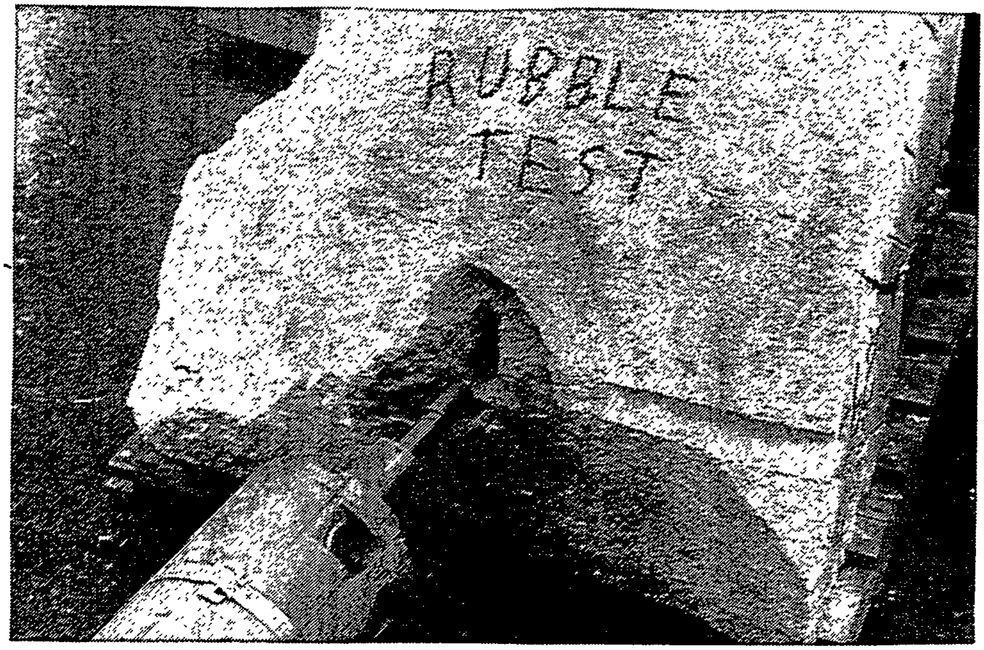


Figure 37. Crater Result After Three Shots

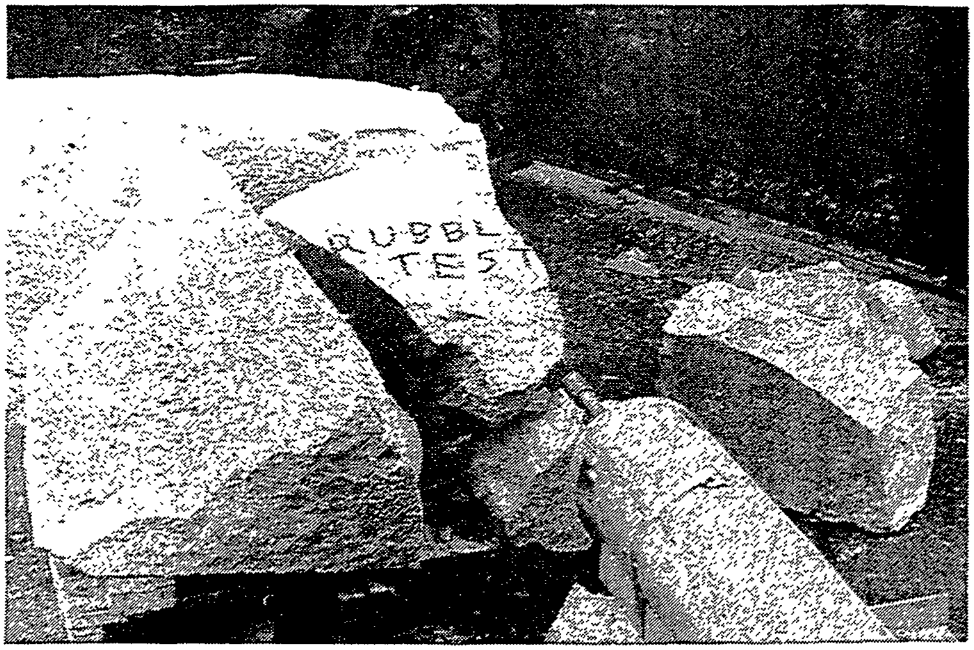


Figure 38. Fracture Results After the Completion of the Second Series of the Rubble Tests

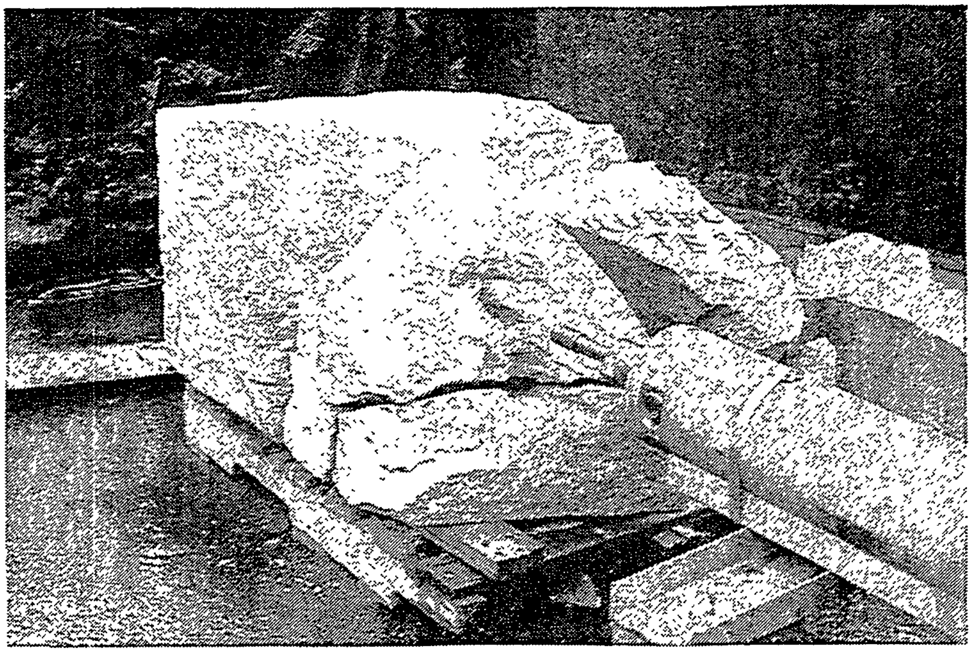


Figure 39. Fracture Results After the Completion of the Third Series and the Creation of the Crater In the Fourth Series of the Rubble Tests

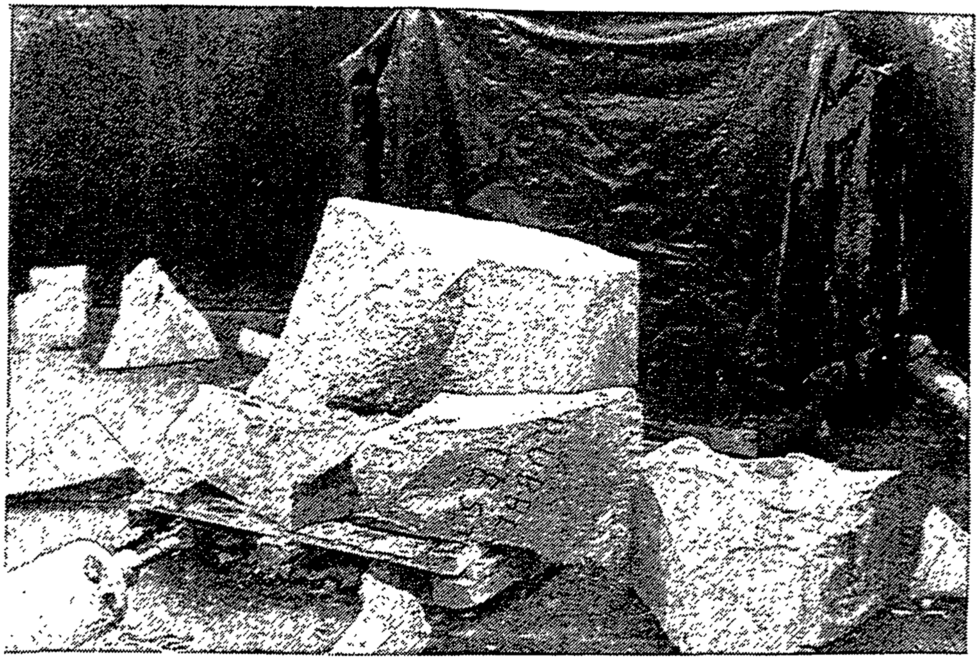


Figure 40. Fractured Results After the Completion of the Rubble Tests

Several of the first 25 shots may not have been fired with 55,000-psi charge pressure. We had mechanical problems with the trigger valve assembly, a seal failure in the impact tool, and a check valve failure in one of the intensifiers during these tests. After these problems were corrected, the remaining shots were conducted. A probable reason why the first series took 13 shots to split the block is due to equipment problems, since it only took six and two shots to split the other two blocks.

A final test was conducted to shear off a corner on another large fragment from the drilled hole tests. An approximate 8-inch-diameter fragment was removed from the corner on a 625-pound block with only two shots. The first shot was 10 inches from the surface, and the second shot was 4 inches away. The nozzle was aimed approximately 6 inches from the edges of the corner. The purpose of this test was to show that material can be easily be fragmented from the edges of larger fragments. Figure 41 shows the resulting gap, located in the upper left corner of the rear block, left by the corner that was blown off. Refer to Figure 39 for a view of the block before the corner was blown off.

Figure 42 shows the fragment distribution results, from the rubble destruction tests, of 0 to 2 inches, 2 to 4 inches, 4 to 6 inches, and 6 to 8 inches in diameter. Figure 43 shows the fragment size distribution of 8 to 10 inches, 10 to 14 inches, and 14+ inches in diameter.

5. CONCLUSIONS AND RECOMMENDATIONS

The key results from these tests are:

- Increasing the charge pressure from 40,000 psi to 55,000 psi increases the material removed per shot. The number and size of the fragments increased with the increasing pressure. The size of the craters on the samples that did not fracture also increased.

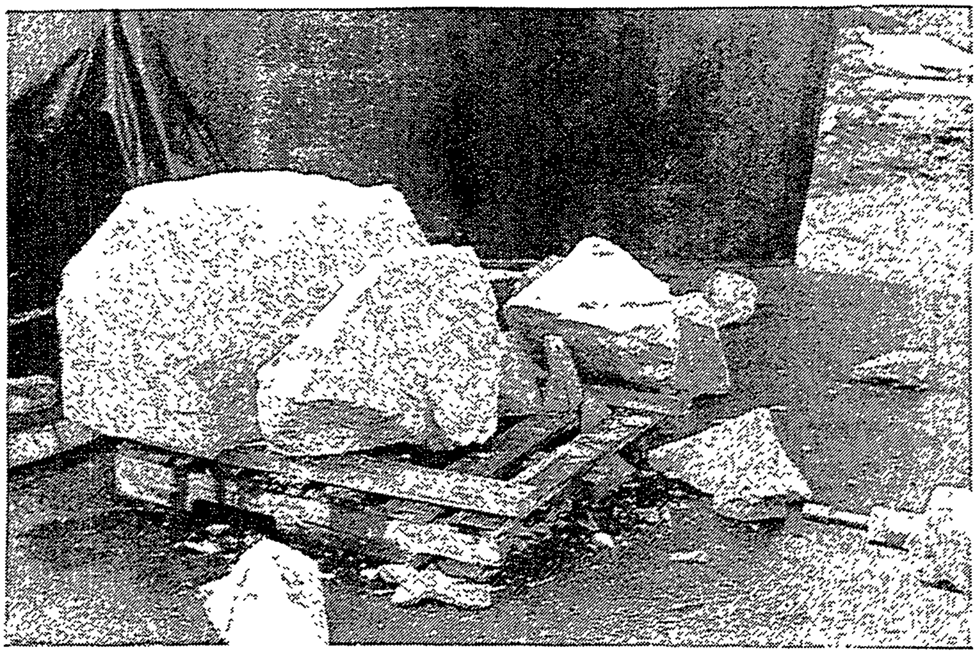


Figure 41. Fractured Results of the Upper Left Side of the Rear Block

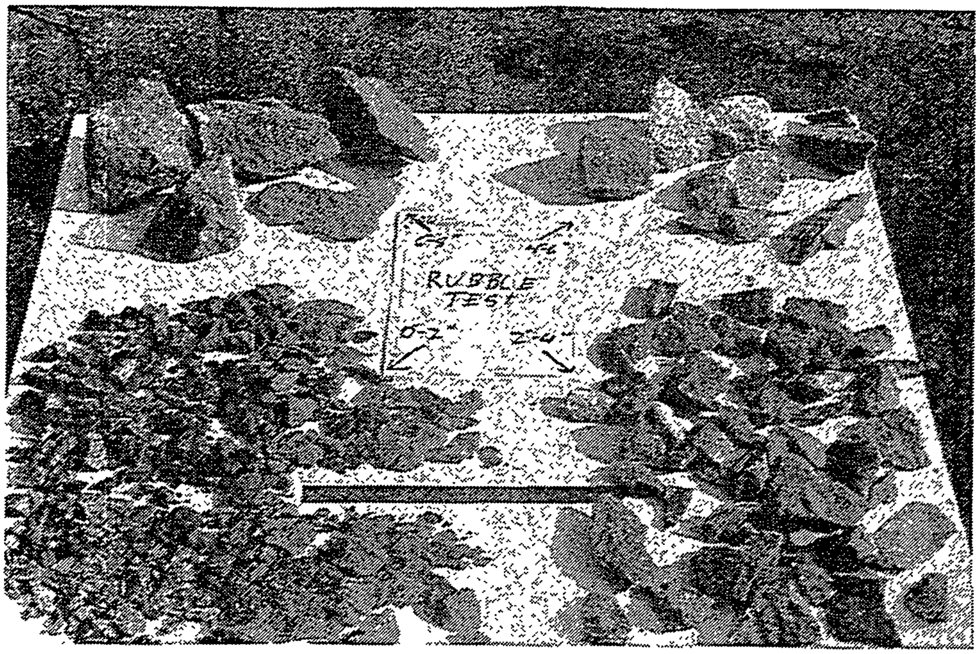


Figure 42. Rubble Test Fragment Size Distributions of 0 to 2, 2 to 4, 4 to 6, and 6 to 8 Inches In Diameter

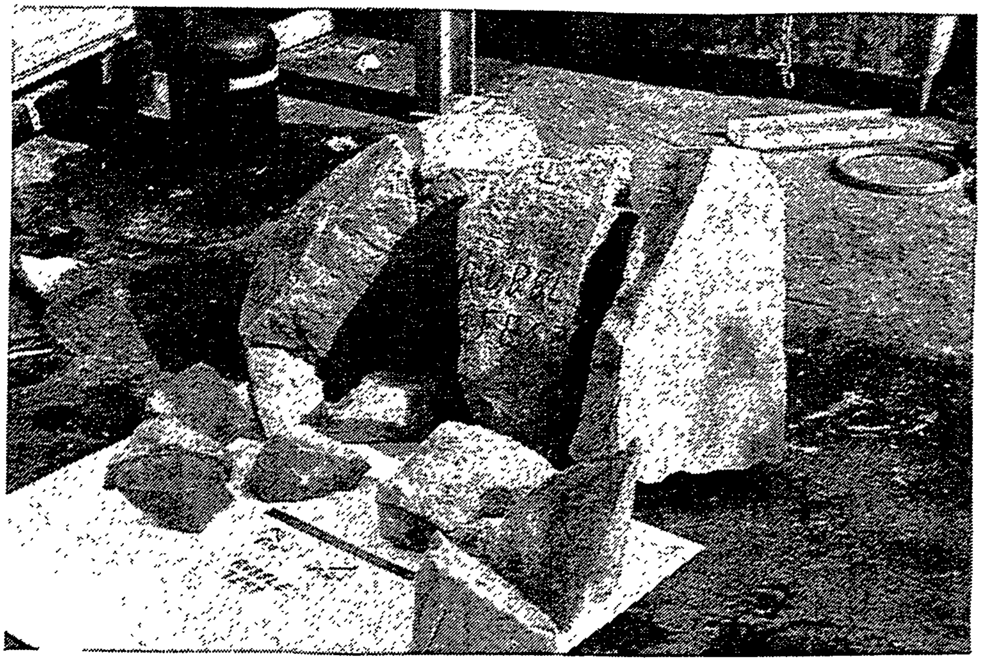


Figure 43. Rubble Test Fragment Size Distributions of 8 to 10, 10 to 14, and 14+ Inches In Diameter

- The alternate nozzle designs used were much more effective at dislodging larger amounts of material. The diverging nozzle increased the impact area on the test sample, thus creating larger craters and greater fragmenting ability. The three-hole, in-line nozzle tended to cleave the samples in half and create narrow but deep craters. The converging nozzle has the most promising results. The craters created were deeper, and the spalled-off areas were greater than with any of the other nozzles used. Also, the test samples fractured more easily with this nozzle. Figure 44 shows that nozzle geometry has a significant effect on material fragmentation.
- Inserting the nozzle into holes bored in the samples caused a large amount of fracturing. In many cases the fragments tended to be quite large, but were likely to be very dependent on the location of the free edges of the sample. The level of break up appears to be related to the depth of the hole drilled. The deeper the hole gets, the larger the fragment sizes produced. Shallow holes tend to shatter the simulant rather than fracturing it. Figure 45 shows a plot of fragment weight versus the depth of the drilled hole.
- The use of a spiral pattern with the insertion of the nozzle into holes proved to be a very successful technique for removing large quantities of small-sized material. Without the holes, insufficient fracturing occurred, preventing the pattern from providing any net benefit.
- The use of multiple shots in the same area was shown to successfully fragment large-sized samples. When firing successive shots into the same area, the small hole created becomes deeper. In essence, the HIEE is drilling a hole. When the hole gets to a certain depth, the material fractures in half. This was observed with the rubble destruction tests. With this procedure, extremely large-sized samples can easily be systematically broken down into small-sized rubble. Also, this method can eliminate the need to predrill holes to fracture large-sized material.

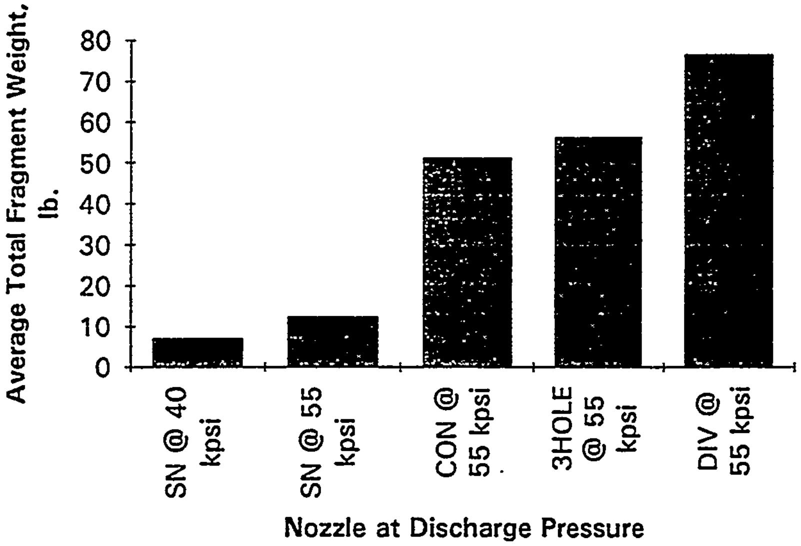


Figure 44. Nozzle Geometry Versus Average Total Fragment Weight. *SN* = standard nozzle, *DIV* = diverging nozzle, *3HOLE* = three-hole, in-line nozzle, and *CON* = converging nozzle.

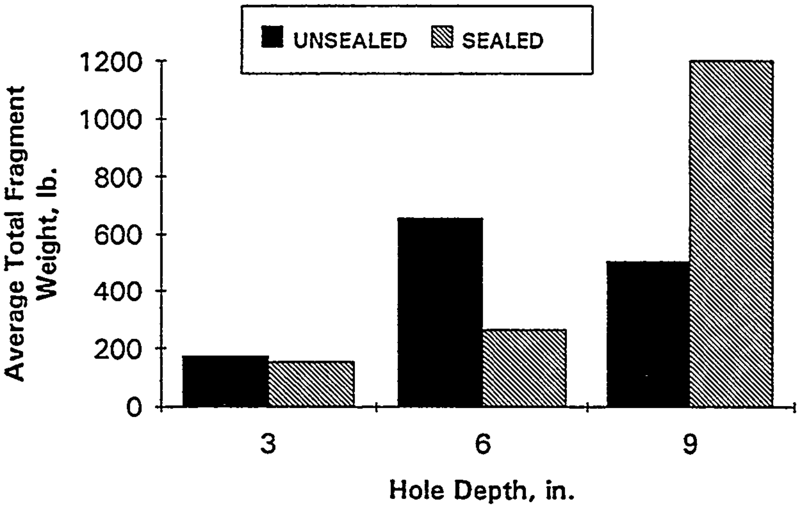


Figure 45. Fragment Weight Versus Hole Depth for the Sealed and Nonsealed Drilled Hole Tests

Based on the results from this test program, the HIEE has demonstrated its ability to quickly fragmentate large-scale salt cake simulant materials into small, easily removable fragments. The HIEE has also demonstrated that its material fragmentation ability can be substantially increased through the use of different nozzle geometries and firing techniques. Therefore, QUEST believes that the HIEE shows significant salt cake fragmentation promise and recommends that further developmental work be conducted so that the HIEE can be brought into actual application.

The following recommendations are made for future testing.

1. Further work needs to be done in nozzle design. The results from these tests show that nozzle geometry has a major effect in material fragmentation. Additional nozzle geometries should be tested to find an optimal configuration, or a set of nozzles should be tested for a particular application. Possible nozzle designs include a four-hole, square-array nozzle, a converging nozzle with a smaller outlet, or a nozzle with a wider row of holes.
2. Further investigation into multiple shots for hole drilling to fracture the simulant, as opposed to predrilling the holes, should be conducted. This should be done using very large samples. Samples under 600 pounds have been shown to be easily fractured with the method.
3. Determine the material's fragmentation ability when the outside boundaries of a test sample are constrained within a rigid container. Since it is believed that the simulants ability to fracture is dependent on the distance from the impact area to a free surface, a test series should be investigated to determine how well the material can fracture when its free surfaces are constrained within a rigid container. If the material only cracks within this container, a test sequence could be carried out to determine the best firing method to dislodge these fragments.
4. Further investigation is needed into excavation patterns or methods. One method could start with multiple surface shots and/or firing into predrilled holes to create an irregular surface and fracture lines. Then later impacts could take advantage of these fracture lines as free surfaces to further fragment the material into small pieces for easy removal. Also, since the material's ability to fracture appears to be related to size, geometry, and location of the test impact area, a critical fracture distance factor should be investigated. This distance factor can be used to locate an optimal fracture impact zone based on the material's geometry to further enhance the excavation method.

APPENDIX A.
RAW DATA

SAMPLE DATA SHEET

HYDRAULIC END EFFECTOR

Performed by

IMPACT TESTS IN SIMULATED SALT CAKE

Date

Type of test

Trial number	Sample weight before test, lb	Mark blast locn	Tool in posn	Photo test area	Standoff distance in	Charge pressure PSI	Video on	Video off	Photo test area	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags
		(X)	(X)	(X)			(X)	(X)	(X)						(X)
COMMENTS:															

→ (X) DENOTES ITEMS TO BE PERFORMED AND CHECKED OFF IN TEST PROCEDURE.

→ TRIALS SHOULD ALL BE NUMBERED SEQUENTIALLY, I.E., 1 THRU 20, NOT 1 THRU 4 FOR FIVE DIFFERENT TESTS. THIS IS MAINLY FOR EASY ID ON PHOTOS & VIDEO.

HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by HOLDEN/MILES

Date 8/11/93

Type of test 40 KSI BASELINE; 2" SOD; LONG NOZZLE

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
1	136	X	X	X	2	40K	X	X	X	136	①	N/A	N/A	N/A	N/A
2	135.75	X	X	X	2	40K	✓	✓	✓	135.75	②	N/A	N/A	N/A	N/A
3	135.25	X	X	X	2	40K	X	X	X	128.25	9" ~~5.25~~	5.25	~~2.25~~ 1.75	~~7.5~~ 7.0	X
4	131.25	X	✓	X	2	40K	X	X	X	131.25	3	N/A	N/A	N/A	N/A

COMMENTS:

① no frag. One large block with a hole in it $\O_{max}$ = 4.0 $\O_{min}$ = 1.5 D = 1.5

② " $\O_{max}$ = 1.5 $\O_{min}$ = 1.4 D = 3/8

③ " $\O_{max}$ = 1.75 $\O_{min}$ = 1.5 D = 3/9

HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by RH/PM

Date 8/12/93

Type of test 55 KSI, 2" SOD, LONG NOZZLE

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
5	$134\frac{3}{4}$	X	X	X	2"	53000	X	X	X	$134\frac{3}{4}$	① NEG.	NEG.	NEG.	NEG.	N/A
6	$135\frac{1}{4}$	X	X	X	2"	54000	X	X	X	$135\frac{1}{4}$	② NEG.	neg	neg	neg	N/A
7	130	X	X	X	2"	54000	X	X	X	$112\frac{3}{4}$	$9\frac{1}{4}$" ③	$16\frac{1}{4}$	1	$17\frac{1}{4}$	X
8	$126\frac{1}{4}$	X	X ④	X	2"	55000	X	X	X	119	$6\frac{15}{16}$	$6\frac{3}{4}$	$\frac{1}{2}$	$7\frac{1}{4}$	X
9	124	X	X ⑥	X	2"	55000	X	X	X	124	⑦ NEG.	NEG.	NEG.	NEG.	N/A

COMMENTS:

① CRATER $1\frac{1}{2} \times 2 \times \frac{3}{4}$ DP SPALLED AREA ~ $2\frac{1}{2}$ DIA $\frac{1}{16}-\frac{1}{8}$ DP

② Crater $1\frac{5}{8} \times 2\frac{3}{4} \times 1\frac{1}{8}$ DP

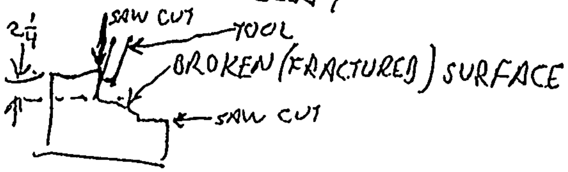
③ Crater $1\frac{1}{2} \times 2$ 4" DP From original surface

④ TOOL POSITION MOVED ~3" AFTER DRIPPING WATER MADE HOLE DURING LONG DELAY

⑤ CRATER $1\frac{1}{2} \times 2\frac{3}{4}$ · $2\frac{7}{8}$ DP FROM ORIG. SURFACE

⑥ POSITIONED ADV. TO SAW CUT EDGE (VERTICAL) $2\frac{1}{4}$ DP

⑦ CRATER $1\frac{1}{2} \times 1\frac{1}{2}$ 1" DP FROM BROKEN SURFACE →



HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by Holden, Miles

Date 25 Aug 93

Type of test Diverging Nozzle

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
10	135 3/4	✓	✓	✓	2"	54 K	X	X	✓	72 3/4	12" SIDE ①	59 3/4	3 3/4	63	✓
11	137 3/4	✓	✓	✓	2"	55 K	X	X	✓	48 ②	12" SIDE ③	86	3 3/4	89 3/4	✓
12	128 3/4	✓	✓	✓	2"	54 K	X	X	X	128	3 1/8 ④	small	small	3/4	✓
13	135 1/2	✓	✓	✓	2"	53 K	X	X	X	135 1/2 ⑤	Neg	N/A ~~Neg~~	neg	neg	N/A

8/26

COMMENTS:

tests → 10-13 Diverging Nozzle
~~14-17 Converging Nozzle~~

① crater 3 3/4 Deep × 1 1/2 × 2 ; spalled area 7" Ø WHEN BIG FRAGS REASSEMBLED

② LARGEST FRAGMENT

③ CRATER 5 1/2" OD, 1/2" × 2" ; SPALLED AREA ~8" Ø WHEN BLOCK IS REASSEMBLED

④ crater 1 3/4 OD, 1 1/2 Ø spalled area ~6" Ø

⑤ crater 1 3/4 D, 1 1/4 × 2 spalled area 5" Ø

HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by HOLDEN/MILES

Date 26 AUG 93

Type of test 3-HOLE NOZZLE

8/27

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
~~13~~14	$125\frac{1}{4}$	✓	✓	✓	2"	55K	✓	✓	✓	70 ① ②	12"	$52\frac{1}{2}$	$2\frac{3}{4}$	$55\frac{1}{4}$	✓
15	$129\frac{1}{4}$	✓	✓	✓	2"	55k	✓	✓	✓	129 ③	N/A	NA	1/4	1/4	
16	$128\frac{1}{4}$	✓	✓	✓	2"	55K	✓	✓	✓	$128\frac{1}{2}$ ④	–	–	–	–	–
17	$127\frac{1}{4}$	✓	✓	✓	2"	55 K	✓	✓	✓	$70\frac{1}{4}$ ⑤ ⑥	12"	$55\frac{1}{2}$	$1\frac{1}{2}$	57	✓

COMMENTS:

① Sample split in half - "sample" is largest piece

② crater 4" DP 3/8 × 1 3/4 spalled area 4" Ø

③ " 3 1/4 DP 1 1/2 × 2 1/4 " 7" Ø

④ crater 2 3/4 DP 3/4 × 2 " 3 1/2 Ø

⑤ SAMPLE SPLIT IN HALF - REMAINING "SAMPLE" IS LARGER PIECE

⑥ CRATER 1 × 2 1/2 × 2 1/2" DP. SPALLED AREA 3 1/2 - 5" ACROSS.

HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by HOLDEN / MILES

Date 8/28/93

Type of test CONVERGING NOZZLE

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
18	131 1/4	X	X	X	2"	55K	X	X	X	70 3/4 ①	10"	56 1/2	4	60 1/2	✓
19	126 1/2	X	X	X	2"	55K	X	X	X	61 1/4 ②	9"	61 3/4	3 1/2	64 1/4	✓
20	131 1/4	X	X	X	2"	55K	X	X	X	130 3/4 ③	neg	neg	1/2	1/2	X
21	135 3/4	X	X	X	2"	56K	X	X	X	107 1/4 ④	12"	27 1/4	1 1/4	28 1/2	X

COMMENTS:

① crater 4 1/2 OP - 1 5/8 Ø, spalled area 8-10 Ø

② crater 3 3/4" OP - 1 1/2 x 2 spalled area 7-9 Ø

③ crater 2 3/4 - 3/4 - 1" Ø, spalled area 3-4 Ø

④ crater 2 , 1 3/4 Ø spalled area 6 Ø

HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by P. Miles

Date 16 Sept 93, 17 Sept

Type of test Blind hole Tests W/no seal

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
22	3000*	X	X	X	hole 10.5 inserted 8	55K	X	X	X	2475*	33	505	20[1]	525	X
23	2475*	X	X	X	hole 6 ins. 6	55K	X	X	X	2150*	26	303.5	21.5[1]	325	X
24	2150*	X	X	X	hole 3 ins. 3	55K	X	X	X	1585*	33 #2	569.5[2]	-4.5[3]	564.5	X
25	1595	X	X	X	hole 3 ins 3	55K	X	X	X	1507*		133 1/4	N/A		X
26		X	X	X	hole 1 ins 1	55K	X	X	X					257.78	X
27		X	X	X	No Barrel 2"	55K	X	X	X						
28		X	X	X	No Barrel 0"	55K	X	X	X						

#22 179
95
173.5
57.5
505.0

#23 102.5
143.0
58
303.5

#24 104.0
112.5
353*
569.5

1585
569.5 ?
2154.5

#26 159.75
98
257.76

COMMENTS:

* 2 Ton Scale only reads in 25 lb increments

1. Frags under 2" may be inaccurate due to the large scale error. All Other frags were weighed using a scale with a 1/2 lb accuracy.
2. 353 lb ~~sampl~~ Frag's ~~fla~~ ~~was mostly~~ fracture line was mostly created in Trial #23
3. There were alot more small frags in this shot then the prior Two shots error is due ~~Too~~ The ~~a~~ uncertanty in The 2 ton Dillon scale

HYDRAULIC END EFFECTOR

IMPACT TESTS IN SIMULATED SALT CAKE

Performed by P. Miles

Date 20 Sept 93

Type of test Blind hole with seal

Trial number	Sample weight before test, lb	Mark blast locn (X)	Tool in posn (X)	Photo test area (X)	Standoff distance in	Charge pressure PSI	Video on (X)	Video off (X)	Photo test area (X)	Sample weight, lb	Size of largest fragment, in	Wt of frags over 2", lb	Wt of frags under 2", lb	Total frag wt, lb	Photo frags (X)
29	2840	X	X	X	9¼ hole ins. 7½	55K	X	X	X	1700	33"	1200 ^{3}	-60	1200	X
30	1700	X	X	X	6" hole ins 4"	55K	X	X	X	1234 ^{1,2}	33	/	/	266	
31	1234				3" hole 2" ins	65K				1060	19	153.5			

COMMENTS:

1 block split ~~down~~ across the middle

2. Approximate weight

3. Two fractured samples, 625 lb, 575 lb

QUEST INTEGRATED, INC.

21414 - 68th Avenue South, Kent, Washington 98032

(206) 872-9500

JOB Ettecr

SHEET NO. 4 oct OF

CALCULATED BY Miles DATE 4 oct 93

CHECKED BY DATE

SCALE

Pattern test B with 1" predrilled holes

0-2" ~~*~~	28 lb*	Fragment weights
2-4"	22 lb	
4+"	78 3/4 lb	

QUEST
INTEGRATED, INC.
21414 - 68th Avenue South, Kent, Washington 98032
(206) 872-9500

JOB Effect

SHEET NO. ______ OF ______

CALCULATED BY P. Miles DATE 19 Oct 93

CHECKED BY ______ DATE ______

SCALE ______

Rubble test number of shots

1st series

| | | | | | | | | | | | | ⑬

2nd series

| | ②

3rd - | | | | | | ⑥

4th - | | | | | | ⑥

5th - | | ②

6th - | | ②

7th - | ①

8th - | ①

9th - Corner 1 - 10" away 2 - 4" ②

QUEST INTEGRATED, INC.

21414 - 68th Avenue South, Kent, Washington 98032

(206) 872-9500

JOB Effect

SHEET NO. ______ OF ______

CALCULATED BY P. Miles DATE 19 OCT 93

CHECKED BY ______ DATE ______

SCALE ______

0-2"	4 3/4
2-4"	7 1/4
4-6"	6 1/4
6-8"	12
8-10"	28 1/4 + 9 1/4
10-14"	46 1/2
14"+	~~153~~ + 104 3/4 + 211 1/2

↓ 100 + 53

↑ 1st split Left side

1st split right side

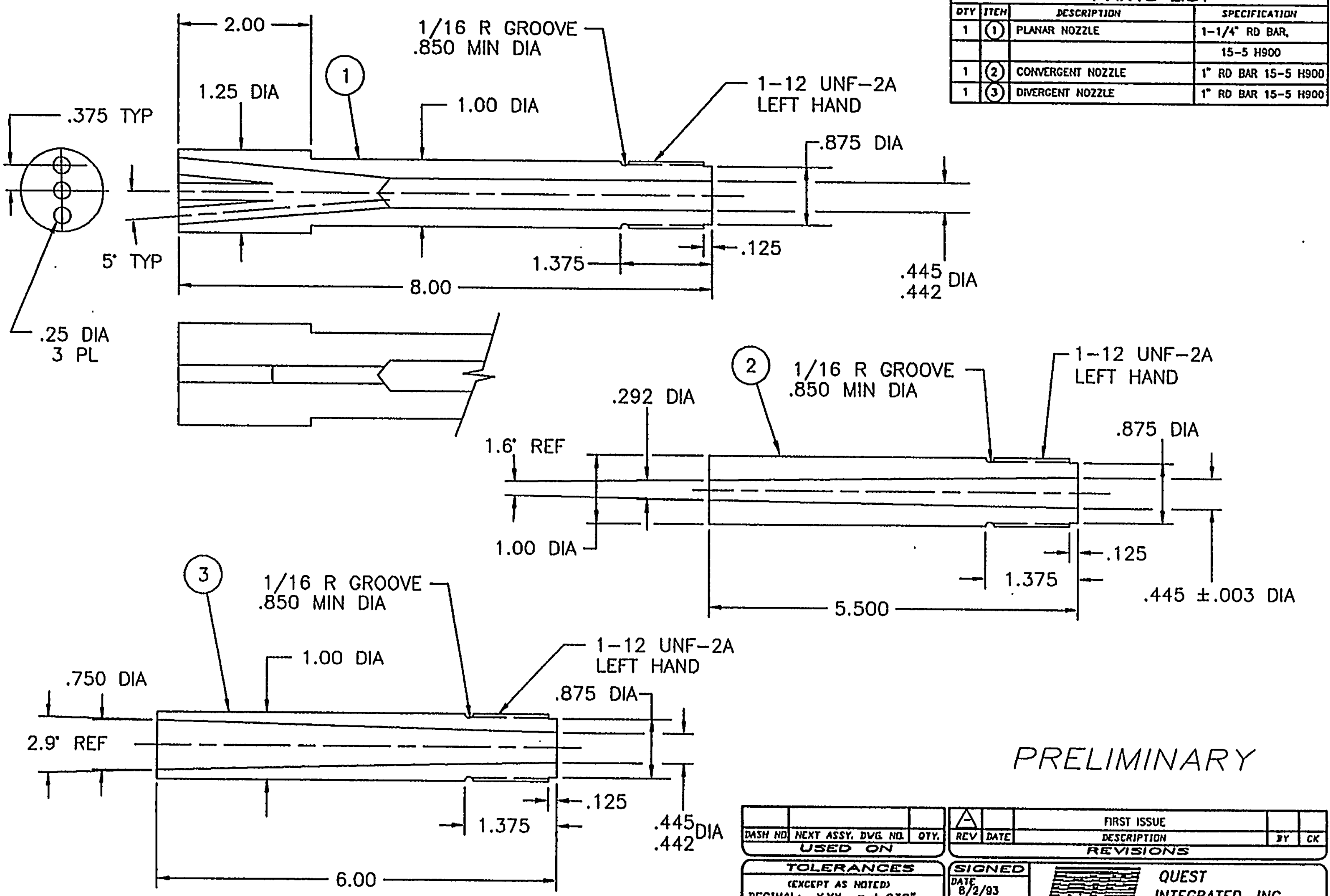
2nd split

Total wt. 574 1/2

~~Determine a critical distance to free surface~~

APPENDIX B.
NOZZLE AND SEAL DRAWINGS

PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	①	PLANAR NOZZLE	1-1/4" RD BAR, 15-5 H900
1	②	CONVERGENT NOZZLE	1" RD BAR 15-5 H900
1	③	DIVERGENT NOZZLE	1" RD BAR 15-5 H900



PRELIMINARY

DASH NO	NEXT ASSY. DWG. NO.	QTY.

USED ON

REV	DATE	DESCRIPTION	BY	CK
△		FIRST ISSUE		

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125√
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ⌀.
BREAK ALL SHARP EDGES.

SIGNED
DATE 8/2/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

QUEST
INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

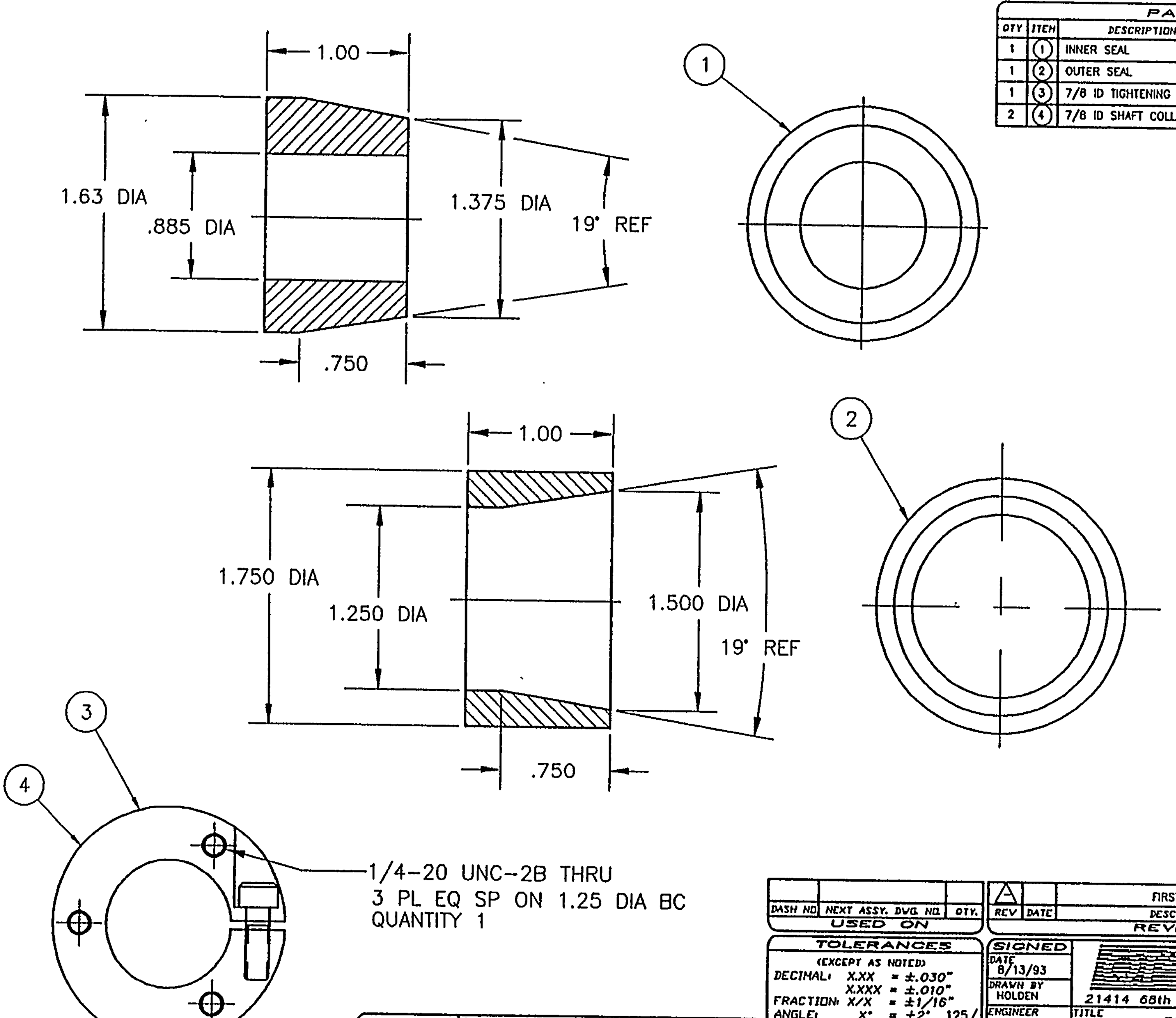
TITLE
3 NOZZLES
EFFECT

SCALE 1:2
DRAWING NUMBER A66985 REV— SH

THIS DRAWING IS THE PROPERTY OF QUEST INTEGRATED INC. AND NOT TO BE COPIED OR REPRODUCED WITHOUT WRITTEN CONSENT OF QUEST INTEGRATED INC

MAKE QTY.	CHARGE NO.		ENGR EXT.
DATE REQ'D.	QUALITY PLAN NO.		EST. HOURS
MACHINIST			ACTUAL HOURS

SHOP INSTRUCTIONS



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	①	INNER SEAL	UHMW
1	②	OUTER SEAL	UHMW
1	③	7/8 ID TIGHTENING RING	McMASTER # 6435K17
2	④	7/8 ID SHAFT COLLAR	McMASTER # 6435K17

MAKE QTY.	CHARGE NO.	ENGR EXT.
DATE REQ'D.	QUALITY PLAN NO.	EST. HOURS
MACHINIST		ACTUAL HOURS

SHOP INSTRUCTIONS

DASH NO.	NEXT ASSY. DWG. NO.	QTY.

USED ON

REV	DATE	DESCRIPTION	BY	CK
△		FIRST ISSUE		

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2° 125√
ALL MACHINED SURFACES:
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" R.
BREAK ALL SHARP EDGES.

SIGNED
DATE 8/13/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

QUEST
INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE
SEAL PARTS
EFFECT

SCALE FULL
DRAWING NUMBER A67028 REV— SH1

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