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7. Abstract

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

This integrated test plan describes the demonstration of a Surface High Resolution Seismic Reflection acquisition system using swept source technology. The test described here is preliminary in nature to determine if the technique can produce a usable time section with recognizable reflection energy.

Compressional wave data will be collected along a previously occupied seismic line associated with a recent seismic survey north of the 300 Area. The swept source system will be employed testing two very different high resolution vibrator sources, one with a frequency range from 10 to 500 Hz and a smaller unit with a range from 20 to 1500 Hz. This will enable a precursory comparison of two vibrator data sets with standard impulse data. Both linear and nonlinear, variable amplitude frequency sweeps will be studied to determine the optimal input signal for the specific earth filter. The data will be evaluated for the presence of reflected energy, signal strength, frequency content and signal-to-noise ratio.

At present the data may not be fully processed since the test objectives require only preliminary cross correlations to compare raw field records. If borehole acoustic data can be acquired, the data will be processed and evaluated for reflection continuity and geologic control. The final product will be an interpreted geologic time section from which the geologic horizons can be mapped.

The results of this test will have direct benefits for the 300 Area Operable Unit for several reasons. If the water table can be distinguished from the Hanford\Ringold formation contact, then the high permeability Hanford-filled channels can be mapped. This is useful since the channels should be preferred fluid migration paths within the saturated zone. Next if details on the configuration of the Ringold middle mud can be discerned, this will allow detecting fluid pathway through the mud and confirm the depositional nature of this unit. Finally by mapping the extent of the lower confining mud unit, areas where the polluted unconfined and lower confined aquifers communicate might be located.

In addition to the system discussed above, another source and acquisition method will be tested by gathering data along the same seismic line. This system uses a lightweight source that produces a high-velocity shock wave that strikes the earth's surface causing an acoustic wave to propagate downward. This source is employed with a moving two-geophone array and a frequency enhancing signal modifier. The acquisition method is nonconventional and is reported to eliminate obstructing noise such as groundroll and air blast. It is unexpected that this system will have the imaging ability of the vibratory systems. However it could prove to be economical for shallow applications when only compressional energy is needed.

1.2 BACKGROUND

At the Hanford DOE Site, current practices of subsurface data acquisition limit knowledge of the subsurface to borehole information either by direct sampling or by gamma ray logs. This results in data that extends at best a few inches from the hole. These severely limited data have several disadvantages. First, supra-basement sediments are usually terrestrial in nature and consequently are very heterogeneous both vertically and laterally frequently on the order of 10's of feet. The heterogeneous nature of these sediments leads to complex fluid migration paths both in the vadose zone and the groundwater. With borehole control alone, the geologist can only "guess" on how to extend lithologies between boreholes and termination of units must be assumed. Indeed, some features such as perched water zones or details of structure can be missed entirely. By the time these interpretations are incorporated into conceptual models of contaminant plumes, only gross approximations can be made unless well control is closely and evenly spaced. At the 200 West Area of the DOE Hanford Site, this is particularly true in the groundwater where most wells do not extend far below the water table.

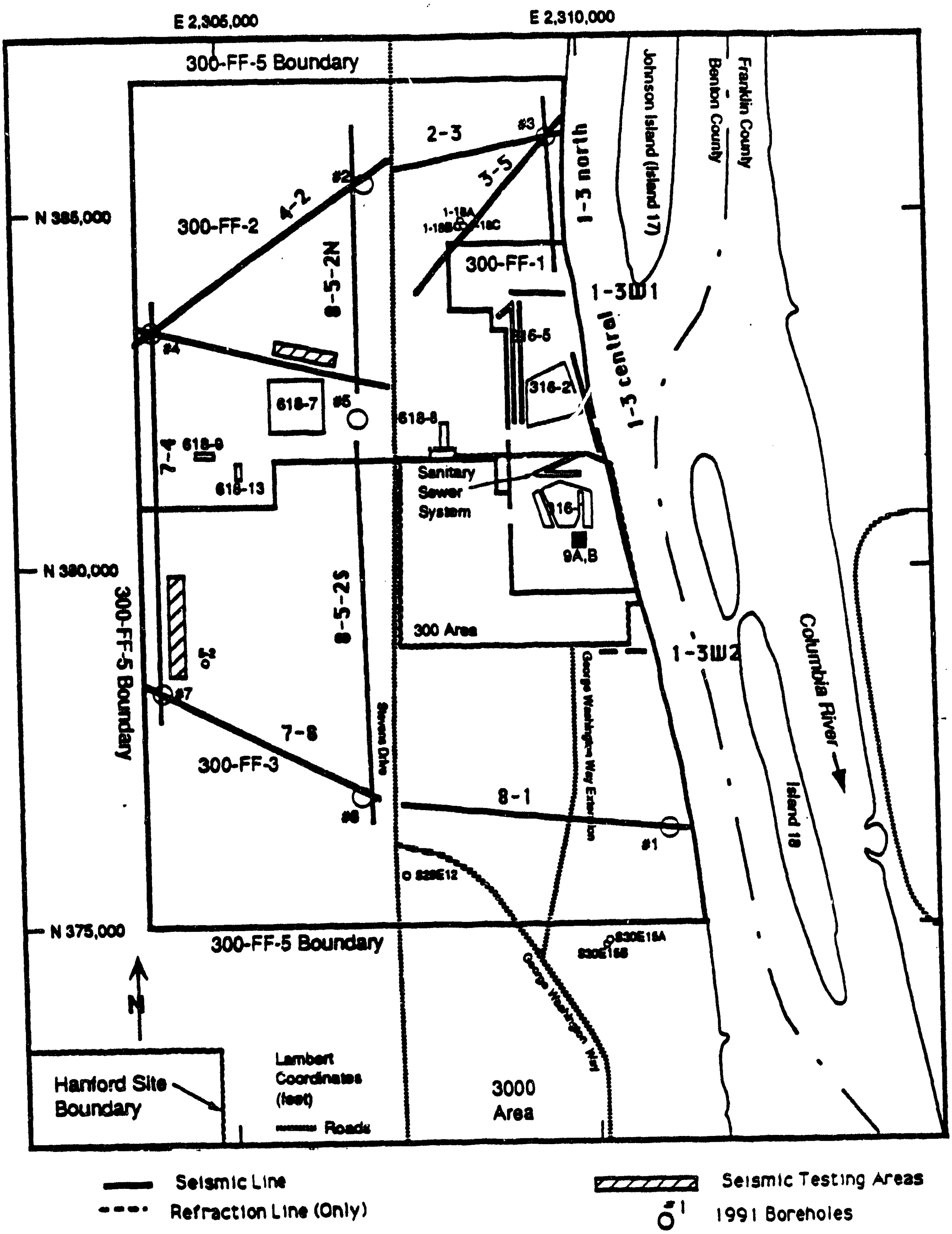
Although surface seismic techniques have been used in the past at the DOE Hanford Site, the acquisition equipment and deployment methods were basic petroleum industry standards that were designed to purposely avoid mapping the unconsolidated sediments of interest to the environmental community. Consequently there was limited success in imaging the basalt surface with those methods. Since the early 1980's, a few individuals have designed and tested acquisition equipment meant to discern the shallow (i.e., less than 1000 feet) geologic environment. In the last 5 years, the area of Shallow High Resolution Seismic techniques has rapidly expanded and advanced both in the methods of deployment and acquisition equipment. Recently swept sources were designed for environmental needs with input frequencies as high as 500 to 1500 Hz. These swept sources will finally allow meaningful spectral shaping of the input energy while greatly increasing the frequency bandwidth of the input signal to optimize the resolution of the returned signal.

The value of detailed subsurface mapping is far reaching. Compressional wave propagation is highly dependent on the bulk modulus (compressibility) of the porous medium through which it travels. As the porosity changes between lithologies, the wave travels with a different velocity and thus, the acoustic impedance (velocity·density) varies. The result of the seismic reflection method is a map of the acoustic impedance boundaries that indirectly relates to porosity. Although saturated fluid migration is controlled by permeability not porosity, it is unlikely that the two material properties do not track together in unconsolidated porous medium. Thus the seismic reflection technique has the potential to provide fluid migration paths for contaminant plume tracking, risk assessment, remediation design and optimal well locations for remediation and long term monitoring applications.

1.3 SITE SETTING

This preliminary test will be located north of the 300-FF-1 fence near the well cluster 399-01-18A, B and C (Figure 1). This is the site of a previous reflection study and by occupying the same line marked 3-5, this newly acquired data can be compared to the previous results.

Figure 1. Location Map, 300 Area.



2.0 TECHNOLOGY DESCRIPTION

2.1 SHALLOW HIGH RESOLUTION REFLECTION TECHNIQUE

Since the requirements of environmental and engineering applications are different from that of the oil industry, there has developed a different suite of acquisition equipment to acquire shallow seismic reflection data. In fact recent advances in shallow sources may significantly increase the quality and resolution of future surface surveys. The goal of shallow high resolution surveys is to reduce the noise and enhance the signal to generate and record high frequency acoustic signal from depths up to 1000 feet. Therefore, the challenge is to input much greater frequencies at the source and be able to detect and identify a weak signal with the receivers and recorder.

A recent review by Steeples, (1990) explains the advantages of spectral shaping, a key advantage of vibratory (or swept) sources. The input signal of the ideal shallow seismic source would contain a broad band of frequencies with more energy concentrated at the higher frequencies. The wide bandwidth increases the information-carrying capabilities of the system allowing greater resolving power. Since the earth acts as a low-pass filter differentially attenuating the higher frequencies, the source should have an output energy that can be controlled as a function of frequency. Furthermore, to allow separate shots to be stacked, the source must be repeatable. Stacking repeated shots compensates for attenuation of the energy. Also the energy should be well coupled to the ground and yet be nondestructive. And finally, air-coupled waves and groundroll should be minimal to avoid interfering with reflected waves.

When it became necessary to explore for and develop stratigraphic reservoirs, the petroleum industry developed a land source called a vibrator that allowed varying the input energy while sweeping from low to high frequencies. This vibrator system rapidly became the standard for land acquisition surveys because it produced a superior signal to noise ratio at higher frequencies (i.e., 60 Hz). Generally the highest input signals are around 90 Hz. The earth and large vibrator define a mass-spring system with natural resonance frequencies typically between 15 and 30 Hz. The generation and coupling of energy to the earth will be less difficult within this limited frequency range. As the vibrator is operated farther from the resonance frequencies, it must provide higher drive forces to generate sufficient energy, especially at frequencies necessary for high resolution work. Consequently there is a difference between the peak design frequency and the peak operating frequency. This lack of ability to get 100 Hz plus signal into the ground and the cost to deploy and maintain the large vibrator trucks eliminates its use for shallow applications.

Recently several swept sources were developed that have peak frequencies of 500 and 1500 Hz respectively with variable hold-down force while still maintaining mobility and reasonable costs. One was designed by a leading manufacturer of the larger vibrators but specifically for use as a shallow high resolution source. This source has most of the ideal characteristics discussed previously, specifically a broad bandwidth from 10 to 550 Hz, output energy controlled as a function of frequency concentrating energy at the higher end, repeatability, and nondestructiveness. If the frequency sweep begins above that at which groundroll propagates, then this high amplitude interfering noise should be significantly reduced.

2.2 SURFACE EQUIPMENT

There are three basic parts to any surface seismic reflection acquisition system, a seismic source, acoustic receivers and a seismic recorder. For this preliminary test, two swept sources and one impulse source will be employed. One swept source is truck-mounted while the other is hand portable (approx. 150 lbs).The larger vibrator is on a standard 3/4 ton pickup truck. Although both are transportable through rugged terrain, the smaller, portable unit can be used where space is limited such as between buildings and fences due to the small base plate size of approximately 12 inches. Also the frequency range (20 to 1500 Hz) allows for ultra-high resolution imaging subsurface changes of less than a foot. However the truck-mounted vibrator has significantly greater hold-down weight and will provide superior depth penetration with a base plate of 3 to 4 feet. This unit can generate frequencies from 20 to 550 Hz. The impulse source is a lightweight, medium-energy source using a high-velocity shock wave. It has no control on the frequencies put into the ground.

Once the signal has been coupled to the subsurface, the reflected signal is received at a series of geophones planted into the ground along the seismic line. For the purposes of this test, these receivers will be standard 28 Hz vertical geophones to sense compressional wave motion.

Finally the signal at each geophone will be recorded as a voltage with a "state-of-the-art", 144 channel, 24-bit recording system that is located inside the field vehicle. This system is equipped with software to perform the initial cross-correlation processing to remove the original input signal.

2.3 DOWNHOLE VELOCITY

To perform a preliminary evaluation of the data, it is not necessary to fully process the data into a standard, stacked time section. However if it does become possible, borehole velocity control will be acquired in well 399-1-18C using the uphole velocity method. A pneumatic acoustic repeater will be used as a borehole source to provide an acoustic signal. This device has an adjustable high-pressure chamber that rapidly discharges to form a pressure pulse in the hole. This pulse couples into the ground as a compressional wave. The tool is approximately 3 feet long and is designed to operate in holes down to 3 inches in diameter. Compressed air is supplied from the surface via a high-pressure line. The release of pressure is controlled electronically from a triggering unit on the surface. Air will be exhausted to the borehole. The source is fluid-coupled and thus requires a liquid-filled borehole to function properly. For the region in the well above the water level, the hole is packed off and filled with water. Later this water is removed so that no water is discharged to the wellbore.

3.0 DEMONSTRATION OBJECTIVES AND PARAMETERS

3.1 DEMONSTRATION OBJECTIVES

- Determine if the technology can acquire recognizable reflected energy at a variety of times and at various distances from the source. Compare signal strength and clarity to the previously acquired raw field records and evaluate the improvement.
- Evaluate the theoretical vertical and horizontal resolution of the received signal.
- Determine the frequency input sweep that optimizes the reflected energy. Evaluate if one vibrator has different possible applications than the other based on differences in reflected events.

3.2 DEMONSTRATION PARAMETERS

The methods that will be employed to evaluate the technology performance within the scope of objectives given above involve standard industry parameters.

- Reflected energy is recognized by the hyperbolic normal moveout seen on minimally processed data. The vibrator data will be evaluated after initial deconvolution and cross-correlation of the data. The effect of refracted arrivals, groundroll and air blast can be determined by the pattern, amplitude and frequency of these arrivals in the wave train.
- By applying a window to the reflected events identified on a given trace, a power spectrum will be generated displaying frequency versus amplitude. This graph allows the frequency content of the signal to be evaluated. Then the maximum vertical and horizontal resolution will be determined using the 1/4 wavelength rule for the vertical resolution and fresnel zone calculations for the horizontal resolution.
- Optimization of the input frequency is carried out during the field testing prior to acquiring the final data set. Various sweep configurations are run consecutively until the acquired data displays the best reflected signal and the least amount of coherent noise.

3.3 DATA PROCESSING

Preliminary cross correlations of the data will be made at the time of acquisition. Later a deconvolution of the source signal and a more complete cross-correlation will be applied and power spectra will be generated. All the test objectives can be met with this relatively unprocessed data. If the borehole velocity data is acquired, then further processing may be justified but will be done at the discretion of the companies performing the test.

If successful this test has specific utility to the cleanup effort at the 300 area. By mapping details of the lithologic units in the saturated zone, a better understanding of fluid migration paths can be achieved. For example, the results from this test could define the pinchout of the lower confining unit against the basalt basement. Information like this is useful to evaluate the risk of contaminating the lower aquifer, to map fluid migration paths for plume tracking, and to assist in designing an appropriate remediation strategy and for better placement of monitoring wells.

4.0 REGULATORY COMPLIANCE

This section identifies the regulatory compliance requirements for this field demonstration. The major requirements for the demonstration are derived from the *National Environmental Policy Act* (NEPA); the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA); and RCRA. Because there are no residuals from this demonstration, no requirements under the Clean Air Act, Clean Water Act, or other federal or state environmental laws are specifically applicable.

4.1 NEPA

The National Environmental Policy Act (NEPA), 42 USC 4321 et seq., is the basic federal charter for protecting the nation's environment. NEPA's focus is to ensure that federal agencies, such as the DOE, give appropriate consideration to environmental impacts in their decision-making.

NEPA compliance for this demonstration is achieved by reference to DOE's determination of December 4, 1992 that characterization and environmental monitoring activities on the Hanford Site fit within a typical class of action currently available for Categorical Exclusion (CX) in Subpart D of the U.S. DOE NEPA Implementing Procedures, 10 CFR 1021. While site characterization is not the central purpose of the demonstration activities described in this integrated test plan, these activities will produce data and information that will be very useful for characterization of the environmental conditions of the 300 Area Operable Unit's subsurface (see sections 1.1 Purpose and 3.3 Data Processing). The minimal environmental impacts that these demonstration activities are likely to cause are well within the impacts described in the materials supporting that categorical exclusion determination. Prior to initiation of the activities under this test plan, detailed cultural and biological resource reviews will have been performed and all 10 CFR 1021 requirements and all other conditions stated in DOE's categorical exclusion determination will have been fulfilled. Therefore, the demonstration activities described in this test plan need no further NEPA review and documentation.

4.2 CERCLA

The *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), 42 USC 9601 et seq., is designed to manage the unplanned, uncontrolled releases of hazardous substances. In particular, CERCLA is the governing framework for the Environmental Restoration program at the Hanford Site. Depending on test results, the data generated could contribute to environmental restoration site characterization in the 300-FF-2 or 300-FF-5 operable units of the 300 area.

4.3 RCRA

Subtitle C of RCRA, 42 U.S.C. 6921-6939b, establishes a comprehensive program to regulate newly generated hazardous waste. Administered by Ecology and EPA, RCRA Subtitle C requirements are contained in Chapter 173-303, Washington Administrative Code (WAC 173-303), and in 40 CFR Parts 260 through 272 (40 CFR 260-272), and apply to the generation, accumulation, treatment, storage, and disposal of hazardous waste. No solid, hazardous, or mixed wastes will be generated by this test. In the event such wastes are generated, they will be managed in accordance with applicable RCRA requirements, including WHC Environmental Investigations Instruction (EII) 4.2, "Interim Control of Unknown, Suspected Hazardous, and Mixed Waste" (WHC 1988a).

4.4 CULTURAL RESOURCES REVIEW

This demonstration will take place along a seismic line that has had field trucks and trailers operated along it. In addition the holes used to bury the earlier geophones still exist; however since the potential need exists to bury the geophones deeper than 12 inches, a cultural review has been performed. It was determined that no special restrictions exist. An excavation permit has been prepared to accompany this test plan.

5.0 HANFORD COMPLIANCE

This section identifies Hanford compliance areas for this field demonstration.

5.1 SAFETY

Activities under this integrated test plan (ITP) will be governed by the Site-Specific Health and Safety Plan for the site and the Radiation Work Procedure (RWP) Number D-072. Although the work site is not in a radiation zone, intermittent Health Physics coverage will occur during and upon removal of the geophones. The well used to obtain velocity control will be screened by a Health Physics Technician (HPT) before use. Decontamination procedures, if necessary, will follow EII 5.4, Rev. 4, "Field Decontamination of Drilling, Well Development and Sampling Equipment" (WHC 1988a). The Health and Safety responsibilities may, at times, be delegated to the Field Team Leader in the absence of the Health and Safety Officer.

5.2 QUALITY ASSURANCE

All work on the Hanford Site is subject to the requirements of DOE Order 5700.6C, *Quality Assurance* (DOE 1991), which establishes broadly applicable Quality Assurance (QA) program requirements.

To ensure that the field demonstration activities are consistent with DOE Order 5700.6C, *Quality Assurance*, all work will be performed in compliance with WHC's QA manual, WHC-CM-4-2 (WHC 1988b) and with applicable procedures outlined in the QA Program Plan, WHC-EP-0383 (WHC 1990). This QA program describes the various plans, procedures, and instructions that will be used by WHC to implement the requirement of DOE Order 5700.6C.

The objective of the test plan is to ensure that the data obtained and the conclusions drawn are sufficiently accurate and reliable to support decisions associated with the evaluation of the demonstration.

5.3 TRAINING

No special training will be required for personnel not entering radiological zones. However, standard training, including the Occupational Health and Safety Administration (OSHA) training for personnel working at hazardous waste sites, plus all relevant training required for specific radiological zones, will be required for any personnel entering these zones.

General training, medical, and security requirements for access to the Hanford Site and field demonstration site can be found in the *Field Access Guide for Visitors of the VOC-Arid Integrated Demonstration Site* (McDonald-McNamar 1993). Specific training and medical requirements to get into certain radiological zones are given in RWP Number D-072.

6.0 ORGANIZATION AND RESPONSIBILITIES

The field test will be performed by Demonstration Operations personnel working with the principal companies demonstrating the technique. General organization and responsibilities for Demonstration Operations is shown in Figure 2. General and specific responsibilities to the field demonstration follow.

6.1 DEMONSTRATION OPERATIONS

Demonstration Operations is responsible for site characterization, engineering, and conduct of field demonstrations. Demonstration Operations ensures regulatory and DOE/Hanford compliance for field demonstration activities.

6.2 PROJECT ENGINEER

The project engineer is responsible for coordinating with the principal investigators and the field team leaders and ensuring the availability of needed equipment and materials.

6.3 FIELD TEAM LEADER

The field team leader is responsible for overall technical field management of the project and control of site access. All onsite personnel report through the onsite field team leader to accomplish their work.

6.4 PRINCIPAL INVESTIGATOR

Because this test is a cooperative effort with several commercial companies, there is no principal investigator. However the companies will assist with the following:

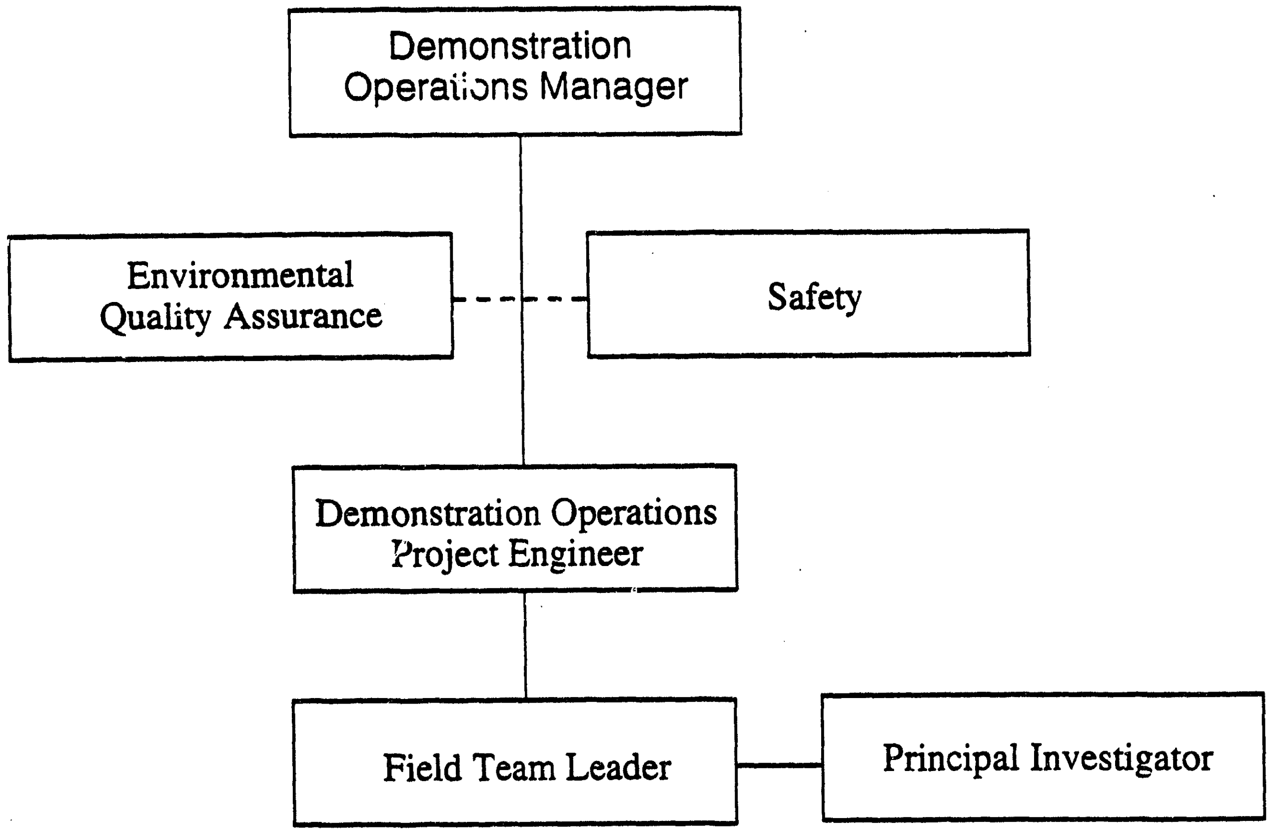
- ensure that the test objectives are met
- conduct the testing through coordination with the field team leader
- provide all equipment to be tested
- provide personnel to perform the test and assist in analyzing the results

7.0 DESCRIPTION OF TASKS AND PROCEDURES

The individual tasks for this demonstration are presented below in the order that they will be conducted except for the acquisition of the borehole velocity data which is a separate operation.

- Set 150 geophones along the seismic line at 2.5-to 5-foot spacing, lay CDP cables next to geophones and connect geophones to the cables. Each geophone must be checked for a firm plant and reset if necessary. This is an important quality control check.
- Connect CDP cables to leaders which connects the geophones to the recording system located in the field vehicle. At this point, the vibrator is connected to the recorder through the trigger channel to allow recording to begin precisely when vibrations start.
- Geophone integrity is tested to be certain receivers are properly connected, signal can be adequately received and that geophones are as "quiet" as possible. Also a self-calibration of the seismic recorder is conducted and the entire acquisition system is checked.
- The next procedure is frequency sweep testing. A series of sweeps are performed beginning with linear functions varying the frequency range progressing to more complex nonlinear sweeps that allocate more energy to the high frequency range. After each sweep, the returned, cross-correlated signal is examined for the presence and clarity of reflected energy, noise reduction and frequency content.

Figure 2. Typical Field Demonstration Organization.



- Once the optimal frequency sweep has been identified, the test will move into "production mode". The source will be activated in an end on spread while 96 channels are monitored then moved 5 feet along the line as the next set of 96 channels are recorded resulting in 48 fold coverage. The near geophone spacing is 5 feet. If necessary successive records will be stacked to reduce incoherent noise and enhance the desired signal. Once acquisition is complete for one swept source, testing will begin on the next source. The impulse source will tested separately since the acquisition method is sufficiently different.

- Comparisons will be made amongst the two swept source data sets and the initial dynoseis data collected previously. The results will be evaluated to meet the stated objectives. If the borehole velocity control is acquired, the vendors have agreed to fully process the data at a later time in FY95.

- Prepare a brief final report with the correlated data tapes included.

The following procedures will control the acquisition of the borehole velocity control using the uphole velocity method but with the source in the hole and the receiver at the surface.

- The borehole pump is removed and the well is swabbed for contamination and scrubbed to remove scale and rust. Any fill is removed and a video camera is run to determine general well condition. If possible, the video should be saved.

- Below the water level, the tool is lowered to the bottom and triggered every foot as the tool is raised. The direct arriving wave is detected at the surface with one geophone planted next to the well.

- For the region above the water level, a packer is set just above the uppermost screened interval and the wellbore filled with water. Then data acquisition proceeds as before.

- Once the data are collected, the water is pumped from the well. The pump is replaced and the well redeveloped.

- The data are analyzed to produce a velocity-depth table that can be used to process the data and to correlated reflectors to specific geologic horizons.

8.0 DEMONSTRATION SCHEDULE

This demonstration is scheduled for August, 1994. The well will be prepared the first week of August and the geophones (150) set prior to mobilization of the truck-mounted equipment. Initial testing begins the second week in August, 1994 and both sets of vibrator data should be collected within 14 days. Once the raw data records have been deconvolved and correlated, the preliminary evaluation can be made. Results will be reported briefly in a short document by September 30, 1994. If it is decided that the data will be fully processed and interpreted based on the velocity control, the schedule for reporting results will be set by the participating companies.

9.0 REFERENCES

DOE, 1991, *Quality Assurance*, DOE Order 5700.6C, U.S. Department of Energy, Washington, D.C.

WAC 173-303, 1990, "Dangerous Waste Regulations," *Washington Administrative Code*, as amended.

WHC, 1988a, *Environmental Investigations and Site Characterization Manual*, WHC-CM-7-7, Westinghouse Hanford Company, Richland, Washington.

WHC, 1988b, *Quality Assurance Manual*, WHC-CM-4-2, Westinghouse Hanford Company, Richland, Washington.

WHC, 1990, *Environmental Engineering Technology and Permitting Function Quality Assurance Program Plan*, WHC-EP-0383, Westinghouse Hanford Company, Richland, Washington.

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