DISCLAIMER

CALCULATED AND MEASURED DRIFT CLOSURE DURING THE SPENT-FUEL TEST IN CLIMAX GRANITE

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Geological storage of spent-fuel assemblies from an operating nuclear reactor has been underway since the Spring of 1980 at the U.S. Department of Energy's Nevada Test Site. The primary objective of this generic test is to evaluate granite as a medium for deep geological storage of high level reactor waste and to provide data on thermal and thermomechanical behavior of granite from imposed heat loads.(1)

The underground installation in the Climax stock granite was sited at about 420 m below the surface and 145 m above the existing water table. As shown in Figure 1, three parallel drifts were excavated spaced on approximately 10 m centers. Seventeen storage holes were drilled at the central drift on 3 m centers in which eleven spent fuel canisters and six thermally identical electrical simulators were emplaced. Electrical resistance heaters were emplaced in vertical holes in the floor of the side drifts on 6 m centers. The thermal output of these heaters is being periodically adjusted to simulate the thermal response of a large storage array. Rock and ventilation air temperatures are being measured continuously in the drifts and throughout the rock surrounding the excavations.

Measurements of drift deformation have been made routinely since the emplacement of the spent fuel. Both vertical and horizontal measurements are being taken at five locations along the heater drifts and at six locations along the central canister drift (Fig. 1). Two types of instrumentaton are being used: convergence wire extensometers which are monitored automatically, and a manually operated tape extensometer with which measurements are taken periodically. The tape extensometer measurements were initiated about 6 weeks following fuel emplacement. The lack of a temperature correcting capability for the convergence wire extensometers make that data unavailable for analysis at this time.

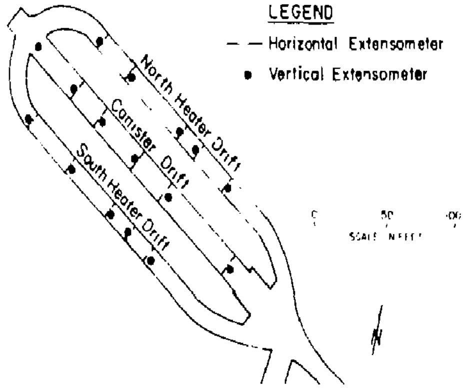

Figure 1. Plan of Spent Fuel Test with Convergence Measurement Locations.

A series of finite element calculations were run with as-built [illegible] geometry and measured physical, mechanical, and thermal properties of Climax Stock granite.[2] The ADINA[3] structural analysis and compatible ADINAT[4] heat flow codes were chosen for this because of their ability to handle diverse factors such as heat flow by conduction, radiation and convection, thermoelasticity, and excavation. ADINAT was adapted to model both internal radiative heat [illegible] within the drifts and ventilation.[5] The ADINA calculations were run with an isotropic thermal-elastic model. Separate ADINA calculations were made using different elastic moduli for the rock. Averages of laboratory measurements on small samples of rock taken from the site give a value of 48 GPa, while the average value from field determinations of effective elastic modulus is about 27 GPa. In addition, an 0.5 m region around each opening that was damaged by explosives during excavation was shown to have an effective elastic modulus of about 13 GPa.[6]

As expected, the thermally induced closures of the drifts are different in each calculation. Figure 2 shows as an example the horizontal closure of the canister drift from the thermal load for each calculation. The smallest closures are for the stiffest laboratory measured modulus. Values are larger by a factor of about 2 for the field determined value, and are about 10% still larger when the low modulus damaged region is included. When plotted as a function of time, the closure of the drifts is in each case parallel for the three calculations. The calculations show that the vertical closure of the canister drift and the horizontal closure of the heater drift occurs within about 6 months after start-up, followed by a small divergence after maximum closure. The horizontal closure of the canister drift and the vertical motion of the side drifts are similar in that most of the closure occurs early, but in these cases the closures continue at a much slower rate without reversal.

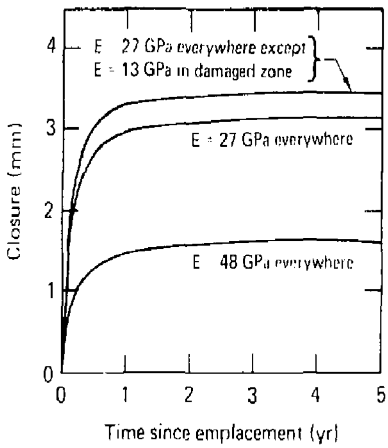

Figure 2. Calculated Horizontal Closure of Canister Drift.

Drift closure measurements reported here were made manually with a model 51855 Tape Extensometer, manufactured by Slope Indicator Co., of Seattle, Washington. A set of measurements were made at each location in the canister and heater drifts at about one month intervals. Potential sources of error in the final values obtained from given readings include thermal expansion effects and operator influences. Measurements are made to the nearest 0.025 mm (0.001 in.). Thermal correction errors are no more than ± 2% of these values if the instrument temperature is known. Of greater significance are operator errors, since measurements are made by several operators. The variation between operators repeating the same measurement falls between ± 0.1 mm.(7)

Measurements from five locations in the canister drift, five locations in the north heater drift, and four locations in the south heater drift were used in the analysis. Those in the curved part of the south heater drift which may show tunnel end effects and the northwest end of the canister drift were not used. Temperature corrected results from redundant measurements and different operators were arithmatically averaged at given locations and times to produce single values for closure with time in a given drift.

Figure 3 shows an example of sets of measurements of horizontal closure of the north heater drift, including one plot for each location where measurements were made. The variations between locations do not appear to be systematic, that is, values do not increase or decrease from the center of the drift to either end. The variation between locations can be as high as ±0.2 mm. Again, these curves were averaged arithmatically to produce an average curve for each drifts' horizontal and vertical closure for comparison with calculational results.

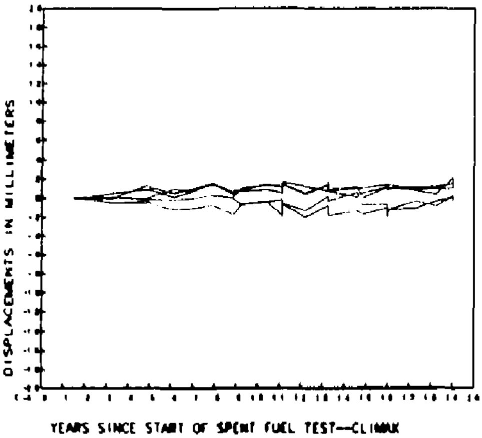

Fig. 3. Measured Horizontal Closure of North Heater Drift.

Tape extensometer results averaged in this manner are compared with the calculated displacements of the drifts at floor and ceiling centerlines and at the mid-height of the walls in each drift. The calculation used is that which has no explosive-damaged region, that is, the modulus is 27 GPa throughout the finite element mesh. This calculation was chosen for the comparison because prior to the installation of the anchor points for drift closure measurements, most of the blast-damaged rock was scaled from the walls. Figures 4a and 4b show the results compared for the horizontal and vertical closure of the canister drift respectively; Figures 5a and 5b for the north heater drift; and 6a and 6b for the south heater drift. The solid lines are the averages of the measured results, and the lines with cross marks are the calculational results. In each case, the total calculated closure since emplacement of the spent fuel (May 6, 1980) is plotted. The tape extensometer values are assumed to agree with the calculated result when the first set of measurements were made. The calculational results show that most of the closure occurred in the interval between the time of emplacement of the spent fuel and the first set of tape extensometer measurements.

The calculations and data track each other very well. For the measurements showing the closure to be continuing throughout the total time, the calculational results also show this effect. Where the measurements show closure followed by dilation, the calculation shows this effect as well. In general, considering the extremely small closures that were measured in the time interval starting at about six weeks after emplacement of the spent fuel canister, the agreement with calculations is very good. When considering the total closure the measured numbers are by comparison extremely small and in all cases are less than one millimeter since the start of tape extensometer measurements. When considering the difference between calculation and measurement, the fractional difference should be based on the total closure. In all cases the difference is less than 30%. When the total closure is almost zero as in the case of the horizontal closure of the heater drifts, this analysis doesn't hold because the calculated displacements are within the range of error for the tape extensometer measurements. Table I shows the results.

Table 1: Difference Analysis between Measurements and Calculations
1.54 Years Since Start

		Calculated Closure since Start (mm)	Calculated Closure since 1st meas. (mm)	Measured Closure (mm)	Diff.	% Diff.
Canister drift	H	2.60	1.13	0.38	0.75	28
	V	2.76	0.60	0.10	0.5	18
S. heater drift	H	----	0.11	0.05	0.06	--
	V	1.88	0.79	0.60	0.19	10
N. heater drift	H	----	0.11	0	0.11	--
	V	1.88	0.79	0.60	0.19	10

SUMMARY

Horizontal and vertical measurements of drift closures have been made with a manually operated tape extensometer since about 6 weeks after the emplacement of the spent fuel at various locations along the length of the drifts. The averaged closures are less than 0.6 mm from the onset of measurements through about two years after the spent fuel emplacement.

These results have been compared with thermo-elastic finite element calculations using measured medium properties. The comparisons show that most of the closure of the drifts occurred between the time the spent fuel was emplaced and the time of first measurement. The comparisons show that the results track each other, in that where closure followed by dilation is measured, the calculations also show this effect. The agreement is excellent, although where closures of less than 0.2 mm are measured the comparison with calculations is limited by measurement reproducability. Once measurements commenced the averaged measured closures remain to within 30% of the calculated total closure in each drift.

ACKNOWLEDGMENT

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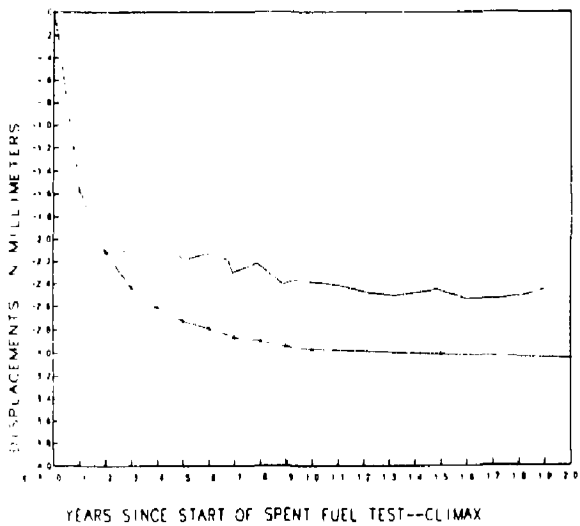

Figure 4a. Calculated and Measured Horizontal Canister Drift Closure.

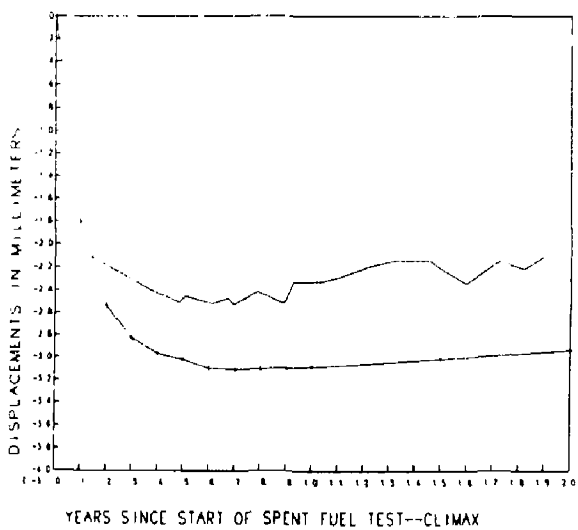

Figure 4b. Calculated and Measured Vertical Canister Drift Closure.

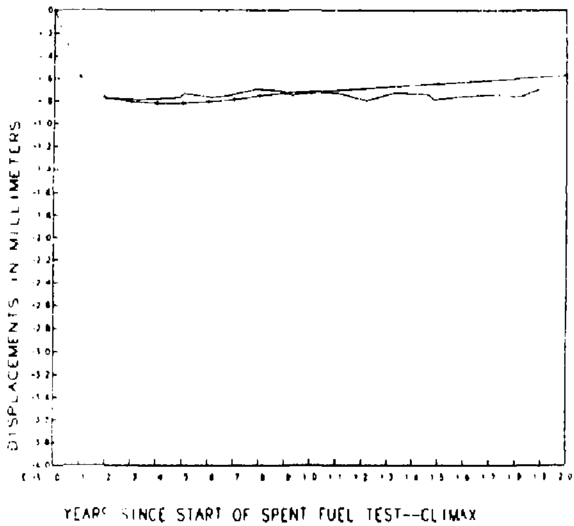

Figure 5a. Calculated and Measured Horizontal North Heater Drift Closure.

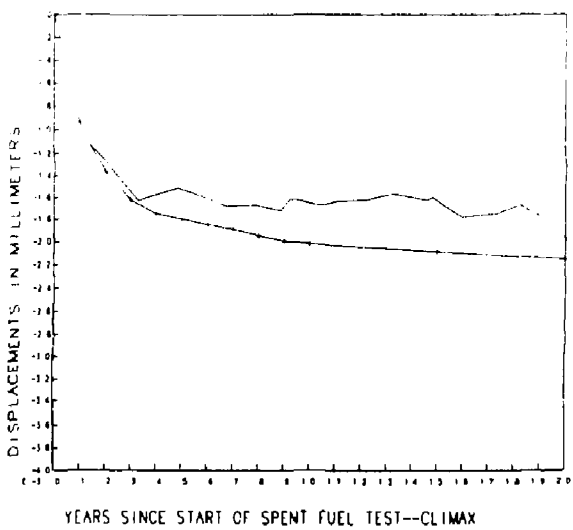

Figure 5b. Calculated and Measured Vertical North Heater Drift Closure.

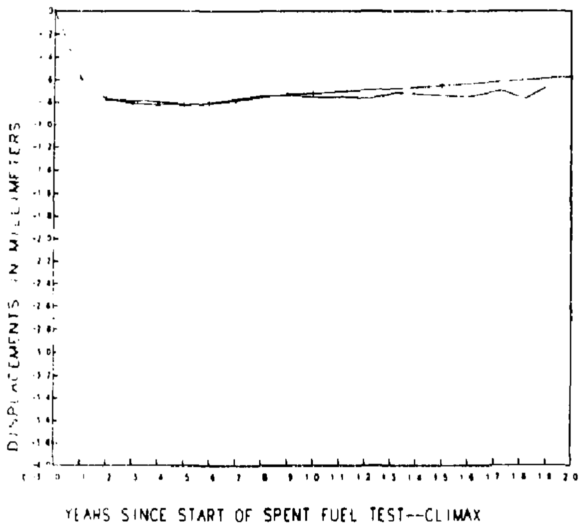

Figure 6a. Calculated and Measured Horizontal South Heater Drift Closure.

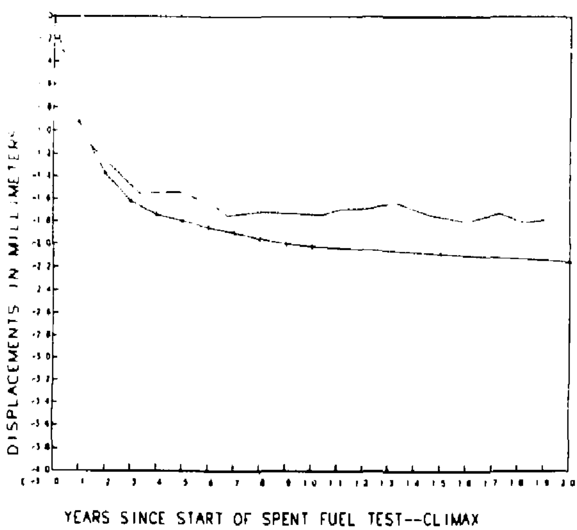

Figure 6b. Calculated and Measured Vertical South Heater Drift Closure.

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