RELIABILITY OF INSTRUMENTATION IN A SIMULATED NUCLEAR-WASTE REPOSITORY ENVIRONMENT

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1.0 Introduction

The international interest in developing mined geologic repositories for heat-generating nuclear wastes offers several challenges to the geotechnical instrumentation community. This new environment includes both high temperatures and high temperature gradients, imposing a need for compensation for thermal effects in instrument components. Although excavation-induced and thermally-induced displacements and stress changes are of a similar magnitude to those encountered in civil and mining applications, we must measure them more accurately so that they can be used to judge the veracity of computer-based models used to predict long-term repository responses. Since repository monitoring will occur over relatively long times and will involve a relatively large number of instruments, a computer-based measurement system is required. While this can have a positive effect on accuracy, it introduces sensitive electronic transducers to a hostile environment. An additional consideration in the repository environment is the presence of intense ionizing radiation near the emplaced waste, where some measurements will be made.

The Spent Fuel Test-Climax (SFT-C) was conceived as a generic test of the feasibility of packaging, transporting, emplacing, and retrieving high-level nuclear wastes in a
mined geologic repository (Ramspott, et al., 1979). The waste form is spent nuclear fuel from a commercial pressurized water nuclear reactor. Eleven spent fuel assemblies (1530 W each) and six electrical simulators were emplaced in 0.61 m diameter drilled holes in the floor of an underground chamber excavated in granite (Fig. 1). The center array was flanked by two rows of ten electrical heaters to produce a region of rock in which the thermal environment of a full-scale repository was simulated. To monitor the response of this facility, we designed an array of over 900 channels of instrumentation located throughout a 10,000 m³ volume (Brough and Patrick, 1982). We describe here the instrumentation plan developed to monitor the test and the reliability and performance of the instrumentation deployed at the site.

![Diagram](image)

Fig. 1 Plan view of the Spent Fuel Test-Climax showing the Repository Model Cell and Radiation Effects Experiment locations

2.0 Instrumentation Plan

A broad range of phenomena are of interest on the SFT-C. Basic rock mechanical responses are measured as displacements and stress changes and are augmented by an acoustic emissions array (Patrick, et al.) (Fig. 2). The temperatures of the rock, air, and selected instrument components are also measured (Fig. 3). In addition, the dewpoint and flowrate of the ventilation air are monitored because of their importance in heat removal calculations. Since highly radioactive materials are present, we also measured the radiation dose to
Fig. 2 Plan view of locations of displacement and stress measuring instrumentation deployed at the Spent Fuel Test-Climax
Fig. 3 Cross-section and plan views of locations of intermediate-field temperature measuring devices
the granite emplacement medium and monitored for the presence of radiation and radioactive gases in the underground openings. A variety of instruments were installed to monitor the test status. Included are measurements of input power to the heaters and utility power. Standard resistance, voltage, and ice-point references confirm the accuracy of the data acquisition system.

This paper focuses on the displacement, change in stress, and temperature instrumentation. A summary of the instruments deployed is given in Table 1. Most of the instrumentation utilized in the test is commercially available and is not pictured here. Figs. 4 and 5 depict the prototype convergence wire extensometer and fracture monitor system which are probably less familiar to the reader.

Fig. 4 Prototype convergence wire extensometer (CWE). Note spherical seat for tape extensometer attachment and 0.635 mm diameter stainless steel connecting wire.

Fig. 5 Prototype fracture monitor system (FMS). Note the spring-loaded potentiometer transducers and cantilever reference bar.
Table 1 - Geotechnical Instrumentation Deployed at the SFT-C.  
(See Figs. 2 and 3 for locations)

<table>
<thead>
<tr>
<th>Phenomena Measured</th>
<th>Instrument Designator and Type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rock mass displacement due to excavation</td>
<td>MBI, Terrametrics 3 and 6-anchor units with Bourns potentiometers.</td>
<td>Installed using mild steel rods, hydraulic anchors with burst lines, not grouted in place.</td>
</tr>
<tr>
<td>2. Rock mass displacement due to thermal load</td>
<td>GxE, Terrametrics 4-anchor units initially with Bourns potentiometers.</td>
<td>Installed using Super-invar rods, hydraulic anchors with a pressure maintenance system, full-column grouted.</td>
</tr>
<tr>
<td>3. Drift convergence</td>
<td>CWE, prototype units with Bourns potentiometers.</td>
<td>Utilize dead-weight loading and a 0.635mm diameter stainless steel connecting wire. Removable without loss of &quot;zero&quot;</td>
</tr>
<tr>
<td>5. Change in stress</td>
<td>NSG and CSG, IRAD Co. vibrating-wire stressmeters.</td>
<td>Electroless nickel plated, sealed in boreholes with closed cell foam.</td>
</tr>
<tr>
<td>6. Temperature of solids</td>
<td>Various designators, Chromel-Alumel thermocouples (all from the same lot), and 4-wire resistance measurements</td>
<td>TCs installed using zone box technique with RTDs. Magnesium oxide insulated, electrically grounded at the junction, and Inconel 600 sheathed. Four-wire resistance measurements on CWE units for temperature compensation.</td>
</tr>
<tr>
<td>7. Air Temperature</td>
<td>Various designators, thermistors, thermocouples.</td>
<td>Used to study ventilation effects and heat removal from the facility.</td>
</tr>
</tbody>
</table>
3.0 Data Acquisition System and Calibrations

Data is acquired by two Hewlett-Packard (HP) Model 1000 disc-based computers. These units are configured to operate in parallel, with each unit sharing one half the total complement of instrumentation. Software and hardware have been designed to automatically change this configuration to allow one computer to acquire all data if a malfunction occurs in either unit. The computers are located on the ground surface about 650 m away from an underground instrumentation alcove where the analog outputs of the instrumentation are digitized before being sent to the surface (Nyholm, Brough, and Rector, 1982).

The digital voltmeters utilized in the test are HP Model 3455A and are maintained to a 90-day calibration specification. Continuous confirmation of the quality of acquired data is obtained by reading precision voltage, two-wire resistance, and four-resistance standards as part of each computer's normal scanning operation. In addition, the temperature of a laboratory standard ice bath is read using a TC and an RTD.

Calibrations are performed through the entire data acquisition system using references traceable to the U.S. National Bureau of Standards, where available. This ensures that the instrumentation system, rather than just the transducer, is calibrated.

4.0 Reliability and Performance of Instrumentation

4.1 Displacement instrumentation. Most of the displacement instrumentation utilized in the test has functioned reliably with only a few minor problems occurring during and subsequent to installation. A notable exception is the potentiometers utilized in the GxE-series borehole extensometers. About six months after deployment, these transducers began to change resistance in a nonlinear manner. Eventually 23 (41%) of the 56 transducers utilized in the GxE-series instruments failed.

To date, we have investigated seven hypotheses for failure of the potentiometers, none of which provides a satisfactory explanation of the cause of these failures (Patrick, Carlson, and Rector, 1981). The most viable hypothesis at this time is that contaminants, in vapor form, are convectively transported from the 40-60°C downhole portion of the instrument to the 25-35°C sealed head assembly containing the transducers and condense there.

The 48 potentiometers on the 12 centrally located extensometers were replaced with four types of transducers to permit an evaluation of the reliability of other transducers: 12 each of Bourns potentiometers, Vernitech potentiometers,
Schaevitz LVDTs, and Kaman Sciences electromagnetic proximeters. Each set of transducers was in turn subdivided for exposure to three different head-assembly environments: normal sealed mode, vacuum purged, and dry-nitrogen flushed.

Failures in the replacement transducers have been completely isolated to the Vernitech potentiometers: 11 of 12 units have malfunctioned, in the presence of all three environments. Once again, the mode of failure was nonlinear change in resistance, this time accompanied by the presence of fractures in the resistive element.

The reliability of the CWE, FMS, and MBI units has been remarkably good. We are particularly pleased with the success of the first generation CWE and FMS units. The only maintenance required to date has been cleaning the resistive element of a total of 5 (4%) of these units. While downhole conditions are quite different in the GxE units, the transducers are subjected to the same temperature environment for all displacement measurements.

4.2 Stress change instrumentation. The initial complement of 18 vibrating-wire stressmeters malfunctioned within a year of emplacement. The mode of failure was a gradual apparent increase in stress followed by erratic gauge output. Following removal of the stressmeters, we opened and inspected them. In each case, the vibrating-wire had corroded severely; leading to mass loading of the wire and, in some cases, damping of the wire against the magnetic coil (Patrick, Carlson, and Rector, 1981). Visual inspections and gas pressure tests showed that the O-ring seal arrangement utilized in the gauge was inadequate. Discussions with the manufacturer led to an improved, hermetically sealed design which we have now fielded. These units have now functioned reliably for more than two years.

4.3 Temperature and humidity instrumentation. The temperature sensors utilized on the test have functioned with high reliability and continue to provide very precise, accurate data. Pretest calibrations at 0, 50, and 150°C indicated mean errors and standard deviations of 0.020 (0.059), -0.016 (0.059), and 0.250 (0.367)°C, respectively. Post-test calibrations at 0 and 100°C indicated mean errors and standard deviations of 0.054 (0.064) and 0.217 (0.156)°C, respectively. These latter units have experienced temperatures in the range of 80-145°C, relative humidity to 100%, and intense ionizing radiation (~10⁴ rad/hr) for three years. Four cases of corrosion have been noted: three thermocouples and one RTD.
Initially, an insufficient number of sensors was installed to adequately compensate for thermal expansion of displacement instrumentation components. This shortfall was remedied by augmenting the existing sensors.

4.4 Data acquisition system. The reliability of the data acquisition system has been outstanding. System availability has averaged about 96%. The system has operated with a high degree of accuracy with voltages generally within a ± 4 microvolt envelope and 4-wire resistances within a ± 0.0092 ohm envelope. Occasionally the voltmeters drifted out of specification (with regard to resistance measurements) and were returned to the manufacturer for repairs (Patrick, et al., 1983).

5.0 Conclusions and Recommendations

In light of the observed performance of the geotechnical instrumentation deployed on the SFT-C, we offer several conclusions and recommendations.

- Further research is required to fully understand the observed failures of linear potentiometers utilized in sealed or partially ventilated extensometer head assemblies.
- Based on our field observations, we recommend deploying LVDTs or proximeters as extensometer transducers where a sealed head assembly is required. The user must be cognizant of the potential drift and thermal instabilities of these units, however.
- The first-generation wire extensometers and fracture monitors developed for this test are an accurate, reliable means for measuring convergence and discrete joint motion, respectively.
- The improved hermetically sealed vibrating-wire stressmeters function reliably. Calibration of the gauge remains difficult and further work is warranted in this area.
- Utilization of a single lot of sheathed thermocouples in a zone box configuration is a cost-effective, accurate, and reliable means of measuring temperatures in the repository environment. Care must be taken to tailor the sheath composition to the test thermal and chemical environment.
Monitoring and post-test studies will continue at the SFT-C through 1984. Included in these studies will be post-test calibrations of all accessible instrumentation. A final report on the performance of the field instrumentation will be prepared at that time.

5.0 References


