Rockwell Hanford Operations  
Richland, WA 99352

BOREHOLE PLUGGING PROGRAM

April 1978

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BOREHOLE PLUGGING PROGRAM

Staff
Waste Isolation Program
Rockwell Hanford Operations

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1.0 INTRODUCTION

Plugging boreholes, particularly oil wells, is a well understood activity. The procedures and types of materials which produce satisfactory plugs have been in use for many years. The filling of holes which penetrate geologic strata near or into a geologic repository for nuclear waste must be of such quality that the filling will provide a barrier to channeling and aqueous transport of any waste to the surface that may get dissolved by some unforeseen mechanism. The assurance of obtaining a plug of the required quality, is the essential challenge of the Borehole Plugging Program. The plug must be a barrier that prevents the waste from reaching the biosphere for a long enough time that the waste is no longer harmful to man.

The quality of the barrier for long periods is difficult to guarantee with any manufactured material. Therefore, natural earth materials are a requirement in the plug. Replacing the original material in the hole is the obvious solution, but it may be impractical in some cases. For instance, putting molten basalt into a hole drilled in basalt appears workable until one considers the fractures which probably would occur around the hole because of thermal shock during plug implantation.

The chemical and physical environment of the hole will play a major role in determining the type of material used for the plug, and the method of putting the material into the hole. A multiple barrier plug is likely to be necessary where different chemical and physical environments exist in the same hole, such as, sandstone layers and basalt flows.

Most abandoned oil wells have been plugged with some variation of Portland Cement. However, Portland Cement is a manufactured product which by itself, most likely, cannot be proven to be stable for sufficient time to satisfy the quality assurance requirements for a nuclear waste repository in basalt.

Portland Cement is commonly used for plugging holes to isolate aquifers. Plugging oil wells with cement is standard oil field practice and therefore, the
engineering procedures are well developed. The degree of isolation of the aquifers commonly required for oil wells is several orders of magnitude less than what will probably be required for borehole plugging near a nuclear waste repository.

The end product of rock weathering is some variety of clay. Clay can be made impermeable with a reasonable amount of compaction and clay absorbs chemicals carried by water which attempt to pass through it. Because of the above characteristics, some variety of clay appears to be a material which can be guaranteed for a long period of time as a borehole plug in basalt when the borehole is dry.

The problems with clay, occur in the compaction and delivery of the clay at the bottom of a 4,000 foot hole as small as 2 inches in diameter or as large as 20 feet in diameter. Compaction impermeability probably could not be achieved in a wet hole because clay readily mixes with water. The chemicals in the water also affect the action of the clay in the presence of water. Different types of clay have different degrees of expansion when water is added to dry clay. Therefore, selecting the correct degree of compaction and type of clay will be critical to achieving an acceptable plug.

1.1 Purpose

The purpose of the Borehole Plugging Program is to:

a. Locate, test and select materials suitable for a borehole plug which can be guaranteed for a long time in the chemical and physical environment of boreholes penetrating the Columbia River Basalts.

b. Design and fabricate a system of placing the selected materials in the borehole; and,

c. Demonstrate the test borehole plugs at Hanford.

1.2 Need

Methods of closing the connections from a nuclear waste repository to the biosphere that are provided by boreholes must be developed if isolation of nuclear waste is to be guaranteed.
2.0 SUMMARY SCHEDULE

A proposed summary schedule of the work required to develop and demonstrate a multibarrier borehole plug is as follows.

<table>
<thead>
<tr>
<th>WORK BREAKDOWN</th>
<th>FY-78</th>
<th>FY-79</th>
<th>FY-80</th>
<th>FY-81</th>
<th>FY-82</th>
<th>FY-83</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Studies</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Borehole characterization, material selection, system fabrication and laboratory testing.</td>
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<tr>
<td>Specification Preparation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System evaluation and specification preparation.</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Demonstration</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bid and award; demonstrate system in large and small holes.</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
3.0 HISTORY OF BOREHOLE PLUGGING

3.1 Background

Borehole plugging per se came into being soon after man began to drill holes in the ground in his search for oil and gas. Many holes were dry or nonprofitable, and these were soon abandoned. The number and condition of the abandoned wells became a problem that the individual states began to address by legislating laws outlining proper procedures for abandonment. Because oil well personnel were well acquainted with cement in their everyday drilling operations, it seemed logical to use cement as a final plugging material as well. Therefore, all legislation required a basic cement plug of some type.

Since early days, the borehole plugging industry has grown and become quite sophisticated. Two giants have emerged; they are Halliburton and Dowell. These companies have done extensive research, not on new plug materials, because they still use a basic Portland cement plug, but on additives and extenders to make cement more versatile.

Borehole plugging requirements specific to a nuclear waste repository in deeply buried geologic media parallel, but are quite distinct from the conventional borehole plugging technology which has evolved to date. For the first time, we are concerned with extraordinary long-term durability on the order of thousands of years. We must assure ourselves that our plug will remain tight even if subjected to earthquakes and extensive differential surface erosion.

As an added complexity, we are not only considering the plugging of conventional boreholes, which we know something about, but also large access shafts to the repository.

3.2 Work to Date

Our present objective is two-fold. First, to be able to plug any test holes which were used to site a repository which may prove to be unacceptable risks as possible avenues of radionuclide transport. Second, to be able to plug the large access shafts to the repository should the site be permanently abandoned. Since this dual nature exists, a separate historical perspective will be developed for the conventional borehole plug and the large access shaft plug.
3.2.1 Conventional Borehole Plugs

3.2.1.1 Office of Waste Isolation Plugging Studies

Some work specifically addressing the plugging of boreholes in the environs of a nuclear waste repository has been sponsored by the Office of Waste Isolation (OWI), Union Carbide Corporation, Oak Ridge, Tennessee. The first study was let to Dowell on March 1, 1973 and ran until October 13, 1973. They were to "...evaluate existing materials and techniques to determine the most suitable system for plugging boreholes that penetrate strata in or near prospective radioactive waste disposal sites." (1) Due to time limitations, their study was only aimed at borehole plugs as they may apply to a nuclear repository in bedded salt. In addition, many of the plugging materials included in their study (see Table I), were ruled out without complete investigation. On the whole, they were strongly influenced by their current Bureau of Mines research on similar problems in coal bearing strata. (2)

Dowell evaluated the physical and chemical properties of eight Portland cements and six specialty sealants. They also tested the possibility of returning formation material to the borehole either along or as a filler in the cementing material. (1) They concluded that Portland cement should be the primary sealant. In New Mexico, specific to the Waste Isolation Pilot Project (WIPP), they recommended Southwest Portland Cement EL TORO V or EL TORO CHEM COMP (expanding) sulfate resistant cement. They also found that by adding formation material to the cement, no additional benefits were derived, and handling problems increased. (1) They also recommended a series of steps to be followed in plugging wells. These are noted in Table II.

The scope of the study was too limited, and OWI then sponsored a more generic all inclusive study which addressed alternatives other than cement. At least four contracts were let in early 1975 which produced final reports and recommendations.

A contract was let by OWI to the Materials Research Laboratory, The Pennsylvania State University, in fiscal year 1975. They were to study the feasibility of using hydrothermal transport to produce an in situ
<table>
<thead>
<tr>
<th>Sealant Name</th>
<th>Type Material</th>
<th>Discussion of Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Type I</td>
<td>Normal of cement construction</td>
<td>Not sulfate resistant</td>
</tr>
<tr>
<td>or Class A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Type II</td>
<td>Moderate sulfate resistance</td>
<td>Tested but probably less stable than Type V</td>
</tr>
<tr>
<td>or Class B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Type III</td>
<td>High early strength</td>
<td>Not sulfate resistant</td>
</tr>
<tr>
<td>or Class C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Type IV</td>
<td>Low heat of hydration</td>
<td>Slow set – usually only moderately sulfate resistant</td>
</tr>
<tr>
<td>Class D, E, G and H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Type V</td>
<td>High sulfate resistance</td>
<td>Recommended – for anhydrite areas</td>
</tr>
<tr>
<td>Chem Comp</td>
<td>Expanding Cement</td>
<td>Recommended – if sulfate resistant</td>
</tr>
<tr>
<td>La Farge</td>
<td>Aluminous cement</td>
<td>Possibly unstable and highly retarded by salt</td>
</tr>
<tr>
<td>Plaster of Paris</td>
<td>Hydrated calcium sulfate</td>
<td>Unstable at elevated temperatures and weaker than Portland</td>
</tr>
<tr>
<td>Nukem 200</td>
<td>Silica-silicate cement</td>
<td>Water soluble and high shrinkage</td>
</tr>
<tr>
<td>Basolit 600</td>
<td>Sulfur-sulfide</td>
<td>Heated to liquify – shrinks on cooling</td>
</tr>
<tr>
<td>Dow D89-D91</td>
<td>Epoxy organic</td>
<td>Recommended – with reservations, stability questionable</td>
</tr>
<tr>
<td>Derakane 411-45</td>
<td>Polyester with styrene</td>
<td>Difficult to control set, dangerous catalyst</td>
</tr>
<tr>
<td>Phenol-formaldehyde</td>
<td>Same</td>
<td>Shrinkage on setting, questionable stability</td>
</tr>
<tr>
<td>and phenol-furfural</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sealant Name</td>
<td>Type Material</td>
<td>Discussion of Acceptability</td>
</tr>
<tr>
<td>----------------------------</td>
<td>----------------------------------------------------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>Seal Ring</td>
<td>Acrylamide in plasticizer</td>
<td>Limited Recommendation - for water shut-off</td>
</tr>
<tr>
<td>Asphalt or gilsonite</td>
<td>Same</td>
<td>Heated to liquefy, shrinks on cooling</td>
</tr>
<tr>
<td>Compacted formation</td>
<td>Same</td>
<td>No bond to formation, normally very porous</td>
</tr>
<tr>
<td>materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melted formation materials</td>
<td>Same</td>
<td>Shrinks and cracks on cooling</td>
</tr>
<tr>
<td></td>
<td>Grouting for fluid shut-off</td>
<td></td>
</tr>
<tr>
<td>Silica gel (acid set)</td>
<td>Sodium silicate reduced to pH 3 (acid)</td>
<td>Recommended - porous formation rapid set limestone</td>
</tr>
<tr>
<td>(Zonelock*)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silica gel (basic set)</td>
<td>Sodium silicate reduced to pH 9</td>
<td>Recommended - porous formation rapid coagulation salt water</td>
</tr>
<tr>
<td>(Siroco*)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland cement</td>
<td>Same</td>
<td>Recommended - fractures and vugs; will not enter porous formation</td>
</tr>
<tr>
<td>AM-9</td>
<td>Water solution of cross-lined acrylamide polymer</td>
<td>Organic - questionable permanence</td>
</tr>
<tr>
<td>Terra Firma, Terranier and Geo Seal</td>
<td>Chrome-lignin gel</td>
<td>Organic - questionable permanence</td>
</tr>
<tr>
<td>Jousten process silicate</td>
<td>Calcium silicate</td>
<td>Multiple stages of calcium chloride and sodium silicate; no control over setting or penetration</td>
</tr>
<tr>
<td>Organic resins</td>
<td>Epoxy, phenolics, etc.</td>
<td>Less penetration than silicate questionable long term stability</td>
</tr>
</tbody>
</table>

*Registered Trademark
TABLE II

RECOMMENDED STEPS TO PLUG WELLBORES
WHERE LONG TERM SEALS ARE DESIRED IN A BEDDED SALT
(Adapted from Reference 1)

1. Characterize The Well
   a. Check all available charts, logs and records on the well.
   b. Clean out the well fluids with fresh fluids of known composition.
   c. Run any additional directional, log or caliper surveys as required.

2. Prepare Well For Sealing
   a. Seal any porous zones in the vicinity of and above the salt zone.
   b. Remove casing -- At least in critical areas through the salt zone.
   c. Clean the formation face.

3. Seal The Well
   a. Portland cement should be the primary sealing material. It may be modified to meet existing conditions.
   b. An epoxy resin seal at the top and bottom of the salt zone is considered optional.
   c. A method for detecting leaks is considered optional since all have some uncertainty.

4. Monitoring The Well
plug taking advantage of the pressure and temperature conditions expected in a deeply buried waste repository. They considered five general types of hydrothermal plugs:

a. Hydrothermal cements;
b. Quartz;
c. Calcium carbonate;
d. Clay-water; and,
e. Sulfur.

Of the five, it appeared that the hydrothermal cements (Type J, such as Unadeep) met the requirements best from an engineering and economic point of view. The hydrothermal reaction takes place at 100-200 degrees centigrade to produce tobermorite, a monomineralic plugging material which expands as the exothermic reaction proceeds. (3)

An initial study by Los Alamos Scientific Laboratory sponsored by OWI indicated that subterranean melting of earth material was a potentially feasible method for sealing boreholes. An in depth study by Westinghouse(4) indicated that, although the method could be feasible, the technique had large technological difficulties associated with it.

"An analysis of various possible compaction methods," was suggested in an MIT Study. (5) These methods (five) covered the basic means to perform downhole compaction and no other methods have been discovered. The methods of compaction are for downhole operation using conventional surface drill rig equipment interface. The commercial market was surveyed for possible equipment for downhole operations or for potential modification. Where commercial equipment does not exist, concepts were outlined and their potential discussed.

This study shows that it is feasible to develop downhole compactors. Of the five basic methods, two must be eliminated due to the lack of quality control over the compaction operation. From the remaining three, two are proposed for future development. They are static and impact compaction. Roller compaction is not recommended because of its limited effectiveness in some soils. (6)
A good background on conventional borehole plugging technology can be found in the publications: "Oil Well Cementing Practices in the United States" (7) and "API Specifications for Oil Well Cements and Cement Additives." (8) A recent publication by Halliburton (9) gives the reader a state-of-the-art review of current technology, tools and materials. Procedures are recommended for plugging boreholes in possible repository sites to obtain long life or service from the plug. Also included in the procedure is a discussion of locating the wells and preparing them for plugging.

Although these publications do not specifically address the science required to plug boreholes, they give the reader a wealth of practical information gained over many years of field experience.

3.2.1.2 Sandia/NTS Plugging

Concurrent with the Office of Waste Isolation effort, Sandia has been working along these same lines since 1975. They have used Halliburton and Dowell as consultants on borehole plugging. Within the last year, they have also contracted with the Concrete Laboratory, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. Their first report, "Initial Investigations and Preliminary Data," ... covers efforts during the first year of the program. A study was initiated to find competent grouts to be used in plugging boreholes associated with radioactive waste disposal. The grouts must be durable for several thousand years and be essentially impermeable. In addition, the grouts should be pumpable to depths of several thousand feet into environments of high temperature. Grouts for use in both salt and nonsalt formations are to be studied. This program is still underway." (10)

Several hundred mixtures were considered, 59 were studied in some detail and 5 were chosen for in depth study. These mixtures were tested for the items listed in Table III. Table IV is a listing of research planned for the future. (10)
TABLE III

INITIAL TESTS ON SELECTED CEMENTS (10)

1. Dynamic modulus of elasticity
2. Compressional wave velocity
3. Unconfined compressive strength
4. Bond strength
5. Unrestrained expansion
6. Porosity with water
7. Flow
8. Time of setting
9. Permeability to water
TABLE IV
RESEARCH PLANNED FOR THE FUTURE
IN THE SANDIA STUDY(10)

1. Continue efforts in the area of mixture proportioning to incorporate as much cement and selected pozzolan as possible into a variety of mixtures commensurate with workability and pumpability, maintaining the lowest possible water/cement ratio.

2. Research the possibilities of achieving an accelerated test to determine the long-term effects of groundwater, pressure, and elevated temperature on hardened grouts.

3. Conduct gas-permeability tests on mixtures now being studied, coupled with water-permeability tests at a higher pressure level than currently used.

4. Study effects of groundwater under pressure on unhardened and semihardened grouts simulating actual downhole conditions of temperature and pressure. This would be a real-time experiment.

5. Study specimens physically cast under pressure. These specimens should be cast in a variety of different types of molds with external pressure, to simulate approximately 500 linear feet of grout, applied in order to simulate downhole pressure conditions more closely. In addition, specimens would be subjected to elevated temperatures beginning the instant they are cast and continuing throughout a testing program. These specimens would be tested for volume change and permeability. This would also be a real-time experiment with the possibility of using these specimens in the accelerated test mentioned above.

6. Enlarge the methods used to determine volume change by casting prototype diameter plugs of nominal length, possibly pressurized, subjected to programmed elevated temperatures, and appropriately instrumented. This type of casting has been done in the past with the exception of the varied, controlled temperature and pressure.

7. Study the densification of grouts under pressure.

8. Investigate possible use of chemical matching grout.

9. Continue testing of field samples from boreholes plugged in New Mexico. Specimens will be tested for gas permeability and porosity.
10. Investigate possible use of API Class H cement due to its reported low water demand. This cement could possibly be combined with pozzolans and a high-range water reducer to produce an especially dense, highly impermeable mixture.

11. Investigate the possible combination of Class H cement with ChemComp and ChemStress cements.

12. Run X-ray diffraction patterns on specimens cast at elevated temperatures and pressure to determine expansive components formed as compared with those formed when specimens are not subjected to elevated temperatures and pressures. In addition, run X-ray patterns on specimens currently under test for comparative purposes.

13. Determine porosities both before and after permeability tests on specimens that are permeable.

14. Examine all grouts currently under test with the scanning electron microscope (specimens to be examined at the same age). Freeze older specimens until younger specimens reach age of older frozen specimens. By this method, a direct visual comparison can be made. Photograph specimens.

15. Determine porosities after permeability tests run on the same specimens that were physically tested for permeability.

16. For permeable specimens, rerun permeability tests at a later age (probably one year) to determine if there is a decrease in permeability possibly brought on by the specimen being saturated with the simulated groundwater for this extended period of time.

17. Experiment with the possibility of substituting a powdered water-reducing admixture for the liquid water-reducing admixture currently being utilized. A powdered admixture would be easier to incorporate into the mixtures for field placement and, in fact, a powdered admixture will be mandatory in the event continuous mixing, as opposed to batch mixing, is used. As a means to this end, examine both Halliburton's CFR-2 and Dowell's D-65.

18. Include restrained volume change measurements using 3- by 3- by 10-inch prisms in conjunction with the unrestrained expansion measurements now being used.
19. Make an analysis of the hardened specimens of the five grouts under study to determine what the organic content is, if any.

20. Information obtained in March 1977 indicates that the new New Mexico site now under study has a groundwater analysis different from the one used in preparing the simulated groundwater used to date in the permeability studies and other tests requiring inundation. It has been suggested and generally agreed upon that the simulated groundwater currently being utilized represents one of the worst conditions that could be encountered in the field. Suggestions have been made to increase the potassium ion content by weight to approximately 50,000 parts per million to more closely simulate groundwater from the new area. In addition, it will be necessary to obtain a groundwater analysis from the new area for other possible changes. It has also been suggested that an analysis be made for silica (SiO₂) that might possibly have been leached from the permeability specimens. This was suggested because the analysis showed that potassium (K) was present in the simulated groundwater even though none had been used in the preparation of the water.

21. Make computer finite element analysis on a related expansive cement program and compare the results with those of the borehole plugging program as a guide for future work.

22. Use a strain gaged, thin-wall conduit (6 to 10 inches by approximately 10 feet long) in a vertical position with a pressure gage at the bottom on the conduit; fill with grout and note the pressure decay with time as the grout stiffens and correlate this with strain gage movement.

23. Place a fluorescent dye in the simulated groundwater used in the permeability determinations and then dissect specimens to determine from observation under ultraviolet illumination the permeability path and degree of saturation.

24. Investigate the bonding properties of selected grout mixtures to various types of rock, e.g. dolomites, anhydrites, halites, sandstones, etc.

25. Study the revised representative brine solutions for Waste Isolation Pilot Plant (WIPP) experimentation.
26. Initiate a study of the need and effect of salt in a mixed grout to possibly improve bonding and decrease dissolution of the borehole surface. This study and the one suggested in paragraph 24 can be performed concurrently.

27. Make continued readings on the specimens currently under test for as long as the specimens exist. Nondestructive testing could conceivable continue for quite a long while, however, no bond strength specimens will be available after one year.

23. Accumulate data from a variety of tests well underway in connection with the field grouting of ERDA-10, Carlsbad, New Mexico.

29. Formulate plans for testing not previously performed including: (1) preparing and using the new water formulation in future permeability determinations and inundation of specimens; (2) gas permeability tests on specimens that exhibited low or no permeability; (3) tests on specimens subjected to pressures and temperatures that would normally be found in a borehole several thousand feet in depth; (4) water permeability tests on specimens previously run and companion specimens not previously run which are at least one year old.
3.2.2 Large Access Shaft Plugging

The procedure may be viewed as an extension of plugging conventional boreholes in which the major obstacle is the change in size. One might actually view it as an easier task, since men and machinery can be at the work face as plugging proceeds, insuring a better control on quality assurance.

What technology exists has been used in plugging access shafts for underground nuclear detonations at the Nevada Test Site. Although the objective was different, the technology might prove very useful to the present project.

Specific research on plug types to be used and reaction mechanisms for large access shafts does not exist. Preliminary investigations can draw heavily upon the literature available in the area of conventional borehole plugging and build upon it as we develop the science and related technology to demonstrate the feasibility of plugging large size shafts.

3.2.3 Field Studies To Date

Only a single borehole has been plugged and monitored as part of the radioactive waste repository plugging program. This plug was placed by Dowell as a follow-up to their laboratory study. The test took place in Lyons, Kansas during the period when the salt deposits in that area were being considered for a repository. The plug made use of the original study's findings, employing a composite plug of expanding cement (NaCl saturated or unsaturated depending upon the strata being plugged) and ten foot sections of epoxy resin. Measurements of cores taken from the plug showed permeabilities for the cement ranging from 0.001 to 0.013 millidarcy. The epoxy showed no permeability. The contractor was satisfied with the procedure, but suggested that the epoxy might be replaced by additional shale filled cement.
4.0 WORK BREAKDOWN

The Borehole Plugging Program is divided into three phases which consist of: (1) material and engineering studies; (2) standard operating procedures and specification preparation; and, (3) field demonstration. The final specifications will be written after the borehole plugging system is demonstrated at Hanford.

Material Studies will include defining the chemical and physical environment of the boreholes to be plugged and then locating and testing materials suitable for plugging which can be guaranteed for long times. The range of conditions in the boreholes at Hanford will probably require at least two types of materials to fill the hole. Where nonstandard materials are required, such that standard methods of emplacement are not available, the materials will be tested to be compatible with machines to be developed and fabricated. The size range of boreholes to be plugged will require development of several machines to be used to place the material in the borehole and to assure a quality plug. These machines will have to be instrumented to record the condition of the plug during emplacement because the plug cannot be inspected after completion. The bottom of a borehole will probably be dry while the top of the hole will be wet after the steel casing has been removed. Therefore, two types of machines may be developed for use in each size hole unless one type of material can be developed which can be guaranteed for long times and be placed in a borehole which is full of water.

Specification Preparation will include a thorough evaluation of the results of the Material Studies and machine design program before the specifications are written. After the evaluation is completed, a bid package will be prepared to obtain a contractor to demonstrate the borehole plugging system. Standard operating procedures will be developed for the contractor to demonstrate the system.

The Demonstration will include preparation and instrumentation of shallow large and small diameter boreholes at Hanford to refine the standard operating procedures and to insure that the specifications can be achieved. If necessary, plugging of tunnels and shafts up to 20 feet in diameter may be demonstrated. After the system has been demonstrated in shallow holes, deep boreholes of selected diameters will be plugged in order to estimate the time and cost of full scale borehole plugging.
### 4.1 Material Studies

**Objective:**

The objective of this work has two interdependent parts. The first objective is to select and test materials suitable for borehole plugging which can be guaranteed for a long time in the chemical and physical environment of boreholes at Hanford. The second objective is to design and fabricate machines for placing the selected materials in boreholes while assuring the plug meets specifications.

**Description:**

The physical and chemical environment of the boreholes at Hanford will be described. Various natural and manufactured materials will be located and tested to determine if they are suitable for borehole plugging at Hanford. Emphasis will be placed on natural materials found within or near Hanford. Factors used for determining suitability of the materials for plugging will include economic availability, ability to be placed in boreholes as well as the physical and chemical properties of the materials. The testing of the materials will require developing techniques, designing machines and fabricating machines to place the plugging materials in boreholes, shafts and tunnels ranging in size from 2 inches to 20 feet in diameter and up to 5,000 feet deep. The machine for placing the plug will be instrumented to indicate the quality and condition of the plug during placement.

Quality Assurance is a major part of the Borehole Plugging Program because the emplaced plug cannot be inspected. Therefore, procedures must be developed throughout the entire program development to insure that the final standard operating procedures and specifications are adequate to guarantee the borehole plug meets required specifications.

The borehole physical and chemical conditions will be examined in detail. This examination will provide a description of the size, shape, wall condition, hydraulic head and chemical environment of the borehole. The chemical analyses of the basalt and its water will be determined to find out what chemicals will be present to react with the plug materials which may improve or degrade the plug. The size, shape and surface conditions will affect the ability of the plug materials to bond to the borehole walls and therefore remain in place under varying hydraulic heads or rock movement. All measurements and tests will be documented with a quality assurance program.
Analysis of materials for borehole plugging will be performed to determine their physical and chemical properties in regard to their suitability for plugging boreholes ranging in size from 2 inches to 20 feet in diameter located in the basalt and sedimentary sequence at Hanford. A thorough literature search for available machines and materials will be conducted. Materials will be examined to determine their reaction to potential radionuclides which may migrate from the repository. Materials which react to block the passage of radionuclides are preferred.

The ability to place the material in a dry borehole or a borehole filled with water will be closely examined. When necessary machines will be designed to place the materials in the borehole which can handle the selected materials. Machines will be designed to assure a borehole plug with uniform properties that can meet quality assurance criteria. The machines will have to be instrumented to provide quality assurance documentation.

The results of the laboratory analysis and testing will be reviewed by Rockwell before fabrication of the machines is initiated.

Materials and machines will be tested under laboratory conditions to determine if a uniform high quality plug can be obtained. Machines and instruments will be assembled according to the approved plans developed during selection of the materials. Model boreholes will be constructed and instrumented to simulate borehole conditions at Hanford including both dry and wet conditions. A complete quality assurance program will be developed to document all procedures and tests. Standard operating procedures will be prepared which describe how the machines, materials and instruments must be used to obtain an acceptable borehole plug.

The Borehole Plugging System developed in Material Studies will be recorded in a detailed report to Rockwell. This report will be used to prepare specifications for a field demonstration at Hanford. The results of field demonstration of borehole plugging will be used in preparation of the Environmental Impact Statement and the Safety and Analysis Report.
Key Milestones:

1. A preliminary report describing the dry borehole plugging system will be transmitted to the Department of Energy by September 28, 1979.

2. A preliminary report describing the wet borehole plugging system will be transmitted to the Department of Energy by September 28, 1979.

3. A final report describing the laboratory testing and operation of the borehole plugging system will be transmitted to the Department of Energy by February 6, 1981.

4.2 Specification Preparation

Objective:

The objective of this work is to prepare specifications for plugging large and small diameter boreholes in a basalt and sedimentary rock sequence located at Hanford.

Description:

Specifications for plugging boreholes in a basalt and sedimentary rock sequence containing both wet and dry conditions will be written based upon information developed by Material Studies. The information developed in Material Studies will be thoroughly evaluated prior to preparing the specifications. The specifications will include standard operating procedures to indicate how the plugs should be installed to meet the criteria set forth in the specifications. More than one specification will be prepared if necessary to meet the requirements for boreholes ranging in size from 20 feet to 2 inches in diameter and up to 5,000 feet deep.

The results of the evaluation of Material Studies will be used in the Demonstration work to prepare the bid package to demonstrate the borehole plugging systems.

The Material Studies borehole plugging systems report will be evaluated for completeness, clarity and suitability for a practical borehole plugging program. Economic practicality, availability of materials, quality assurance, and the potential for guaranteeing a long
Term plug will be carefully studied before specification and standard operating procedures are prepared for field demonstrations of the various systems proposed. If systems are approved, the Demonstration phase will utilize this evaluation to prepare a bid package for field demonstration at Hanford.

Specifications and standard operating procedures will be prepared in Rockwell format based upon the Material Studies report. The specifications and procedures will be submitted to a complete Rockwell review.

Key Milestone:

A report of standard operating procedures and specifications for borehole plugging systems will be transmitted to Department of Energy by February 27, 1981.

4.3 Demonstration

Objective:

The objective of this work is to field test and demonstrate that the specifications prepared in the Specification Preparation phase can be achieved at Hanford with the borehole plugging systems developed by Material Studies.

Description:

Sites will be prepared at Hanford to demonstrate borehole plugging for different diameter boreholes at shallow depths. These sites will be instrumented to determine if the systems and procedures have met the specifications. Necessary borehole plugging materials and equipment to demonstrate the borehole plugging systems which were developed by Material Studies will be obtained.

When the borehole plugging systems and procedures have been demonstrated and evaluated satisfactorily in shallow boreholes, the systems will be used to plug deep boreholes. This second demonstration will be a final check of the entire system to assure that increased depth will not affect the performance of the system.
The systems and procedures will be modified when warranted and final specifications and standard operating procedures for the borehole plugging systems will be prepared.

Quality assurance is a major part of the borehole plugging system because the emplaced plug at depth cannot be inspected. Therefore, procedures must be developed throughout the entire demonstration to insure that the final standard operating procedures and specifications are adequate to guarantee that a borehole plug meets required specifications.

A bid package will be prepared to obtain a contractor to demonstrate the borehole plugging systems selected by Rockwell from the systems developed by the Material Studies work.

Sites will be selected and prepared at Hanford for field testing and for demonstrating the borehole plugging systems in basalt and sedimentary strata present at Hanford. Sites for drilling and instrumenting shallow holes to test and demonstrate the systems will be selected first. Sites for deep hole demonstration will probably be selected from existing boreholes. The diameter of the boreholes selected will be representative of the boreholes expected to be plugged at Hanford. These diameters may range from 2 inches in diameter to 20 feet in diameter. If it is decided that the materials need to be tested in tunnels, and the systems permit this, sites for tunnel demonstration may be selected and prepared.

The materials and machines for emplacing the borehole plugs will be obtained and shipped to Hanford prior to starting the demonstration. The contractor will arrange for preparing, drilling and instrumenting the sites according to specifications prepared by Rockwell.

The borehole plugging systems will be demonstrated and evaluated in shallow holes before deep holes are attempted. This evaluation will include examination and documentation of the quality of the plugs after emplacement. If a plug is unsatisfactory, the procedures will be modified and the demonstration repeated until a satisfactory plug is obtained or the system is determined to be inadequate.

After the borehole plugging systems are demonstrated satisfactorily in shallow holes, the equipment, materials and procedures will be tested in deep boreholes.
This second test is to evaluate the systems for the effect of increased depth on the systems.

A final report, combining all results of the various tests both satisfactory and unsatisfactory, will be prepared. This report will include a description of specifications obtained, description/material used, manufacturing drawings and descriptions of machines used, standard operating procedures used to obtain specifications and an evaluation of the borehole plugging systems.

Key Milestones:

1. The borehole plugging systems will be demonstrated in shallow holes by June 25, 1982.

2. A final report describing the demonstration of the borehole plugging systems and standard operating procedure will be transmitted to the Department of Energy by June 3, 1983.

5.0 SCHEDULE FOR WORK BREAKDOWN

The first important accomplishments in this program will be the preliminary reports on the wet hole and dry hole plugging systems (Figure 1). These reports will include selection of materials for plugging and design of machines to place the materials in the boreholes. These will be followed by fabrication of the machines and laboratory testing of the materials and machines. Standard operating procedures will be developed to assure the system produces a uniform plug of high quality.

Rockwell will evaluate the system report and prepare specifications for demonstration of the systems at Hanford. During the demonstration in shallow and deep holes in the range of hole diameters found at Hanford, the systems and procedures will be modified where necessary to meet the specifications. The end result will be a report describing a working system.

6.0 CONSTRAINTS AND DEPENDENCIES

The primary constraint is knowing how much time will be required for definitive laboratory and field testing. The estimates provided are thought to be adequate, but until the materials are selected and the chemical environment is defined, the length of time for chemical reactions to reach equilibrium can not be defined.
Successful location of materials which are compatible with the range of chemical and physical environments distributed over approximately 1,000 feet of borehole may be a more difficult task than anticipated.

The success in developing quality assurance procedures to guarantee an acceptable plug may require unique instrumentation not currently available. Developing instrumentation could delay the program.

Preliminary characterization of the chemical and physical environment is dependent upon work in progress within the Site Studies Program.

7.0 QUALITY ASSURANCE PLAN

A quality assurance program will be developed and implemented to assure that all policies, procedures or instructions are in compliance with the requirements set forth by Rockwell in RHO-CD-318 which are in compliance with 10 CFR 50, Appendix B.

The quality program and all aspects of the quality program shall be subject to review and approval by Rockwell Quality Assurance.

Those requirements which apply are as follows:

1. Organization
2. QA Program
3. Design Control
4. Procurement Control
5. Instructions, Procedures And Drawings
6. Document Control
7. Control of Materials
8. Identification of Materials
9. Inspection
10. Test Control
11. Calibration and Test Equipment Control
12. Handling, Storage and Shipping
13. Inspection, Tests and Operating Status
14. Nonconforming Materials
15. Corrective Action
16. QA Records
17. Audits

8.0 IMPACT IF NOT FUNDED

This program is necessary to select materials and procedures that will block pathways provided by boreholes, shafts and tunnels through which radionuclides might reach the biosphere if the wastes should become solubilized by some yet unforeseen mechanism. Without plugging these pathways the isolation provided by the geologic repository may become compromised. Provisions for permanent storage and abandonment of the repository
can guarantee that man-made pathways will not be the means for waste to reach the environment. The borehole plugs must resist breaching by most anticipated events which can occur while the radionuclides are dangerous to mankind.

Careful selection and testing will be required to meet the quality assurance requirements of the Safety Analysis Report and licensing. Proven methods and materials for borehole plugging, which include Quality Assurance, in a basalt and sedimentary rock sequence do not exist at present.

9.0 REFERENCES

1. L.H. Eiler, Borehole Sealing, DL 9018-5, Dowel Division of the DOW Chemical Company, (1973)


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10. J. A. Boa, Jr., Initial Investigation and Preliminary Data, Miscellaneous Paper C-78-1, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi (1978)

11. L. H. Eiler, Sealing AEC #1 Well, Lyons, Kansas, DL9018-6, Dowell Division of the Dow Chemical Company (1974)