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GEOTECHNICAL INSTRUMENTATION WORKING GROUP MEETING

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ABSTRACT

Responding to the widespread need for the geotechnical community to discuss instrumentation for nuclear waste repositories, a meeting was held December 2 and 3, 1981, in Denver Colorado, This report gives the group's consensus recommendations to aid in making decisions for development of instrumentation for future repository work.

The main conclusions of the working group meeting were as follows:

- Monitoring of geotechnical parameters in nuclear waste repositories will be necessary to meet licensing requirements.

- Currently available instruments are underdeveloped for this monitoring.

- Research and development to provide adequate instrumentation will need to be performed under federal sponsorship by national laboratories, universities, contractors, and consultants. Manufacturers have neither the economic incentive nor the desire to commit resources to perform the needed R&D.

- A NASA-type reliability program is needed to meet the quality assurance, durability, calibration, and time schedule demands of geotechnical instrumentation development. This will require significant financial commitments from the federal sector.

1.0 EXECUTIVE SUMMARY

An informal working group, consisting mainly of experimenters in nuclear waste isolation programs, met December 2 and 3, 1981 to discuss experiences in using geotechnical instrumentation under conditions similar to those anticipated for repositories. The conclusions reported here represent their consensus profession judgement but does not reflect the official position of the agencies for whom the individuals work.

The consensus of the working group is that currently available instrumentation is inadequate for meeting the goals of the national program in Nuclear Waste Isolation. The extent of the inadequacy depends upon the objectives of the monitoring program. For instance, monitoring for model validation and verification requires precision and accuracy beyond that required in normal engineering applications of geotechnical instrumentation. Long term repository performance monitoring requires precision similar to that in other civil engineering programs, but requires life expectancy of instrumentation well beyond that of currently available instruments. The working group believes that development of geotechnical instrumentation has been neglected in the national programs. The lead time necessary to develop instrumentation, by and large, has not been recognized nor have the inadequacies of current instrumentation been fully appreciated. All of the programs reported a recurring common problem of having to use basically off-the-shelf equipment. While many objectives of the studies have been achieved using off the shelf equipment, there are many failures and difficulties in data analysis.

We in the working group believe that instrumentation development is a critical path item in the development of licensable waste repositories. While it may be possible to over-design a repository so that monitoring is minimized, nevertheless, we believe that long term monitoring, regardless of the over-design of the repository, will be required in the licensing process.

RECOMMENDATION

We recommend that a task force be set up to interface with the DOE National Waste Terminal Storage (NWTS) program and the Nuclear Regulatory Commission (NRC). Much of the basic structure for this task force already exists within NWTS and NRC or their contractors. This task force should be charged as follows:

1. Scheduling and planning instrument development for geotechnical monitoring issues in the national program. The task force could unify efforts of all project participants for DOE, NRC and other agencies.

2. Providing input to agencies responsible for repository design and planning on how repository designs constrain instrumentation. This will assist in acheiving the most effective use of instrumentation.

We recommend that the first action of the task force be evaluation of actual instrumentation needs. Clearly defined needs for instrumentation are required before any large research program is undertaken. We recognized four separate instrumentation needs:

1. Instruments which are common to all instrumentation programs and which therefore, must be developed in order to meet any future monitoring requirements.

2. Research and development to provide instrumentation for model verification. This verification is basically short-term monitoring under semi-controlled conditions.

3. Research and development to provide instrumentation for moderately short-term field monitoring, such as at-depth test facilities. This monitoring involves a time frame of five to ten years.

4. Research and development necessary to provide instrumentation for long term monitoring of repository performance under harsh environmental conditions.

We recommend that the task force develop a NASA-type reliability approach to instrument research and development. This could be undertaken by the task force in concert with established NWTS programs or through individual agencies such as DOE and NRC and their contractors.

We recommend that an early item of research be a thorough analysis of the relationships that govern gauge interactions with rock. An evaluation of each gauge type is necessary to determine whether that gauge truly measures the parameter it is intended to measure. The purpose of first evaluating the physics and constitutive laws of current instruments is to consider whether it is productive to continue trying to improve them, or whether complete redesign is required. The physics of some instruments is straightforward, and their responses and calibrations, therefore, can be demonstrated to be meaningful. Other instruments are very complex, and in an environment of changing temperatures, particularly elevated temperatures, many questions must be resolved.

We recommend that agencies such as DOE, NRC. or others, begin funding as soon as possible. There will be no time to field check the performance of newly developed instruments for long term monitoring other than during the execution of the at-depth test (ADT) program. It is critical, therefore, that these instruments be available at the beginning of the ADT so that their performance can be evaluated under field conditions in the likely repository medium before requiring long-term monitoring in actual repositories. If we are to meet the requirements for instrumentation testing early in the ADT program (1983-1984), instrument development must begin immediately.

A few organizations are starting instrumentation research groups. The Office of Nuclear Waste Isolation (ONWI) has recently released a request for proposal (RFP) for stress and displacement instrument development. In general, however, there is insufficient funding and resources available for instrument development. Therefore, setting up of a task force and/or a contract to begin the NASA-type evaluations is an immediate and pressing need.

2.0 INTRODUCTION

An informal working group that evolved from discussions at earlier professional meeting identified a need for further discussion and exchange of experiences in using geotechnical instrumentation in waste repository experiments (see Appendix 1).

This working group convened on December 2 and 3, 1981, in Denver, Colorado. Attending the first day were principally users of geotechnical instrumentation. After reviewing of the anticipated requirements for geotechnical instrumentation in waste repositories, they discussed common experiences and identified issues. See Appendix 1.

The second day included users and also manufacturers of instrumentation. A wrap-up session included a detailed review of discussions from the first day and comments by the users. We were gratified by the continuing candid and open discussion on this second day.

The objective of this group was narrowly defined to include only the experience bases gained on past programs. We did not include discussions of philosophy of instrumentation, of a need for specific instrumentation during nuclear waste isolation programs, or of any of the associated issues.

This report summarizes the results of the 2-day working group meeting. The report is general and does not include site-specific information, ie - failure rates or successes, from individual programs. Specific information is available from reports of those projects. The report represents the professional opinions of the participants but does not represent the official position of the agencies for whom the individuals work.

This report is a consensus of experience of current users of geotechnical instrumentation, both in nuclear waste isolation programs and other civil engineering projects, who attended the meeting. The agendas and attendence lists are included in the appendices. The experiences reported were confined to off-the-shelf or modified off-the-shelf instrumentation and do not deal with instruments that could be developed or that are in developmental stages.

Section 3.0 discusses by instrument type this common experience. Section 4.0 discusses the consensus and issue identification for research and development that is needed to meet national program goals as we understand them.

3.0 DISCUSSION OF EXPERIENCES

The basis for the working group's discussions of current instrumentation was the experience gained in conducting nuclear waste isolation field programs and planning for future programs, including both those of Department of Energy (DOE) and of the Atomic Energy of Canada Ltd. The field studies stressed the Stripa granite study in Sweden, the Hanford basalt study, and the Nevada Test Site Climax granite study, with some discussion of other programs such as Avery Island Salt and Nevada Test Site tuff studies.

3.1 General Findings

Four major items were discussed on a recurring basis during the session to identify issues. The first item was a need to clearly define the objectives of any geotechnical monitoring program. This became apparent in discussions of various phases of monitoring. For instance, monitoring required to validate models and to do rock mechanics studies leading up to site characterization is different from monitoring done for repository closure and stability. Monitoring done in different media differs in scope. The length of time or the lifetime of instruments varies tremendously depending upon the phase of monitoring. Greater accuracy is needed during shorter term monitoring such as model validation than during repository monitoring. But during repository monitoring the reliability of instrumentation would need to be much greater. This is a key concept when discussing the need for geotechnical instrumentation development. To achieve precise and accurate instrumentation which also has a long life expectancy is a challenging undertaking. To achieve instrumentation with high sensitivity and precision with shorter life expectancies is a more readily achieved objective.

The second item, common to all instrumentation, was the need to improve instrument reliability and survivability in the environmental conditions typical of waste isolation projects. One of the most significant lessons to be learned from DOE nuclear waste related experiments is the importance of detailed analysis of the environmental conditions that can effect instrument reliability, and the selection of materials that can survive those conditions over the prescribed time. The significance of moisture has largely been underestimated. Some participants suggested that all instrumentation should be designed assuming that there will be water surrounding the instruments regardless of the presence of "dry holes." Even during short term monitoring, moisture is a problem when instruments are used in very humid or below-water-table applications. Temperature further complicates moisture problems. Many seals which are otherwise satisfactory for typical civil engineering works are unsatisfactory at elevated temperatures. Likewise, at elevated temperatures and possibly in radiation fields, corrosion can be a major problem. We identified a need to prevent water from refluxing into the boreholes or instrument tubes, or else to design the assemblies so that they are not affected.

The third item was that of calibration which was seen as a particularily difficult problem with some instruments. With other instruments calibration is fairly straightforward. The capability to check the total system operation separate from the normal operating data gathering mode is a key item for all instruments.

The fourth item was the need to establish proper quality assurance programs. A consensus was not obtained on whether one could rely on manufacturers to provide quality assurance. However, there was a general consensus that a quality assurance program was necessary and should be required of the instrument manufacturers. If manufacturers provide the quality assurance program, the verificaton that the quality assurance program is being followed should be the responsibility of the project geotechnical engineers. The manufacturers pointed out that they typically have relied on the quality assurance programs of their suppliers. We recommend that, rather than relying on the quality assurance of manufacturers and suppliers, a user integrated quality assurance and testing program be established, either through in-house or consulting facilities. It was suggested that a quality assurance checklist be developed for the manufacture and field construction of instruments. It was also suggested that quality assurance techniques be applied to qualification testing of the measurement system. Quality assurance is seen as a key and critical item to the satisfactory performance of geotechnical instrumentation, therefore, in any repository monitoring program the quality assurance needs to be a well planned control program, not just a system of documentation.

An issue relative to the use of unionized labor for instrument installation was discussed. Because instrumentation combines electronic, hydraulic, and mechanical systems, there is no clear determination of which skilled labor crews should assemble and install the instruments. Proper procedures are needed to ensure that instruments perform their intended functions. These procedures can help to minimize the jurisdictional problems which are likely to arise when using unionized labor because of the mix of electrical, hydraulic (sometimes pneumatic), and mechanical components.

3.2 Instrument-Related Findings

Discussions of geotechnical instrumentation were largely restricted to rock mechanics instruments, not including hydrologic, geophysical, or rock property instrumentation. Instrument categories discussed included:

Extensometers, both rod and wire
Stressmeters, both rigid inclusion (vibrating wire) and hollow inclusion strain or stress cells (CSIRO).
Borehole deformation gauges (USBM).
Thermocouples

The working group identified several controlling factors in instrument design, selection, manufacture, and installation. These include:

- o Accuracy
- o Sensitivity
- o Measurement range
- o Environmental factors
  - temperature limits
  - humidity

- corrosive agents
- o Operating life
- o Quality control

These key items are discussed below for each instrument type

3.2.1 Multiple Position Borehole (Rod) Extensometers (MPBX)

3.2.1.1 Experiences/Applications

This section covers information gained from field installation and data collection involving 112 multiple position rod extensometers placed in various media, and from planning and testing for future applications at three other sites. We recognize that projects other than nuclear waste isolation have used extensometers, and this report is not intended to be a comprehensive treatise on all applications of rod extensometers.

Four major components of MPBX's are the anchors, rods, tensioning systems, and head assemblies and/or read-out systems. Two types of anchoring systems have been used, and a third has been evaluated and tested. Many of the experiments used a hydraulic anchoring system in which a copper bladder is inflated in the hole to set the anchor in position. The external pressure system required for inflation varied between experiments. Grouting was sometimes used to supplement hydraulic anchors. In one case a borehole was fully grouted around the hydraulic anchors, and in other cases the grout column was interrupted by spacers or "donuts" of foam rubber. By breaking the grout column into discontinuous segments, the anchor could move freely with rock displacements without being restricted by a continuous grout column. Two types of mechanical anchors were either used or tested for future emplacement. One is the expanding platen (Cobb type) that is used in rock bolting operations, and the other is a "C" clamp that expands against the hole.

The majority of rod extensometers in waste isolation projects used Super Invar (a nickel-cobalt steel alloy) rods because at temperatures below approximately 150° C to 200° C, Super Invar has a low coefficient of thermal expansion. Mild steel rods were used where moderate temperature rises were expected.

Programs reported that typical ranges of measurements in hard rock between the deepest anchor and the head were less than 3mm. Some measurements have been taken in rock where temperatures exceeded 200°C; however, the majority of measurements have been taken below 160°C.

All experiments used the standard spring system, with minor modifications to tension the rods. All experiments used electronic sensors in the head assembly to read displacements. Two types of transducers were widely used: linear potentiometers and linear variable differential transformers (LVDTs). In some applications mechanical dial gauges were used as backup sensors. The only attempt to use mechanical gauges as the primary displacement monitor was abandoned because of blast damage to the rod extensometers.

3.2.1.2 Accuracy

The sensitivity of the electronics of a system using an LVDT can be on the order of 0.001 mm. However, experience indicates that a system accuracy on the order of 0.025 mm can be achieved. This accuracy assumes adequate temperature compensation. Super invar has a non-linear coefficient of thermal expansion which must be accounted for, and two aspects related to temperature compensation have caused problems. Thermal behavior of extensometer rods requires that there be a sufficient number of precise temperature measurements along the rod to obtain accurate temperature profiles. It also requires a thorough understanding of the thermal expansion characteristics of the rod. The thermal expansion characteristics depend on the heat treating, past temperature history, and stress history of the rods. Various investigators measured temperature at the anchors. In some investigations, temperatures will be measured along the rod at mathematically determined points, i.e, Radau quadrature points.

Various techniques have been used to characterize the non-linear thermal expansion coefficient of Super Invar including spline, piece-wise linear and exponential curve fits. Accuracy of measurements requires that this detail be attended to carefully. However, even with the need to carefully account for the expansion characteristics, the coefficient of expansion for Super Invar, for temperatures between 0^0 C and 200-400^0 C is significantly less than for mild steel. Therefore even more precise measurements of temperature are required for mild steel, although the calculations of expansion are more straightforward.

It was recommended that the Super Invar manufacturer perform the full MIT three-cycle heat treatment of the rods to reduce hysteresis. The user should verify that adequate heat treatment was performed. Furthermore, nickel and cobalt will recrystallize out of Super Invar, so that it reverts to normal steel, if it is exposed to below freezing temperatures. In one experiment a five-hour stress release method was used by preloading the rods prior to insertion. This technique was believed to decrease some of the nonlinear time-dependent deformation of the rods. Each of these factors will influence the thermal expansion of Super Invar rods.

Investigators have found that twisting of rods during installation has caused binding. Alignment problems cause friction within the rods and tensioning systems, which can cause unresponsiveness. It was also reported that the rod and enclosing conduit tended to float when grouted in horizontal boreholes which also affects the alignment. Rods are contained within a protective conduit and there can be friction between these components. There can be friction between rods as well as between rods and anchors and between rods and splices. One experimenter used teflon and delrin spacer guides to minimize this problem. Also, if one is not careful, a splice could be placed at an anchor guide which would bind the rod in place.

Sensor alignment within the head is also important. Friction or "stiction" within the head assembly causes a stick-slip sensor response. In one case, a light rapping on the head assembly minimized this. The LVDT-type system appears to be less sensitive to alignment problems than the potentiometer type; however, in a laboratory experiment LVDTs responded in a stick-slip fashion. This may indicate that the stiction problem is in the sensors themselves. In one case, bench tests to evaluate the friction within the head found that mechanical vibration at the anchors was more effective than the vibrations of the head in relieving the stick-slip. To minimize mechanical friction, the design of the multiple borehole extensometer was modified to decrease the fleet angle in the head. In recent designs this fleet angle has been eliminated.

3.2.1.3 Reliability/Environmental Survival

Multiple-position borehole extensometers used in nuclear waste isolation programs were not designed to last for several years, nor to operate unattended and unmaintained. Most experiments have been conducted for various periods of time, mostly less than 2 years. Even during those short time periods, there have been significant instrument failures. This failure rate would be unacceptable for repository monitoring where it is expected that long-term monitoring, tens of years, will be required.

All projects reported pressure loss within some hydraulic anchor systems. Preliminary pull tests indicate that even when deflated, the hydraulic anchors will maintain anchoring beyond the 100-pound rod tension. However, one test inside a steel pipe did not confirm these results.

Two projects reported significant transducer failures. One used linear potentiometers and the other used LVDTs. The causes of failure are not well understood at this time. In addition, post test recalibrations of some LVDT's showed a slight drift that could affect repeatability, but this is considered negligible. All projects recommended that a mechanical readout backup system be provided.

Multiple-position borehole extensometers in nuclear waste isolation projects have had a water tight-sheathed protective conduit over the rod assemblies. This conduit is intended to seal the rod system against moisture and prevent corrosion. It also decreases the likelihood of moisture migrating towards the sensing heads. Sealing both the sensor head and the conduit around the rod are necessary for environmental survival. However, there are some preliminary indications that sealing the rod system may trap outgassing from sealant compounds which in turn may damage head assemblies. A recent design, as yet unproven, involves a stainless steel bellows rather than sheathed conduit to eliminate these problems.

One of the experiments has nuclear waste canisters emplaced for storage in a simulated repository. Measurements from that test indicate that the extensometer system is relatively insensitive to radiation. However, the head assembly is above the irradiated area, and the down-hole portion of the extensometers are in a low-level radiation field. The experiment has not been completed, and the extensometers have not been removed for investigation. It is noted that organic materials are subject to radiation damage.

3.2.1.4 Design/Installation

The installation of multiple point borehole extensometers is relatively straight forward if properly planned and supervised. Anchor locations need to be carefully selected to avoid fractures, but otherwise borehole preparations are minimal.

Excavation as well as thermal effects perturb a significant volume of rock. We suggest that experiment designs for multiple point borehole extensometers include use of deep anchors that are outside of the perturbed zone in order to establish an absolute reference point. This is important because the head assembly is in one of the most disturbed zones, on drift ribs, where an absolute reference is not available. There is a need to have redundancy in the measurements to better evaluate the data, particularly where discrepancies occur. Finally, in the design of the systems it is important to emphasize the volumetric behavior of the rock mass. This is particularly important in fractured media, where a fracture near a borehole can influence the deformation response of the relatively small volume of rock immediately surrounding the borehole.

3.2.1.5 Calibration

Laboratory calibrations of rods and sensors are needed. It is necessary to establish precise thermal expansion characteristics of the rods. Super Invar's nonlinear thermal behavior must be evaluated to develop the software to make thermal corrections to deformation data. Variability of composition of Super Invar leads to questions as to whether the thermal expansion characteristics of each individual rod should be determined or whether a statistical sampling program should be employed. The sensors can be readily calibrated with a micrometer, a test jig, and a temperature-controlled environment.

In the field, calibrations have typically been performed by offsetting the head assembly a known amount and recording the offset monitored by the sensors. This is a good check on the performance of the head assembly, but does not duplicate anchor response due to friction along the rods. Recent nuclear waste isolation programs have proposed rod designs that provide latching devices at the anchor so that rods can be freed to move. This provides a check on rod binding, and indications of the movement of the rod at the anchor is provided by a second position on the rod latching system which allows the rod to move a precisely known amount. The accompanying measured displacements by the sensors provide a calibration of the entire system.

3.2.1.6 Instrumentation Suitability

The multiple-point borehole extensometer is a fairly reliable system. There have been localized failures, i.e., loss of anchor pressure, but they have had minimal effects. Some cases of corrosion have been observed as well as failures of the waterproofing systems. In general, overall system accuracy and durability (excluding sensor) appears to have been good. These instruments should be acceptable for use in long-term monitoring provided the following conditions are met:

- the head assemblies are in accessible drifts
- the electronics are designed for operation at high temperatures and in potentially high radiation fields
- moisture intrusion and corrosion problems are solved
- the effects of downhole rod friction are reduced
- reliable anchoring systems are proven,
- transducer reliability is increased.

The geology itself is possibly the most significant parameter that effects MPBX measurements. All projects discussed here have been in fractured rock so that joint closure, and rigid block rotations and/or translations have influenced the measurements. Subsequent investigations and more research should provide insight regarding limitations in use of extensometers in fractured media, at elevated temperatures.

As indicated earlier, multipoint borehole extensometers are planned for long-term experiments. Experience to date, while not definitive, has been discouraging regarding potential long-term reliability. Several failures have been noted. However, most failures have been either in the pressure systems for hydraulic anchors or in the sensors and head assembly. There are indications of rod oxidation and corrosion, but there have been no reports of catastrophic rod system failures. While the replacement of the downhole portions of multipoint borehole rod estensometers is difficult, replacement of the head and electronics is relatively easy. Replacement of rods may be facilitated if removable rods are fully developed.

3.2.1.7 Suggested Development

One suggested improvement is to isolate transducers from moisture. Water has been a problem in both liquid and vapor phases. There can also be sealant outgassing into sensors and various parts of the equipment. This requires an improvement in sealing systems. Independently sealing both sensor assemblies and rod-conduit assemblies would be desirable.

There is a need to develop sensors and recording apparati (if placed in high temperature environments) that can operate at elevated temperatures. Temperatures within the drifts of repositories may rise to values higher than experienced by head assemblies of the projects reported here. This will require considerable electronics design to ensure stable measuring systems. In short-term or scientific monitoring, a mechanical backup system can, and should, be used.

It is important to develop systems that will allow installation of more anchors in a single borehole so that deformations in fractured media can be better described. Allowing a larger number of readings would minimize the localized effects of anomalies such as nearby fractures.

Also considered important are improved anchor design and development of nondestructive anchor seating proof tests that can be used in the field (ideally, as a function of time) without compromising the measurement system.

Methods whereby rods could be removed and replaced would be desirable, as would anchors that could move freely with the rock without being attached to any other portions of the system. This would eliminate system friction and anchor creep problems. The sonic multipoint borehole extensometer is a step in this direction, but has not eliminated the problems associated with other MPBX systems.

3.2.2 Convergence Wire Extensometer (CWE)

3.2.2.1 Experience/Applications

Experience with 32 convergence extensometers was reported. These extensometers have wire lengths ranging from 3-6m (10 to 22 feet). Over a period of 1-1/2 years, no failures have occurred. The wires and instruments are removed periodically. To date, the reinstallation has been performed with an average repeatability before and after removal of 0.06mm (60 microns). Calibration of the potentiometers and data acquisition system has been performed. Checks on wire length have also been performed through the use of tape extensometer readings.

The major problem identified with the use of convergence wire extensometers is correction for thermal expansion of the wire. Because the ventilation patterns within drifts are complex, the measurement of wire temperatures is also complex. Therefore, corrections for thermal expansion of instrument components are difficult. A possible modification uses a four-wire resistance measurement to determine changes in temperature.

3.2.2.2 Accuracy

No thermally corrected data are available with which to analyze the total system accuracy. Indications are that the system accuracy will be significantly better than tape extensometers which are the normal alternative.

3.2.2.3 Reliability/Environmental Survival

CWEs have been operating for 1½ years. There have been no failures, although corrosion and precipitation of minerals from groundwater has occurred on one CWE. Long-term reliability cannot be assessed at this time.

3.2.2.4 Design/Installation

The experimenter designed, fabricated and installed CWEs; therefore, they cannot be considered an off-the-shelf instrument. They were designed to last the relatively short time period of the experiment and it appears that they will do so.

3.2.2.5 Calibration

Field Calibration of CWE units has been accomplished by using feeler gauges to offset the potentiometer shafts a known amount resulting in an observed offset in the reading recorded by the data acquisition system. No other system calibration is provided. A check on wire length is provided by routine tape extensometer measurements; however, the accuracy of the tape is limited to $\pm .003$ inches which is considerably less sensitive than the sensitivity of the CWEs.

3.2.2.6 Suitability/Suggested Development

CWEs are deployed to monitor drift closure. If drifts are to remain open (no backfill) for any length of time, this instrument type should be fairly reliable. The most critical development need is to provide a more thorough system calibration. Provisions for corrosion prevention should be improved. Reduction in friction within pulley systems may be desirable but cannot be evaluated at this time. Provisions to replace wires maybe important for long-term survival.

3.2.3 Vibrating Wire Stressmeter (VWS) - Rigid Inclusion

3.2.3.1 Experiences/Applications

Although rigid inclusion stressmeters have generally proved to be reliable instruments for a wide variety of geotechnical instrumentation programs, use of approximately 90 units at elevated temperatures in waste isolation experiments has generally been unsatisfactory. High failure rates (based on analysis of reading) of 75% to 100% of units installed in vertical boreholes and from zero up to about 75% in horizontal boreholes have been reported by several investigators. The primary cause of the failures has been either moisture leakage into the gauge body-cavity area and into the electromagnetic coil assembly or possibly entrapped humidity in the gauge at the time of manufacture.

In addition to failures, severe corrosion, especially to the sensing wire, can strongly influence the basic calibration and response of the unit. Some investigators have identified "soft" failures where the gauge appears to remain functional but gives erroneous readings as a result of probable sensing-wire mass changes.

The manufacturer has recently developed a technique to hermetically seal the cavity area, and it is likely that moisture leakage into this area has now been minimized or eliminated. Concurrently, the manufacturer developed a new technique for sealing the electromagnetic coil assembly, again with the intent of preventing moisture leakage. Corrosion of the tensioned sensing wire should be eliminated in these new hermetically sealed units. The manufacturer also now coats the gauge body and the wedge/plateu assembly with approximately 0.127mm (0.005 in) of electroless nickel to minimize gauge body corrosion.

The improved stressmeters have recently been installed at two test sites, and the results of these tests will shed new light on the reliability and life expectancy of the rigid inclusion stressmeter for waste isolation projects.

3.2.3.2 Data Analysis/Accuracy

To date, no experimenter has reported on fully analyzed data from rigid inclusion stressmeters in a heated waste isolation experiment. While part of the reason is the high failure rate, an equally important reason is the complexity of the data analysis. The stressmeter is not a uniaxial stress sensor. The calibration constant and gauge response is a complex relationship involving the ratio of the stresses parallel and perpendicular to the tensioned sensing wire. Furthermore, gauge response is a function of rock modulus and is subject to rock/gauge moduli interactions.

In field applications, the ratio of parallel and perpendicular stresses are a function of the principal stresses and their orientation relative to the tensioned wire. One researcher reported that the solution of this problem involves three independent, nonlinear, simultaneous equations with a variable calibration constant. Therefore, solutions would require that three stressmeters be installed in a single borehole. An iterative solution may be used to solve these equations. However, if fewer than three stressmeters are installed, an assumption must be made on the orientation of the sensing wire relative to the principal stresses in order to determine the stress change.

All programs to date have employed automatic scanning devices, and several experimenters have reported difficulties with the general quality of the electronics package. This portion of the instrumentation system could be improved with an updated version of the scanner/logger.

3.2.3.3 Design/Installation

Most experimenters agreed that improved techniques and procedures need to be developed for the manufacture and installation of the rigid inclusion stressmeter. Of primary importance during the manufacturing process is the method of tensioning and securing the sensing wire. The present technique involves not only a high fabrication rejection rate, but also a wide range of acceptable initial wire tensions. Since the initial wire tension controls the usable range of the instrument and potential output drift as a result of wire creep, it is desirable that initial wire tension be more consistent between individual units.

Installation techniques and equipment should be modified so that it is possible to stress the gauge in the borehole to beyond the expected in-situ stress changes and then to cycle back down to a predetermined setting stress. This should minimize the hysteresis effect noted by several experimenters during the initial load/unload cycle. A standardized installation procedure is needed to preload the stressmeter. Laboratory testing has demonstrated that the output characteristics of the gauges are dependent upon the setting stress. Additionally, the experience to date suggests that the installation equipment should be modified to ensure better concentric alignment among the platen, wedge, gauge body, and borehole.

3.2.3.4 Calibration/Characterization

Several experimenters reported on programs to characterize the calibration of the rigid inclusion stressmeter in various media. The calibration constant is dependent upon several factors, including the elastic properties of the media, the platen contact area, the size of the borehole, the prestress level during installation, the loading conditions, and the temperature.

All reported a great deal of scatter among similar tests. Two independent programs indicated that the standard deviation between numerous similar tests is approximately 20% of the mean value. The causes of such variation are not thoroughly understood and must be investigated further. Furthermore, system hysteresis causes different calibration constants during loading and unloading. Significant differences have also been noted between ambient and elevated temperature calibration constants.

Several techniques for determining the calibration constant have been reported by different investigators. Since the calibration constant, as determined by laboratory testing, is dependent upon the method of loading, a more unified testing approach is warranted in order to facilitate comparisons of results in the various media.

Of even greater importance is the effect of increased temperature on a rigid inclusion stressmeter when stressed in a borehole. Reported results of six laboratory tests documented that, for a 180°C temperature increase, the change in stress of the tensioned wire varied between 46.8 MPa (6800 psi) and 95.7 MPa (13,000 psi), with an average value of 70.3 MPa (10,200 psi). Hence, the required correction to field data would be several times larger than the expected in-situ stress change. All experimenters agree that this phenomenon is a serious drawback to future use of the rigid inclusion stressmeters on waste isolation programs. They expressed concern that a rigid inclusion gauge, which has a different coefficient of thermal expansion and modulus than the rock, cannot properly indicate rock stresses. Measurements from rigid inclusion stressmeters are sensitive to body corrosion, to modulus changes in the steel, and to localized rock crushing or microcracking under high inclusion forces. This could invalidate the entire concept of using this type of gauge in nuclear waste isolation programs or repository monitoring.

3.2.3.5 Instrument Suitability

Problems of gauge and gauge/rock responses with increased temperature must be eliminated, minimized, or better understood and physical relationships investigated if this type of instrument is to be used in the monitoring phases of future repositories. Most researchers agree that if these problems can be solved, the rigid inclusion stressmeter could prove to be a widely used monitoring device since it does have several strong points, including low cost, ease of installation by semi-skilled workers, mechanical ruggedness, and suitability for long data transmission distance.

3.2.4 Borehole Deformation Gauge (BDG) - Soft Inclusion

3.2.4.1 Experience/Applications

The three-component borehole deformation gauge (BDG) typically used for waste isolation applications was originally developed by the U.S. Bureau of Mines for short-term use to measure the in-situ stress field in a rock mass. The gauge measures borehole diametral changes in a given plane, using bonded, resistance strain gauges mounted on six cantilevers. Elastic theory and rock material properties are used to calculate the changes in stress from measured borehole deformations. The model used in waste isolation programs has undergone extensive design and testing modifications to improve long-term monitoring performance characteristics in a high temperature (up to 200°C), moist and potentially corrosive environment.

3.2.4.2 Accuracy

The accuracy of the BDG is highly dependent on the test environment and installation. Borehole deformation measurement accuracy is dependent on several factors, such as:

- Gauge temperature
- Bridge input voltage
- Bridge output voltage
- Gauge sensitivity as a function of temperature
- Bridge offset as a function of temperature
- Gauge thermal expansion coefficient.

Laboratory testing in engineered materials (e.g., aluminum or steel) have yielded highly accurate deformation measurements of 0.002mm with a sensitivity of 0.001mm. Gauge sensitivity and bridge offset as a function of temperature and gauge thermal expansion are relatively easy to characterize utilizing new techniques (reports in progress). However, gauge sensitivity and bridge offset are subject to long-term drift which is greatly influenced by localized test conditions at the transducer. The magnitude of drift is not predictable and must be quantified by some method such as periodic recalibration in order to accurately measure deformation. Otherwise, stress estimates can be in error by orders of magnitude.

Stress changes are calculated from deformation data; therefore, accuracy is dependent on the knowledge of rock properties (Young's modulus, Poisson's ratio, and thermal expansion coefficient) and the degree to which the rock mass behaves as a linear-elastic and isotropic medium. Estimates of error range from 20-150 percent (or greater) in magnitude and 10-30 percent in direction. Errors in calculating stress changes are directly proportional to the errors involved in selecting the appropriate rock modulus, where the scale of rock features such as grain size, joints, and fractures are the greatest influencing variables. The greater the variability of these parameters over the tested zone, the greater the inconsistencies in stress measurement. Correspondingly, a highly homogeneous, linearly elastic rock would yield highly accurate field results. These relationships apply to both short-term and long-term applications. Because of the uncertainties involved in the calculations of stresses from deformation, many users question the use of the BDG for stress determination in waste isolation applications, and feel that reporting borehole deformation may be more appropriate.

3.2.4.3 Reliability/Environmental Survival

BDGs are highly reliable in short-term applications. Life expectancy during in-situ stress measurement is primarily dependent on the gauge surviving the overcoring operation. Careful monitoring during drilling can eliminate most gauge failures. The same BDG can be used for several years, and moisture infiltration problems can be overcome by drying out the unit in an oven between uses.

Only a small percentage of gauges have survived throughout the test period (up to two years) in waste isolation applications. Stability is a critical factor in long-term use, whereas, drift is not a problem in short-term applications. Life expectancy for long-term use is dependent on environmental conditions. The ability to seal the gauge is critical to survivability.

The failure rate for BDGs used in long-term tests has been extremely high, approximately 60 percent of gauges were malfunctioning after one year of service. The major factor affecting BDG survival has been attributed to moisture effects. Small amounts of moisture infiltrating the gauge can affect its performance and result in erroneous data and gauge failure. Often failure has been attributed to internal corrosion problems. Corrosion can also attack external components, such as pistons or the centering springs, and can affect the results depending on the amount of deterioration. Severe corrosion of the pistons can reduce the effective piston length and be interpreted as borehole diametral changes. Corrosion of the centering springs can allow the gauge to pitch or promote axial slippage in vertical boreholes.

Waterproofing has been approached through the use of multiple moisture barriers. However, on gauge removal, free water has been found inside the gauge and up to several meters away in the signal cable. Even traces of moisture too small to detect visably can lead to gauge failure. Moisture enters the piston ports or, more commonly, where the signal cable enters the rear of the gauge. Silicon-oil filled versions of the BDG have been used to displace moisture; this additional moisture barrier appears to increase gauge life.

3.2.4.1 Manufacturing, Testing and Field Installation

The manufacture of a BDG is a complex operation involving several steps. To ensure that the BDGs have appropriate measurement capabilities, the specifications must carefully define the requirements.

Each BDG should be proof tested prior to calibration to ensure its performance characteristics. Recent testing programs have required that each gauge be tested in steam, under pressure for a 48-hour period as qualification for further use. Strain gauge resistance-to-ground measurements are monitored throughout the test period and are maintained at certain levels for acceptance. Ideally, proof testing should replicate the "worst case" field environment, but not be so severe as to induce failure under unrealistic conditions.

Borehole walls should be inspected using a borescope or borehole TV camera and careful core logging at the intended gauge location prior to installation to ensure that gauge placement is in intact zones of rock.

3.2.4.5 Calibration

BDGs should be fully calibrated prior to installation, as follows:

- o Bridge offset as a function of temperature
- o Gauge sensitivity as a function of temperature
- o Gauge thermal expansion coefficient

Bridge offset as a function of temperature should be determined for individual axes as change in magnitude and direction are bridge dependent. During this procedure, pistons should be out of contact with the cantilevers to ensure repeatable results.

Gauge sensitivity is bridge-dependent and each gauge axis should be tested at ambient temperature. Change in sensitivity with temperature can be estimated within 10% by measuring temperature characteristics of selected gauges from a common batch. However, it is preferable to determine sensitivity as a function of temperature for each gauge axis. This procedure is typically performed using micrometers to deflect the gauge pistons. A recent innovation aligns the gauge in a stepped cup, representing various borehole diameters, and sensitivity can be determined on all gauge axes simultaneously.

Compensation must be made for thermal expansion of the BDG. This measurement can be obtained separately or in conjunction with sensitivity tests using the above-mentioned cup fixture.

Drift is not predictable; therefore, periodic field calibration should be performed after installation. A gauge should be recalibrated when data are in question. Experience has shown that when drift does occur, bridge offset is the most affected parameter.

3.2.4.6 Current Instrument Suitability/Suggested Development

BDGs were designed for short-term applications and are most suitable when used for this purpose. If characterized properly, gauges are adequate for one-two year testing programs in a moist, heated environment provided waterproofing is sufficient. However, periodic gauge removal is required for calibration to compensate for drift and gauge replacement. For long-term applications (greater than two years), BDGs are probably not adequate using current designs unless frequent replacement is acceptable.

BDGs should be hermetically sealed to improve performance for long-term use. Additionally, some technique should be employed so that in-situ calibrations can be performed. Previous investigators have used a BDG with cantilevers activated by internal air pressure. This type of system could eliminate the necessity for periodic gauge removal, and compensation of drift would be automatic. Several modifications are possible if the BDG were increased in size but would mean using larger boreholes. In any case, further development is necessary to improve BDG performance for long-term, high temperature applications.

3.2.5 Thermocouples (TC)

3.2.5.1 Experience/Applications

Thermocouples have been the principal temperature measuring devices used in nuclear waste isolation experiments. A total of 940 type K (Chromel-Alumel) TC's, and 371 type E (chromel-constantan) TC's were installed in three DOE experiments. These devices are mechanically simple and rugged, and have been relatively reliable in operation.

Three types of thermocouple wire coverings were used: Inconel-600 sheaths were used exclusively in one experiment and in two other experiments where higher temperatures were expected. In the latter experiments, teflon (Type TFE) thermocouples were used where initial calculations predicted temperatures below 200°C, but in one of these experiments 304 stainless steel sheaths were used where temperatures might exceed 200°C, but remain below 400°C.

3.2.5.2 Accuracy

Experience has shown that temperature accuracies of 1°C or 2% of reading, whichever is greater, are easily obtained. With computer-based thermocouple conversion routines that include a complete temperature measuring system calibration, these accuracies are improved to better than 0.5°C or 0.5%, whichever is greater. Thermocouple limits-of-error and individual calibration criteria have been selected to meet specific accuracy requirements. Experiences to date have shown that the selected TCs and temperature references have been sufficiently accurate and stable to meet application requirements.

A certain amount of drift may occur in the thermal-electric characteristics of thermocouples. Application requirements should take this into account. Drift effects can be minimized and computationally compensated by data from initial and repeated thermocouple calibrations.

3.2.5.3 Reliability

In most waste isolation programs, thermocouples have been very reliable devices over the relatively limited period of the experiments (1-1/2 to 3 years). There have been no catastrophic failures except in one experiment. These catastrophic failures were due to sheath corrosion in sand-backfilled boreholes. No failures were experienced in boreholes that were not sand backfilled. Corrosion of approximately half of sixty 304-stainless steel sheathed thermocouples necessitated their replacement. Only a few of the corroded thermocouples completely failed; however, all thermocouples (including some which had not corroded) were replaced with Teflon insulated (50) and Inconel-600 sheathed (10) thermocouples. Upon removal at the end of experiments the Inconel sheath also showed effects of corrosion. All sheathed thermocouples that failed had been heat treated prior to installation to stabilize their thermal-electric characteristics which probably contributed to the corrosion by making the sheath material more corrosion sensitive.

Some Teflon-insulated thermocouples developed water leakage at RTV coated junctions. This caused no real problem in itself, but in some of the grouted boreholes, head pressure forced water between the thermocouple wire insulation and the outer teflon insulation and into the electronics enclosures. Even so, temperature readings seemed to remain valid when compared with predicted data. At another experiment loop-resistance of each thermocouple is continuously monitored and compared with pre-installation resistance to verify that the hot-injection has not migrated due to moisture influx or other phenomena such as shorting of wires.

Another phenomenon was observed at two experimental sites when small quantities of water were captured in closed bottom thermocouple tubes. This resulted in a boiling and condensing cycle within the tubing, which caused thermocouple readings to oscillate erratically between 100°C and the valid temperature above boiling. This continued until the tubes were cleared of the moisture.

3.2.5.4 Design/Installation

Early experimenters used electrically floating junctions enclosed in the sheaths. Later experiments used grounded enclosed junctions to reduce electrical noise. Magnesium oxide (MgO) was used as insulation in all sheathed TC. One experiment used sheath-covered wire the full distance to the reference junction boxes. In other experiments, the sheathed wire was connected to teflon insulated thermocouple extension wire in a transition junction outside of the borehole. Thermocouples were connected to ice point references in one experiment and to RTD-monitored isothermal blocks as temperature references in the other experiments.

Some thermocouples were attached directly to heaters or instruments with clamps or epoxy; some were installed in metal or teflon tubes on heater casings in grouted boreholes; some were grouted boreholes, and some were in boreholes backfilled with sand. Where tubing as provided, a traveling thermocouple could be used to obtain a detailed temperature profile along the borehole, or to check other thermocouple readings in the borehole. Later experiments installed TCs so that they could be easily removed replaced, and recalibrated.

The following design recommendations resulted from experiences with thermocouples:

- o Use thermocouple sheath and insulation material that will survive the environmental conditions without corrosion or decomposition.

- o Use grounded junctions in enclosed sheaths.

- o Obtain all thermocouple wire from single material melts.

- o Retain control samples of thermocouples to check long-term stability.

- o Install tubing whenever possible for traveling thermocouples. Take care that this tubing does not collapse during installation or grouting.

- o Thermocouples should be removable for recalibration and/or replacement.

- o Provide a means to drain or remove moisture from long thermocouple wells (tubes).

- o Provide periodic loop resistance measurements to verify that TCs are operational.

3.2.5.5 Suitability

Thermocouples have proven to be guite suitable for nuclear waste isolation programs.

4.0 Conclusions and Recommendations of the Wrap-up and Issues Session

In July 1981, the Nuclear Regulatory Commission published for public comment proposed rules relating to disposal of high-level radioactive wastes in geologic repositories (10 CFR 60). In the rules, the NRC has identified a minimum set of required geotechnical parameters to be measured and monitored. Some question the need for all of the measurements proposed, i.e., in-situ stress changes. Others feel strongly that they will be needed. We feel that the geotechnical community needs to become more involved in rule making and in establishing standards to help resolve these issues. Participation on standards committees, which are part of organizations such as ASTM, ISA, IEEE and ANSI, will help develop and establish industry standards.

It is important that the members of the geotechnical community keep abreast of the constantly changing rules during the rule development phase of NRC work related to geological repositories. The rule development will help the community know what will be required.

However, regardless of the specifics of the rule, if monitoring is performed over long time frames, the geotechnical community does not have available the reliable instrumentation necessary. Currently available geotechnical instruments are largely proving to be unreliable in scientific studies at elevated temperatures and extended time frames, and are unable to provide the scientific data that are anticipated to be necessary with a high level of confidence. Most of the current technology used in hard rock studies has been transferred from soil mechanics, mining and civil engineering fields. The instrumentation is proving to be inadequate, unreliable or unable to make the needed measurements for high-level geologic repositories.

To satisfy the requirements of the rule, the geotechnical community will have to develop new instruments and measurement techniques or refine existing ones. Instruments and techniques likely will not evolve soon enough to be ready when the first repository is licensed unless there is a significant, accelerated development program. Without significant development monitoring program maybe inadequate and regulatory agencies may not be able to meet their charter of protecting public health and safety.

Geotechnical instrument manufacturers do not have the needed rsources or the economic incentive to develop or improve currently available instrumentation for an unknown market. Therefore, rather than relying on manufacturers to be able to supply instruments when required, a program needs to be organized to proceed with instrumentation R&D so that the geotechnical community will have the needed instrumentation to ensure the integrity and safety of future geological nuclear waste disposal sites. Governmental agencies need to develop or fund the development of the needed instruments. This R&D effort needs to be accelerated in order to meet the licensing requirements for the first waste disposal site in 1988.

The instrumentation program is a critical path item, and if instrumentation is not available to monitor critical parameters, then the repositories would need to be redesigned so that those parameters would not be critical to the repository. Once the repository were so redesigned, the monitoring would not be performed. This has significant implications for the national program itself. The additional expense for overdesign could be significant.

We recommend the application of techniques similiar to those applied in the space program, both in terms of quality assurance and also in terms of the short time frame and intense research necessary to achieve the objectives. Appendix 4 shows the elements of a typical NASA high-reliability program. A similar approach should be beneficial to further development of geotechnical instrumention programs for repository monitoring.

A key issue was identified by the manufacturers. It was the consensus of the manufacturers represented that they cannot be expected to do the basic research and development work to improve instrumentation as needed for repository monitoring. Among reasons were the lack of financial and technical resources, the lack of clear projection of return on investment, and the need for excessive bookkeeping. Research for government entities does not result in exclusive patents for the manufacturer. Also, manufacturers are not in the business of preparing research reports and felt they would be in competition with their clients if they did so. The manufacturers are not totally involved in national programs and, therefore, are not as aware of the overall objectives as governmental agencies and national laboratories. It follows, therefore, that research and development will need funding and most appropriately belongs in the realm of the national laboratories, consulting firms, universities and governmental agencies. Close consultation with manufacturers will be necessary to facilitate development of instrumentation that can be readily constructed and applied in the field.

We discussed the need for more cooperative interfacing between users and manufacturers. Part of the hindrance to cooperation is the specification bid-system with awards usually to the low bidder. This often ends up in an adversarial type of a relationship, with information flow not being as free as it should be. The working group recognizes that major changes in the procurement system are unlikely. Experience of the aerospace industry, which went through a similiar development program under similiar constraints, can be used as a guide to solving some of these problems.

The working group challenges the technical profession to become more involved in the setting of standards and in providing input to design constraints on repositories. As an example of the need for input, many of the difficulties in geotechnical instrumentation are a function of high design temperatures. If repository temperatures are kept below 200°C, early development of instrumentation would be facilitated. For instance, many of the current techniques for sealing using materials such as elastomers and teflons are applicable below 200°C, whereas, above that point, more exotic materials must be considered. Temperatures may not exceed 200°C by much, if at all, as a natural result of other repository design constraints, ie overpack designs. Therefore, suggesting that repository designs ensure that temperatures will remain below 200°C may be a minor additional constraint that could yield significant benefits to instrument development, and therefore to the national program at large.

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The authors also acknowledge the significant contributions made by all of the participants without whom this material would not have been available. These participants willingly worked long past normal dinner hours after already having participated in intense day-long discussions.

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APPENDIX 1

History

Two of the authors met during the 1981 Rapid Excavation and Tunneling (RETC) conference, and discussed the use of geotechnical instrumentation in nuclear waste isolation programs. They noted that application of geotechnical instrumentation in current nuclear waste isolation programs had largely involved transfer of technology which had been developed for other purposes, merely with some modification of parts of the instrument systems but with no real development. They felt that the results were not satisfactory and that there was a need for a meeting to discuss instrumentation experiences. After discussing this with others in the geotechnical instrumentation community, they decided there was a widespread interest in sharing experiences.

Two ad hoc meetings were held at the 22nd U.S. Rock Mechanics Symposium (attendance lists in Appendix 3) to discuss the need, format, and type of information to be discussed at the proposed meeting. The first informal ad hoc meeting selected a chairman and decided to hold a more publicized gathering to propose a future geotechnical instrumentation working group meeting. A notice was placed on the Rock Mechanics Symposium announcement board, and the second ad hoc meeting was held. At that meeting it was determined that the working group should meet separately from any other conference or symposium to discuss issues specifically related to nuclear waste isolation programs and the common experience of the geotechnical community associated with those programs. A second meeting was proposed where the results of those discussions could be reported to the profession at large, to obtain a wider perspective. Two upcoming national meetings were considered for this purpose. One was the 2nd ASCE Geotechnical Conference and the second was the 23rd U.S. Symposium on Rock Mechanics. Since it was desired to get the information to the profession as rapidly as possible, the earlier scheduled meeting, the second ASCE Geotechnical Conference, was chosen. A request was made to ASCE and a one-half day block of time was allocated as Session E-1.

A working group was established, whose objectives were summarized in the meeting invitation (See Appendix 2), after several iterations in establishing the group and meeting format.

APPENDIX 2

MEETING ANNOUNCEMENT, INVITATIONS, AND AGENDAS

This appendix is information as it was sent out. This material was subject to change and indeed some changes did occur.

GEOTECHNICAL INSTRUMENTATION WORKING GROUP MEETING AND SYMPOSIUM

Hosted by Lawrence Livermore National Laboratory

I. INTRODUCTION

Instrumentation for geotechnical applications has evolved over the years to meet needs which can be typified as being short-lived, involving relatively large displacements and moderate stress changes (especially in low modulus soils) in a somewhat controlled environment. Monitoring of nuclear waste repositories will likely be characterized by small displacements, potentially large stress changes and adverse environmental conditions, (e.g. exposure to groundwater, heat, etc.) over very long periods of time. It has therefore become apparent that geotechnical instruments capable of performing these functions need to be performance tested and further developed. See for example, Proceedings of a Workshop on Thermomechanical Modeling for a Hardrock Waste Repository, June 1979, ONWI. Those involved in nuclear w e studies are currently endeavoring to apply available geotechnical instrumentation to their programs and have found increasing difficulties in doing so. Since their major client needs have been met to date, many of the instrument manufacturers have not felt a need to spend the amount of money that would be required to make instrumentation modifications that are somewhat unique to nuclear waste isolation. However, many of these modifications would also be helpful in monitoring of underground coal gasification, in situ oil shale recovery, and hazardous waste disposal. On the other hand, many research labs and some consultants have not felt it to be their prerogative or charter to develop instruments.

Therefore a geotechnical instrumentation working group and symposium is being hosted by Lawrence Livermore National Laboratory. Objectives of these meetings are: to define research and development goals and tasks in order to break the cycle of waiting on the next person to develop instruments, to candidly discuss experiences with available instruments and to suggest modifications, procedures and calibrations that will increase the utility and quality of geotechnical instrumentation programs.

To achieve these objectives a two-meeting approach is being taken. The format of the first will be an off-the-record, by invitation only, working group meeting to discuss instrument failures, data aquisition, installation, and general problems. An assessment will be made as to whether instrumentation, procedures or crews need to be improved and just what kind of improvements are necessary. A second open meeting will then be held as a symposium at which the findings of the first meeting will be summarized by an executive committee. This report will be followed by selected reports on current research, and a panel discussion which will be recorded and published as proceedings. This symposium will be held as session E-1 of the 2nd ASCE Geotechnical Conference and Exhibit, April 26-28, 1982, Las Vegas. The format and agenda for both meetings are outlined below.

II. WORKING GROUP MEETING

A. Objectives

The objectives of the working group meeting will be: to identify instrumentation objectives and needs, to provide an experience base or historical basis for evaluating effectiveness of current instruments, to identify current trends in instrument development and to allow candid discussions of experiences without jeopardizing confidentiality or funding.

B. Format and Agenda

Presentation by each participant of their instrumentation experience in (a) vibrating wire stress meters, (b) US Bureau of Mines stress meters, (c) rod extensometers, (d) wire extensometers, (e) piezometers, (f) data acquisition systems including electronic and computer readouts, (g) instrumentation selection, location and installation procedures, (h) environmental protection procedures, (i) quality assurance procedures, (j) calibration procedures. The working group meeting will be attended by invitation only. All participants are expected to add to the information of the meeting whatever experience they have had in instrumentation. This meeting will be totally off-the-record, and nobody is to use or publish information given at the meeting with the exception of the above mentioned report of the working group to the symposium. This report will be generic and nonspecific so that the confidentiality may be protected.

All presentations assume informal format with questions and interfacing throughout.

Dec. 1 -	8:00 - 8:15 a.m.	Welcome - L. Ramspott, LLNL
	8:15 - 8:30	Review Workshop Objectives and Format - D. Wilder, LLNL
	8:30 - 9:00	Summary of DOE and NRC Monitoring Guidelines that will be the Basis for Defining Needed Instrumentation - F. Rogue and W. Patrick, LLNL
	9:00 - 10:00	LLNL SFT Instrumentation - W. Patrick, N. Rector and D. Wilder, LLNL a) Program design b) Instrument experience & types c) Calibration & QA d) D.A.S. e) Electronics
	10:00 - 10:30	AECL Perspective and Instrumentation Experience - D. Jung, Whiteshell Nuclear Reaserch Establishment (tent.)
	10:30 - 10:45	Break
	10:45 - 11:15	U.S. Bureau Mines Experience - C. Babcock
	11:15 - 12:15	Stripa Instrumentation - Andy Dubois,

	12:15 - 1:15	Lunch LBL
	1:15 - 2:15	BWIP Instrumentation - C. Gregory/P. White, Rockwell-Hanford
	2:15 - 2:45	Terra Tek Experiences - D. Lingle
	2:45 - 3:10	Soil and Rock Instrumentation Experiences - B. Beloff
	3:10 - 3:20	Break
	3:20 - 3:45	J. Dunnicliff
	3:45 - 4:10	Foundation Sciences, Inc. Experiences
	4:10 - 4:30	Re/Spec
	4:30 - 4:40	Break
	4:40 - 5:00	Agapito Report Summary - C. St. Johns
	5:00 - 5:30	USGS
	5:30 - 7:00	Dinner
	7:00 - 8:00	Identification and Discussion of Issues
	8:00 - 10:00	Committee Caucus
	10:00	Adjourn
Dec. 2	8:00 - 8:45 a.m.	Committee Report - D. Wilder
	8:45 - 9:15	SINCO
	9:15 - 9:45	IRAD Gage
	9:45 - 10:15	Geokon
	10:15 - 10:30	Break

10:30 - 11:00	Terrametrics
11:00 - 12:00	Formulation of

a) where instrumentation research is heading
b) what needs to be done
c) sensitive issues that should be carefully worded

12:00 noon	Adjourn

C. Participants

This meeting will be limited to approximately 25 to 30 participants consisting of representatives from LLNL, LBL, Rockwell Hanford, Terra Tek, Foundation Sciences, Inc., Terrametrics, Soil and Rock Instrumentation, Geokon, Agapito and Associates, SINCO, IRAD, Re/Spec, Atomic Energy of Canada, Ltd, John Dunnicliff, U.S.G.S., and U.S. Bureau of Mines. In addition, the executive committee will consist of Dale Wilder - LLNL, Dick Lingle-Terra Tek, Christine Gregory - Rockwell Hanford Operations, Andy Dubois - LBL, Bill Beloff - Soil and Rock Instrumentation, and Frank Rogue - LLNL. Instrument manufacture representatives will participate the second day only.

D. Date and Times:

Dates up in the air (tentatively December 1 and 2).

1st Day - General Session, 8:00 a.m. to 6:00 p.m.
- Committee Meeting, 8:00 p.m. to 10:00 p.m.
2nd Day - General Meeting, 8:00 a.m. to 12:00 noon

E. Location: (tentative)

Sites under consideration include:

San Francisco
Salt Lake City
Denver

F. Cost:

No registration fee will be required.

Participants will be responsible for their own travel and lodging unless special arrangements are made ahead of time.

G. Results

The findings of the working group, particularly instrumentation case histories, will be summarized in a non-specific or generic report along with *recommendations. This generic report will* _not_ *identify individual projects,* products or name brand instruments, companies or dates that could cause problems to the participants. The generation of this report will be the responsibility of the executive committee. A draft report will be sent to all participants for comment on confidentiality, however, review response time will be very limited. The final report will be published by LLNL as a pre-print to be available at the symposium.

II. Symposium

A. Objectives:

The objectives of this meeting will be: to allow wide spread dissemination of the results of the working group, to allow a dialogue to develop between users, manufacturers, and consultants regarding geotechnical instrumentation, to define what improvements or developments need to be made to geotechnical instruments, to recommend who should be responsible for making improvements, to identify what segment of the geotechnical community will need these improvements, and to identify what procedures and/or quality assurance and calibration programs should be developed.

B. Format

The meeting will consist of a 15 minute report by the executive committee of the working group followed by approximately three 15-to 20-minute selected papers on new instrument developments, improvements, and modifications. Panel discussion will follow which will be open to the entire symposium. The panel and audience will then discuss which of the suggested developments appear to be useful and necessary, and which are interesting and/or useful but not critical and which are not productive. This session will be recorded and proceedings will be published. This meeting will be held as session E-1 of the geotechnical conference to be held April 1982, at Caesar's Palace in Las Vegas.

C. Participants

Members of the working group should be present. The meeting will be open to all registrants of the sponsoring conference (tentatively ASCE geotechnical conference). An invitation or announcement will be sent to other major societies.

D. Date: April 26-28, 1982

E. Location: Caesar's Palace, Las Vegas, Nevada

F. Cost

This meeting should require no subsidy other than the related costs for recording, some meeting room expenses, and the report preparation costs. Key individuals identified by the working group who may not be able to attend the geotechnical conference may require subsidy. However, at this point, it does not appear that that would be necessary.

G. Report

The panel discussion will be recorded. A proceedings report covering the panel discussions will be submitted for publication in the Journal of the Geotechnical Division, ASCE. This report and the working group report will be the final output of these meetings.

III. Field Trip:

A field trip will be arranged to the Climax Stock to look at the Spent Fuel Test geotechnical instrumentation and to observe installations, environmental protection, new instrument type development, etc. This field trip will be held at the time specified by the conference organizers.

November 18, 1981

Dear Invited Participant:

This letter is to update you about our geotechnical working group meeting. We have now finalized the meeting place and time. We will be meeting in Denver on December 2 & 3. We have blocked out rooms at the Best Western Inn at the Mart, and will be meeting in their conference room facilities.

We have modified, slightly, the original format and attendence list. We have done this to incorporate suggestions we have received, while maintaining our original objectives. Because there has been some confusion, I would like to restate those objectives and then outline the changes we have made.

The first objective was to provide a forum wherein instrumentation users could candidly discuss their experiences, to provide a basis for evaluating how well currently available instruments are meeting existing needs. While these needs are specifically related to nuclear waste isolation programs, I feel that there are some who are not involved in nuclear waste who have sufficient background in instrumentation to be able to add perspective and I have invited them.

The second objective is to define the direction that geotechnical instrumentation is heading and if that direction is adequate for the needs of nuclear waste isolation programs. This objective can be met much more completely by including ONWI, NRC and others (who are responsible for developing the technical guidelines and criteria) in our discussions. Therefore, we have modified the program to invite representatives of ONWI, NRC, etc. to participate the second day. This will allow the candid discussion among users to take place the first day (objective one) while more fully meeting our second objective.

The third and final objective is to identify who should be doing the reseach and development, as well as development of quality assurance programs, etc. By having users, manufacturers and institutional representation present, this objective can be achieved to a significantly greater degree. This will require that the second day be extended to a full rather than half day.

I appreciate your past comments, and would appreciate any further input you may feel is appropriate. I recognize that funding has been curtailed for many of us. I hope that we can have sufficient participation so that the results will be meaningful. We have tried to minimize the individual costs by choice of location, by blocking out rooms and by limiting the meeting to two days. If you plan to attend, please contact me immediately at (415) 422-6908 and then call the Best Western Inn at the Mart by dialing TOLL FREE 800-525-6650, to make your reservation. Be sure to mention that you are with the Lawrence Livermore National Laboratory group.

Sincerely,

Dale G. Wilder

AGENDA*

December 2

8:00 - 8:20 a.m.	Welcome - Review objectives and format
8:20 - 8:40	Potential NRC guides and how they will be implemented - F. Rogue
8:40 - 9:00	Possible DOE/ONWI Guides
9:00 - 10:00	Climax SFT Instrumentation Disussion Leaders - W. Patrick N. Rector D. Wilder
10:00 - 10:15	Break
10:15 - 10:45	AECL Perspective Discussion Leaders - D. Jung P. Baumgarten
10:45 - 11:45	LBL Stripa Instrumentation
11:45 - 1:00	Lunch
1:00 - 2:00	BWIP Instrumentation (Hanford) Discussion Leaders - C. Gregory P. White
2:00 - 2:30	Soil and Rock Instrumentation Discussion Leader - B. Beloff
2:30 - 2:45	Break
2:45 - 3:15	Foundation Sciences, Inc.
3:15 - 3:45	Sandia
3:45 - 4:15	Agapito
4:15 - 4:30	Break
4:30 - 5:30	Identification of Issues and Wrap-up
5:30 - 7:00	Dinner
7:00 - 10:00	Executive Committee caucus

*Guideline only to help discussion - meeting should be discussion format rather than formal presentations.

AGENDA

Users, Manufacturers and Institutional Reps Meeting

December 3

8:00 - 8:45 a.m.	Welcome and committee report
8:45 - 9:45	Anticipated technical/regulatory requirements ONWI - M. Lemcoe
9:45 - 10:15	Break/interactions
10:15 - 11:15	Anticipated technical/regulatory requirements NRC
11:15 - 11:45	Wrap-up - Possible technical/regulatory requirements
11:45 - 1:00	Lunch
1:00 - 2:00	SINCO a) Comments on committee report and instrumenation requirements b) Modifications and/or application of currently available instruments c) Suggested research
2:00 - 2:30	Terrametrics (same topics as above)
2:30 - 2:50	Break
2:50 - 2:20	Rogers Arms
2:20 - 4:00	Wrap-up discussions

APPENDIX 3
ATTENDANCE LISTS

Ad Hoc Meetings

First Ad Hoc Meeting

Richard Lingle	Terra Tek
William Beloff	Soil & Rock Instrumentation/G.Z.A., Inc.
Mike Lemcoe	Battelle/ONWI
Dale Wilder	Lawrence Livermore National Laboratory
Frank Rogue	Lawrence Livermore National Laboratory
E. Christine Gregory	Rockwell Hanford Operations
Jesse Yow, Jr.	Lawrence Livermore National Laboratory
Poyush Dutta	IRAD Gage

Second Ad Hoc Meetings

Clarence O. Babcock	Division of Mines
William R. Beloff	Soil & Rock Instrumentation/G.Z.A., Inc.
Rodolf V. Dela Cruz	University of Wisconsin, Madison
John Dunnicliff	
Chris Gregory	Rockwell Hanford Operations
Joseph Guertin	Soil & Rock Instrumentation
Dick Lingle	Terra Tek
Abelardo Ramirez	Lawrence Livermore National Laboratory
Barrie Sellers	Geokon
Frank S. Shuri	Foundation Sciences, Inc.
Dale Wilder	Lawrence Livermore National Laboratory
Paul A. Witherspoon	University of Califoria - Berkeley, Lawrence Berkeley Laboratory
Jesse Yow, Jr.	Lawrence Livermore National Laboratory

December 2, 1981 Attendance

Jim Aggson	Agapito & Associates
Clarence Babcock	U.S.B.M. - Denver
Lyn Ballou	Lawrence Livermore National Laboratory
Peter Baumgartner	A.E.C.L.
William R. Beloff	Soil & Rock Instrumentation/G.Z.A., Inc.
Eugence P. Binnall	Lawrence Berkeley Laboratory
Mark P. Board	Science Applications
R. C. Carlson	Lawrence Livermore National Laboratory
Don Dodds	Foundation Sciences
Dennis Dolinar	U.S. Bureau of Mines
Andrew O. DuBois	Lawrence Berkeley Laboratory
Gordon E. Green	Shannon & Wilson
E. Christine Gregory	Rockwell Hanford Operations
Michael Hardy	Agapito & Associates
Verne Hooker	Consultant
Frank Horino	U.S.B.M. - Denver
Dieter Jung	A.E.C.L.
Mike Lemcoe	Battelle/ONWI
Richard Lingle	Terra Tek
Jeffrey W. Nelson	D'Appolonia
Wesley C. Patrick	Lawrence Livermore National Laboratory
Norman Rector	Lawrence Livermore National Laboratory
Frank Rogue	Lawrence Livermore National Laboratory
Leo L. Van Sambeek	RE/SPEC & Colorado School of Mines
Hans Swolfs	U.S.G.S.
William F. White	Rockwell Hanford Operations
Dale Wilder	Lawrence Livermore National Laboratory
Roger M. Zimmerman	Sandia National Laboratory

December 3, 1981 Attendance

Lyn Ballou	Lawrence Livermore National Laboratory
Peter Baumgartner	A.E.C.L.
William R. Beloff	Soil & Rock Instrumentation
Eugene P. Binnall	Lawrence Berkeley Laboratory
Mark Board	Science Applications
Brad Boisen	Terrametrics - Golden, Colorado
R. C. Carlson	Lawrence Livermore National Laboratory
Don Dodds	F.S.I.
Andrew O. DuBois	Lawrence Berkeley Laboratory
Gordon Green	Shannon & Wilson
E. C. Gregory	Rockwell Hanford Operations
Dieter Jung	A.E.C.L.
Mike Lemcoe	ONWI
Jeffrey W. Nelson	D'Appolonia
Wesley C. Patrick	Lawrence Livermore National Laboratory
Norman L. Rector	Lawrence Livermore National Laboratory
Frank Rogue	Lawrence Livermore National Laboratory
Dale Shoup	SINCO
Hans Swolf	U.S.G.S.
Rogers S. White	Rogers Arms & Meh. Co.
William F. White	Rockwell Hanford Operations
Dale Wilder	Lawrence Livermore National Laboratory
Roger Zimmerman	Sandia National Laboratory

APPENDIX 4

ELEMENTS OF A NASA-TYPE RELIABILITY PROGRAM

Establish criticality of equipment and systems

List of critical items

Establish list of requirements for:

- o Performance
- o Environment
- o Testing
- o Life
- o Reliability
- o Relieability design criteria
- o Testing programs
- o Certification programs
- o Verifications programs
- o Identify parts of unknown reliability
- o Establish failure rates for parts or class of parts
- o Identify limited life parts
- o Specify inspection and replacement requirements
- o Design for simplicity
- o Reliability documentation for all vendor supplied parts
- o Standard parts lists
- o Fail-safe design philosophy