PNL-8040
UC-510

Extrapolation of Creep Behavior of High-Density Polyethylene Liner in the Catch Basin of Grout Vaults

G. A. Whyatt

July 1995

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

DISCLAIMER

Foreword

This report was originally written in June 1991, when it was planned to dispose of Hanford's low-level radioactive liquid wastes from double-shell tanks in a grout waste form. Grout is no longer being considered as the waste form for disposal of Hanford's low-level waste. Instead, low-level liquid wastes from single-shell and double-shell tanks will be vitrified and disposed in a glass waste form. However, grout disposal is currently being maintained as an option in case there is an emergency need to provide additional tank space. The report has not been modified to reflect this change in approach.

Summary

Testing was performed to determine if gravel particles will creep into and puncture the high-density polyethylene (HDPE) liner in the catch basin of a grout vault over a nominal 30-year period. Testing was performed to support a design without a protective geotextile cover after the geotextile was removed from the design. Recently, a protective geotextile cover over the liner was put back into the design. The data indicate that the geotextile has an insignificant effect on the creep of gravel into the liner. However, the geotextile may help to protect the liner during construction.

Two types of tests were performed to evaluate the potential for creep-related puncture. In the first type of test, a very sensitive instrument measured the rate at which a probe crept into HDPE over a 20-minute period at temperatures of 176°F to 212°F (80°C to 100°C). The second type of test consisted of placing the liner between gravel and mortar at 194°F (90°C) and 45.1 psi overburden pressure for periods up to 1 year. By combining data from the two tests, the long-term behavior of the creep was extrapolated to 30 years of service. After 30 years of service, the liner will be in a nearly steady condition and further creep will be extremely small.

The results indicate that the creep of gravel into the liner will not create a puncture during service at 194°F (90°C). The estimated creep over 30 years is expected to be less than 25 mils out of the total initial thickness of 60 mils. The term "creep" is used here to refer to slowly recoverable or nonrecoverable deflection that occurs slowly over a period of time after the initial deflection under load. It does not include the deflection under load, which is recovered almost immediately after the load is removed. The test temperature of 194°F (90°C) corresponds to the design basis temperature of the vault. Lower temperatures are expected at the liner, which makes the test conservative. Only the potential for failure of the liner resulting from creep of gravel is addressed in this report.

Contents

Foreword iii

Summary v

1.0 Introduction 1.1

1.1 Objectives of Testing 1.1

1.2 Creep Versus Deflection Under Load 1.2

1.3 Use of Geotextile 1.2

2.0 Test Methodology 2.1

2.1 Short-Term Probe Tests 2.1

2.2 Long-Term Gravel Tests 2.2

3.0 Results 3.1

3.1 Short-Term Probe Tests 3.1

3.2 Long-Term Gravel Tests 3.1

3.3 Extrapolation of Data 3.3

4.0 Conclusions 4.1

5.0 References 5.1

Figures

1.1 Schematic of Grout Vault Design With Liner in Catch Basin 1.1

3.1 Master Curve for Creep of HDPE: Best Fit Slope 3.2

3.2 Master Curve for Creep of HDPE: Conservative Slope 3.2

Tables

3.1 Comparison of Samples Using Micrometer with Ball Anvils 3.4

3.2 Comparison of Samples Using Penetrometer 3.4

3.3 Recovery of Creep at Ambient Temperature and 194°F 3.5

3.4 Extrapolation of 361-day Data to 30 Years 3.6

3.5 Comparison of 361-day Equations to 53- and 232-day Data 3.8

1.0 Introduction

At the Hanford Site, it is currently planned to dispose of low-level radioactive waste by mixing the waste with dry grout formers and pumping the resulting slurry to a concrete vault where the mixture will harden. Concrete catch basins are constructed beneath the concrete vaults, as shown in Figure 1.1. If liquid leaks from the concrete vault, the catch basins will collect the liquid for removal. The concrete catch basin is lined with a high-density polyethylene (HDPE) liner. Gravel fills the space between the lined catch basin and the bottom of the concrete vault.

1.1 Objectives of Testing

The objective of the testing described in this report was to evaluate the potential for the drainage gravel in the catch basin to creep through the HDPE liner. The tests were designed to provide high confidence that this type of failure would not occur during the first 90 days following grout production when liquids may be in the vault. It was also intended to provide assurance that the liner would not be punctured by gravel particles creeping into the liner over a period of 30 years or more.

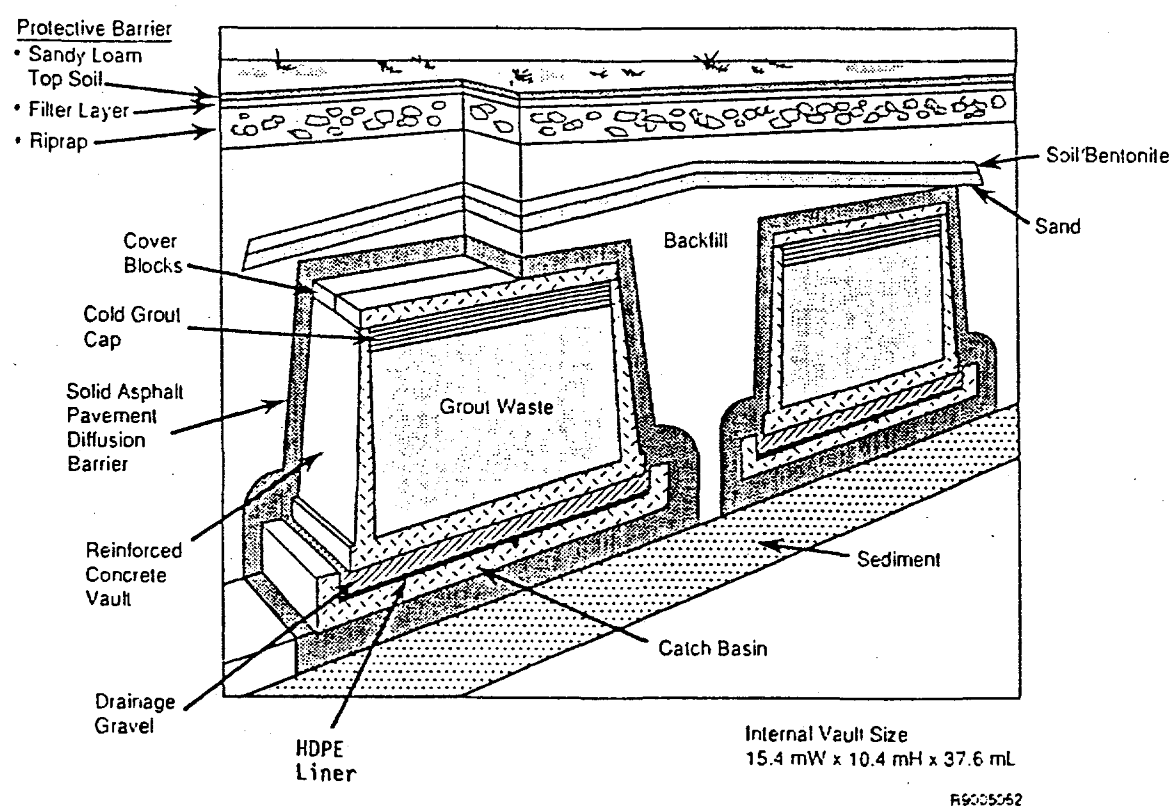

Figure 1.1. Schematic of Grout Vault Design With Liner in Catch Basin

1.2 Creep Versus Deflection Under Load

This report makes a distinction between deflection under load and the creep measurement. When a material is loaded it deflects by an amount that is determined by its modulus. In a material subject to creep, the modulus is not a constant value under a constant temperature and load. The mathematics that describe the deflection of polymers do not make a distinction between the initial deflection, which is recovered almost instantly when the load is removed, and the creeping deflection, which is not recovered for extended periods. Instead, the rate of deflection continuously drops off with a log relationship to time. In this report, "rebound" refers to the deflection that is quickly recovered when the load is removed from a sample. The deflection and rebound behavior is sensitive to temperature and accounts for this analysis. For purposes of this report, creep is defined as the deflection of a liner sample under load minus the rebound that occurs when the load is removed for 3 minutes at 39°F(4°C). This time and temperature correspond to those for removing the load from the 361-day sample and making measurements. Using this definition, the creep represents a change occurring over time under sustained load and may be thought of as a degradation of the liner at that point. The deflection under load, which is quickly recovered when the load is removed, should not be a concern because it does not represent a decrease in the ability of the liner to resist puncture.

1.3 Use of Geotextile

In the initial design of the leachate collection system, a protective geotextile was used between the gravel and the HDPE liner. Some short-term testing was performed with a geotextile in place. The geotextile was then removed from the design due to concerns that it would delay the time required to detect a leak in the vault. Tests were then started to evaluate the system without a geotextile present. Finally, the geotextile was put back into the design because the protection it provided was judged to be more important than a potential delay in detecting leachate. The majority of the data in this report are taken without geotextile present. The data available for the geotextile-covered liner are used to evaluate the protection provided by the geotextile covering.

2.0 Test Methodology

Two tests were performed to provide the required information. In the first test, very sensitive measurements were made of a probe creeping into HDPE over short time periods. These measurements were then extrapolated to long time periods based on theory developed for polymers. However, it was difficult to compare the well-characterized load conditions of the probe to the complex point loads associated with a gravel bed. This difficulty was addressed by the second test.

In the second test, the conditions of the liner were more closely simulated. The liner was placed under a representative load between mortar and gravel at 194°F (90°C) for extended periods and then removed and inspected. This test provided data that could be combined with the results of the first test to extrapolate the results to a 30-year time period.

2.1 Short-Term Probe Tests

2.1.1 Theory

Using an empirical relationship, the response of a polymer to an applied stress at different temperatures can be extrapolated to a fixed temperature for an extended time period. This is accomplished using a time "shift factor," which allows all of the data for different temperatures to be placed on the same plot at an arbitrary reference temperature. The theory and procedure are described in detail in Ferry (1961). More recent references which discuss the theory are also available (Baer 1964, Gillen 1978, Aklonis and MacKnight 1983, Crissman 1986).

2.1.2 Apparatus and Procedure

Tests were performed using a Perkin-Elmer Thermal Mechanical Analyzer. Samples of 60-mil HDPE from National Seal were cut to form 250-mil-square samples. The sample and measurement device were brought to the desired temperature and maintained at that temperature throughout the test. A 0.040-in. hemispherical probe was used to apply a load of 70 psi configured so that strain occurred in the 60-mil dimension of the sample. The measurement device provided output both as printed values and on a chart recorder with a sensitivity of (5 X 10^{-5} in. deflection)/(in. of chart). The printed values were recorded every 2 seconds at the start of the test and at longer intervals as the rate of change slowed. Each test was continued for approximately 20 minutes. Tests were conducted at several different temperatures to provide data for the extrapolation.

2.2 Long-Term Gravel Tests

The apparatus consisted of a 6-inch-diameter test cell with mortar in the bottom. A liner sample was placed on top of the mortar and then covered with a rounded gravel of the following size gradation.

% passing 1 in.	100%
% passing 1/2 in.	90%
% passing 3/8 in.	50%
% passing No. 4	22%
% passing No. 8	0%

A test machine with an oven was used to maintain a constant load of 45.1 psi (±1%) at a temperature of 194±5°F (90±3°C). The load represents the estimated overburden pressure to which the liner will be exposed. The temperature corresponds to the design basis temperature for the vault. The liner temperatures are expected to be lower, which will reduce the rate of creep. Therefore, the temperature selected for the test is conservative.

After the specified period of time the test machine and oven are turned off. In the tests of the geotextile-protected samples, the sample was allowed to cool to room temperature before the load was released. In the 53- and 232-day liner-only tests, the oven was turned off and the load released at the same time. The sample was then removed and transported to another building where the thickness of the liner at various indentations was measured. In all cases the sample was measured the same day it was removed from the test machine. The measurement was performed using a Humbolt H-1300 penetrometer. The penetrometer has 0.1-mm divisions and may be read to approximately 0.05 mm. The accuracy of the final value for thickness of liner (a difference between two readings) is expected to be ± 3.9 mil (0.1 m). Thickness readings were taken on a 4 X 4 grid (16 points) to determine the average thickness of the liner. This average was then compared to the minimum thickness measured in the deepest dent to determine the extent of creep.

In the final sample (361-day duration), the methodology was improved to address concerns over the extent of rebound that may have occurred between the time the sample was removed from the test machine and the dents were measured. Prior to releasing the load, the sample was cooled to 39°F (4°C). The load was then released and initial measurements completed within approximately 3 minutes. A ratchet stop micrometer with ball anvil attachment was used to improve the accuracy and precision of measurements for detection of creep recovery. The sample was remeasured over a 22-hour period and was then placed in a 194°F (90°C) oven for 80 minutes to encourage creep recovery. The sample was then measured again after its removal from the oven. To provide a comparison of measurements to other samples, all previous samples were remeasured using the ratchet-stop micrometer with ball anvil attachments.

3.0 Results

3.1 Short-Term Probe Tests

A number of liner samples were tested at temperatures of 176°F, 187°F, 203°F, 208°F, and 212°F (80°C, 86°C, 90°C, 95°C, 98°C, and 100°C). For temperatures where repeat runs were made, results were averaged for that temperature and then used to determine the master curve. The data is displayed in Figure 3.1. The variables plotted are defined as follows: E is the modulus of the material which changes with time under a constant load, thus resulting in creep, T is the temperature, T_0 is an arbitrary reference temperature selected as 536.8°R (298.2°K) for this work, t is time in seconds, and A_t is a time shift factor. If the data were perfect, all points would be in a line in this plot. A flat slope indicates very little creep over extended time periods, while a steeper slope indicates more creep occurring over long time periods. The line shown in Figure 3.1 is a best-fit line through the data. In order to ensure that the extrapolated results conservatively estimate the creep behavior, the line was redrawn through the data in a conservative way so that the line did not pass above any data. This line is shown in Figure 3.2 and was used to provide extrapolation. The intercept was then adjusted based on information obtained from the gravel creep tests described below. Equivalently, the measured creep in the gravel test is divided by the fraction of the 30-year creep that is estimated to have occurred at the time the sample was removed.

The primary limitation to the data generated from these tests is that the well defined area and force delivered by the probe is difficult to relate to the series of point loads that exist for a known overburden pressure of gravel on top of the liner. The extent of creep would be expected to increase proportional to the local loading. There was no acceptable method for calculating the maximum point loads based on the overburden pressure.

In addition, HDPE is a partially crystalline material while the theory used is developed primarily for amorphous polymers. Extrapolating creep behavior of partially crystalline HDPE using the theory developed for amorphous polymers may lead to some overestimation of the extent of creep over time. However, the theory provides the best available estimate of creep behavior.

To allow extrapolation, it was desired to have data from a more representative test configuration in order to fix a point from which to extrapolate. Therefore, long-term gravel type tests were performed.

3.2 Long-Term Gravel Tests

The objective of the initial tests performed using a geotextile-protected liner was to determine if the liner could be punctured by creep during the period in which liquid will be present in the vault (taken as 60 days). The measurements of thickness in the geotextile-protected samples indicated that the liner would not be punctured during this period. Due to the shorter time period of concern, probe-type tests were not necessary.

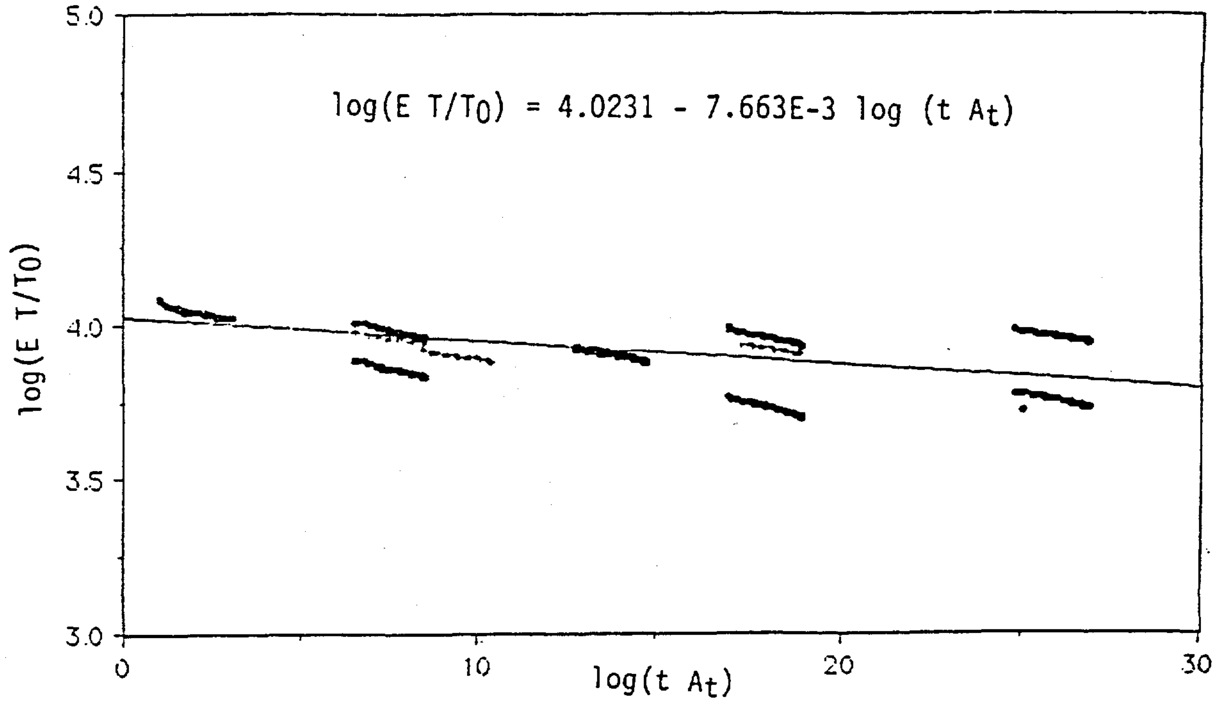

Figure 3.1. Master Curve for Creep of HDPE: Best Fit Slope

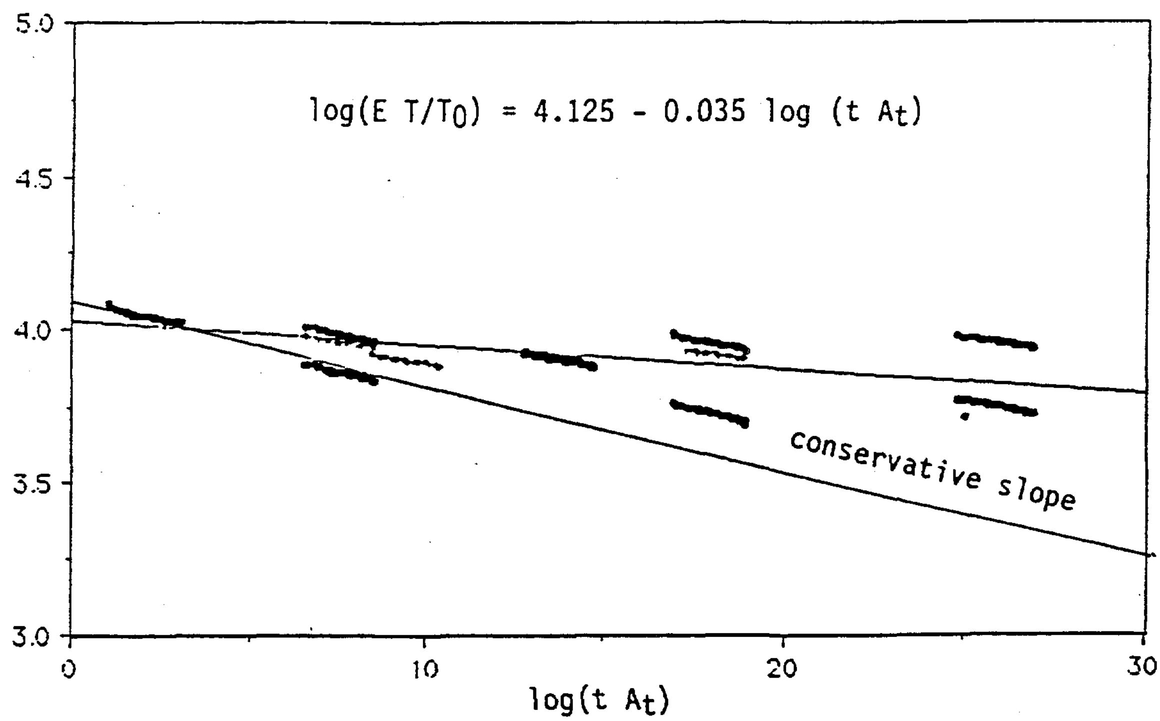

Figure 3.2. Master Curve for Creep of HDPE: Conservative Slope

The objective of the second set of tests was to determine if the liner would be punctured over 30 or more years. Samples were tested for periods of 53, 232, and 361 days. As discussed under methodology, the measurement technique was improved for the 361-day sample. The 53- and 232-day samples and the geotextile-protected samples were remeasured using the ball anvil micrometer. The results are shown in Table 3.1. The conclusion drawn from these measurements is that the geotextile does not significantly reduce the extent of creep. The comparison is not exact because there are differences in the period the samples were in the test cell and in the period prior to remeasuring the samples. However, in comparing the 32-day geotextile-protected sample to the 361-day unprotected sample, both of these factors should bias the results toward demonstrating that the geotextile provides a reduction in the creep. Reduction in the creep of the geotextile-protected samples was not observed.

For the 361-day sample (Table 3.1), there is some recovery of creep after removal of the load. The recovery is fairly slow at ambient temperature but is significant at 194°F (90°C). Reverse creep occurring at ambient temperature is extremely slow if the liner has already recovered at 194°F (90°C) for any length of time. The micrometer used in the final measurements was more precise than earlier measurements performed using a Humbolt penetrometer. In addition, the technique for using the penetrometer was changed between the initial 32-day tests and the subsequent tests. Table 3.2 provides a comparison of measurements performed using the penetrometer with a consistent technique. Readings between the penetrometer and the micrometer were generally consistent, although the micrometer was more precise and more accurate. Note that for the 232-day sample the micrometer provides smaller standard deviations on individual measurements and improved repeatability (Tables 3.1, 3.2).

The measurements of creep made on the 232-day samples after the sample was removed and several days after removal from the test cell agree fairly well, as shown in Table 3.3. The measurements on the 361-day sample after recovery also indicate that recovery at ambient temperature is very slow after recovery at 194°F (90°C). Samples which have recovered at 194°F (90°C) for any length of time may be remeasured at a later date with little loss in accuracy. In addition, the geotextile-protected sample did not show significant recovery over a period of 414 days at ambient temperature. When the sample was then heated to 194°F (90°C) for 80 minutes, it recovered approximately 40% of the remaining deflection.

3.3 Extrapolation of Data

Using the combined results of the gravel and probe tests, the creep of the liner can be extrapolated to long time periods. The equation from the probe creep tests predicts the modulus (and resulting deflection) over time at constant temperature and load. If the deflections are small, the rebound would exhibit the same type of behavior, returning to the original shape in the same period of time that was required to create the deformation in the first place (assuming constant temperature). However, for larger deformations the creep is not recovered. This is similar to a proportional limit for a spring. The spring will return to its original shape for small deformations, but if the spring is stretched beyond the proportional limit it will not return to its original shape.

Table 3.1. Comparison of Samples Using Micrometer With Ball Anvils

Test Period (days)	Recovery Period[a] (days)	Geotextile?	Average[b] Thickness (mil)	Minimum[c] Thickness (mil)	Estimated Creep [d] (mil)
32	414	yes[e]	58.4 ± 0.45	43.4	15.0
32	414	yes	57.4 ± 1.1	48.0	9.4
53(f)	308	no	58.9 ± 0.59	53.2	5.7
232(f)	11	no	59.2 ± 0.47	52.6	6.6
361	3 min.	no	57.5 ± 0.58	44.3	13.2
361	1 day	no	57.6 ± 0.66	45.2	12.4
361	80 min 194°F	no	57.7 ± 0.32	49.5	8.2

(a) Period of time between sample removal from test cell and remeasurement of sample. Some reverse creep could occur during this period.
(b) Average thickness at grid points, ± value is one standard deviation for individual measurements.
(c) Minimum thickness obtained from measurement of all dents in the liner sample.
(d) Calculated as (average)-(minimum). No extrapolation included in value.
(e) The geotextile used was a Polyfelt TS750 nonwoven polypropylene geotextile. Properties: thickness 120 mil (ASTM D1777), fabric weight 10.3 oz/yd^2 (ASTM D3776), other properties available (TMI# HGTP-036).
(f) Load and heat removed simultaneously. As a result some rebound at 194°F (90°C) occurred prior to measurement of sample.

Table 3.2. Comparison of Samples Using Penetrometer

Test Period (days)	Recovery Period[a] (days)	Geotextile?	Average [b] Thickness (mil)	Minimum[c] Thickness (mil)	Estimated Creep[d] (mil)
32	403	yes[e]	62.0 ± 2.8	49.2	12.8[f]
32	403	yes	58.2 ± 1.2	51.2	7.0
53	266	no	58.3 ± 2.1	53.2	5.1
232	3	no	60.9 ± 1.3	54.3	6.6
232[g]	3	no	59.1 ± 1.4	55.1	4.0

(a) Period of time between sample removal from test cell and remeasurement of sample. Some reverse creep could occur during this period.
(b) Average thickness at grid points, ± value is one standard deviation.
(c) Minimum thickness obtained from measuring all dents in the liner sample.
(d) Calculated as (average)-(minimum). No extrapolation included in value.
(e) The geotextile used was a Polyfelt TS750 nonwoven polypropylene geotextile. Properties: thickness 120 mil (ASTM D1777), fabric weight 10.3 oz/yd^2 (ASTM D3776), other properties available (TMI# HGTP-036).
(f) The next deepest dent would indicate 8.9 mil creep.
(g) Repeat of previous set of measurement on same sample.

Table 3.3. Recovery of Creep at Ambient Temperature and 194°F (90°C)

	232-day sample			
Date	7/31/90[a]	8/3/90[a]	8/3/90[a]	8/14/90[b]
Recovery time	same day	3 day	3 day	14 day
Average (mil)	59.6 ±0.9	60.9 ±1.3	59.1 ±1.4	59.2±0.47
Minimum (mil)	53.5	54.3	55.1	52.6
Residual Deflection (mil)	6.1	6.6	4.0	6.6
	361-day sample[b]			
Date	9/18/90	9/19/90	9/19/90	11/13/90
Recovery time	3 min	1 day	80 min 194°F	56 day
Average (mil)	57.5±0.58	57.6±0.66	57.7±0.32	57.7±0.25
Minimum (mil)	44.3	45.2	49.5	49.9
Residual Deflection (mil)	13.2	12.4	8.2	7.8
	32 -day sample with geotextile			
Date	6/26/90[c]	8/3/90[c]	8/14/90[b]	9/19/90[b]
Recovery time	same day	403 day	414 day	+80 min 194°F
Average (mil)	57.9 ±4.0	62.0 ±2.8	58.4 ±0.45	58.0 ±0.32
Minimum (mil)	41.3	49.2	43.4	49.1
Residual Deflection (mil)	16.6	12.8	15.0	8.9

(a) Measurement made with penetrometer with ball anvils.
(b) Measurement made with ball anvil micrometer, which is the most precise method used.
(c) Measurement made with penetration needle, which is significantly less precise than subsequent methods.

The objective of the testing was to examine whether the liner would be punctured over a period of 30 years or more. A puncture would be a serious, nonrecoverable deformation. In the case of minor deformations, the rebound when the load is removed may be a significant portion of the total deflection under load, as discussed below.

The extrapolation of greatest interest is that of the 361-day sample since changes under load beyond this time are likely to be very small. The equations representing the lines plotted in Figures 3.1 and 3.2 describe the long-term deflection of the liner under load. The sample removed from the gravel test has a history of 361 days under load at 194°F (90°C) followed by 3 minutes at 39°F (4°C) without load before completing the measurements. The extrapolation is a trial-and-error process. First, a total deflection under load in the gravel test is estimated. Based on the estimation, the intercept of the creep equation is determined and the rebound of the liner prior to measurement in the gravel test is calculated. The calculated depth of the dent is then compared to the depth measured in the gravel test and a new estimation for total deflection under load is made until the predicted measurement agrees with that measured in the gravel test. The extrapolation of the 361-day sample is summarized in Table 3.4.

Table 3.4. Extrapolation of 361-day Data to 30 Years

	Conservative Slope[a] (mil)	Best Fit Slope[b] (mil)
Predicted 361-d deflection under load	26.5	43.4
Predicted measurement in gravel test	13.2	13.2
Actual measurement in gravel test	13.2	13.2
Predicted measurement in gravel test after 30 years[c]	16.6	13.2
Time required for 1 mil additional creep after 30 years under load[d]	46 yr	512 yr
Predicted measurement after 80 min at 194°F (90°C)	7.0	2.8
Actual measurement after 80 min at 194°F (90°C)	8.2	8.2

(a) Refers to Figure 3.2 derived equation. Changes occur over a longer time frame with this equation.
(b) Refers to Figure 3.1 derived equation. Changes occur more rapidly and reach a near final condition in a shorter period of time.
(c) This is a prediction of the depth of dents that would be measured in a sample if the test were continued for a 30-year period.
(d) If extrapolation is continued beyond 30 years, this is the number of years required for an additional 1 mil of creep.

The first line in Table 3.4 provides the prediction of the actual deflection while the liner is loaded. This represents the successful estimation in the trial-and-error solution. The accuracy of this value is uncertain since no measurements are available for deflection under the gravel point loads. However, the extrapolation is calibrated to deflections remaining when the load is removed so that the accuracy of this value is not critical. Several factors may contribute to inaccuracy in the deflection under load value. First, the area over which the load is applied tends to increase as a particle forms a dent in the liner. Also, some changes may not be completely reversible and the relationships used are developed for amorphous polymers while HDPE is partially crystalline. All these factors would tend to make the predicted deflection under load larger than the actual value. However, the most important limitation is that the temperature behavior data was only collected in the region of 194°F (90°C). Therefore, the prediction of rebound at 39°F (4°C) prior to measurement is a significant extrapolation. Comparisons of rebound at ambient temperatures (sample with geotextile in Table 3.3) indicates that rebound is slower at lower temperatures than predicted. While this has a significant effect on the calculation of the deflection under load, the effect on the extrapolated creep value is relatively small as long as the conditions assumed for rebound prior to test measurements and predicted 30-year measurements are the same.

The equations developed by combining the gravel and probe type tests are shown below.

$$\log(E\ T/T_0) = 2.5961 - 0.035 \log(t\ A_t) \qquad \text{"conservative" eq.}$$

$$\log(E\ T/T_0) = 1.9758 - 7.663E{-}03\ \mathrm{Log}(t\ A_t) \qquad \text{"best-fit" eq.}$$

where E = modulus (psi)
T = temperature (°R)
T_0 = reference temperature (536.8°R)
t = time (seconds)
A_t = time shift factor (2.291E+07)

The equations developed are limited in that the temperature dependence is only known near 194°F (90°C). Also, the equations are only applicable to the gravel used in the tests since they have been adjusted to account for the transmission of a general overburden load to point loads which will vary with the type of gravel used. The "conservative" equation predicts that the creep and recovery processes occur over a longer period of time. The "best-fit" equation would suggest that the process occurs rapidly and reaches a near steady condition in a shorter period of time. It also predicts greater rebound prior to measurement and therefore results in a greater deflection under load value.

The second and third rows in Table 3.4 represent the predicted and measured deflection after 3 minutes and 39°F (4°C). These values agree because the equation has been adjusted so that the prediction is correct at this point. This adjustment is required because no method was available to extrapolate the well-defined surface area of the probe to the irregular point loads of the gravel.

The fourth row in Table 3.4 represents the prediction of the 30-year creep. This value corresponds to the measurement that would be made on the sample if the sample were left in the test cell for 30 years at 194°F (90°C), and was then cooled to 39°F (4°C) and measured within 3 minutes of releasing the load. Both equations predict that the additional creep would be small between years 1 and 30. The fifth row of Table 3.4 shows the estimated time required for the liner to creep one additional mil after first being exposed to the load for 30 years. This indicates that the liner has reached an essentially steady condition and that further creep is extremely small.

After the measurements were made on the liner it was placed in an oven at 194°F (90°C) to promote recovery of the creep. The measurements are compared to predicted results based on each of the two equations in lines 5 and 6 of Table 3.4. Surprisingly good agreement is obtained with the conservative equation, while the best-fit equation shows more recovery than what occurred. This may indicate that the conservative equation is a better predictor of the liner creep behavior.

An additional comparison can be made to data generated from the 53-day and 232-day samples. These samples were not cooled before releasing the load. Instead, the load was removed at the same time that the oven door was opened to allow the sample to cool. The temperature history during this period is not well known, but the samples likely remained near 194°F (90°C) for a period of approximately 15 minutes. If it is assumed that the liners obey the equation developed from the 361-day sample, the period of time that these samples remained at 194°F (90°C) can be calculated. These values are compared for the two equations in Table 3.5.

Table 3.5. Comparison of 361-day Equations to 53- and 232-day Data

	Estimated Period of Recovery		
	"Best-Fit" Eq.	Conservative Eq.	Actual
53-day sample	0.001 min	52 min	≈ 15 min
232-day sample	0.0003 min	105 min	≈ 15 min

The values for the best fit equation are in poor agreement. Clearly the liner would have remained at 194°F (90°C) for periods of time greater than this. However, the "conservative" equation provides realistic numbers. Because the creep recovery is dropping off inversely proportional to the log of time, the time values are not far off. For example, to obtain another 1 mil of creep recovery for the 232-day sample would require an additional 320 minutes. Considering that the comparisons are made using average liner thickness and minimum liner thickness, the times are in reasonable agreement.

The creep measured for one geotextile-protected sample was greater than that of the 361-day unprotected sample (see Table 3.1). The samples were remeasured using the same instrument used in the final 361-day test, so the difference cannot be attributed to the measurement technique. The fact that this liner demonstrated a greater creep is difficult to explain from a mechanistic point of view. It is unlikely that the presence of geotextile increased the extent of creep. Most likely, a rock may have been oriented to provide an unusually high point load on this sample. If this is the case, this data point should be considered in evaluating the long-term creep behavior of the liner.

If the 32-day geotextile-protected sample is extrapolated using the conservative equation using the same approach as with the 361-day sample, the 30-year creep value is 24.8 mil. This extrapolation uses a 1-hour, 77°F (25°C) rebound period rather than 3 minutes and 39°F (4°C) in order to match the test conditions for this sample. The recovery of this sample over 414 days at ambient temperature did not appear to be significant, while a subsequent period of 80 minutes at 194°F (90°C) caused significant recovery. This suggests that the equation predicts faster recovery at low temperatures than actually occurs.

4.0 Conclusions

The data clearly indicate that the liner will not be punctured during a 30-year period. After 30 years the liner will have reached an essentially steady condition such that further creep will be extremely small. The conclusion that the liner will not be punctured is reached on the basis of tests that are conservative from the standpoint of the following:

1. The temperature of 194°F (90°C) is higher than expected temperatures at the liner.

2. The extrapolation assumes a constant load over time. As the creep progresses into the liner, the area of the rock supported by the liner increases and the pressure at the point of the individual rock decreases.

3. The relationship used for extrapolation was developed for amorphous polymers and is conservative when applied to a partially crystalline polymer such as HDPE.

4. The slope drawn for the master curve used for extrapolation was drawn conservatively.

The 361-day sample indicates that the creep over a 30-year period would be approximately 17 mil. Because one geotextile-protected sample from the previous tests showed creep that was greater than the 361-day sample, it was used to estimate a maximum 25-mil creep over 30 years. This creep represents what would be measured after 30 years if the liner were cooled, removed from the catch basin, and measured. The deflection under load would be greater than this. However, deflection that is quickly recovered does not represent a degradation of the ability of the liner to avoid puncture and is therefore not included as a component of creep.

5.0 References

Aklonis, J. J. and W. J. MacKnight. 1983. *Introduction to Polymer Viscoelasticity*. Second edition, John Wiley and Sons, Inc. New York.

Baer, E., editor. 1964. *Engineering Design for Plastics*, Polymer Science and Engineering Series. Reinhold Publishing Corporation, New York.

Crissman, J. M. 1986. "Creep Recovery Behavior of a Linear High Density Polyethylene and an Ethylene-Hexene Copolymer in the Region of Small Uniaxial Deformations." *Polymer Engineering and Science* 26(15).

Ferry, John D. 1961. *Viscoelastic Properties of Polymers*. John Wiley and Sons, Inc. New York.

Gillen, K. T. 1978. "Use of a Thermomechanical Analyzer to Estimate the Tensile Compliance for Polymeric Materials." *Journal of Applied Polymer Science* 22:1291-1302.

Distribution

No. of
Copies

OFFSITE

12 DOE/Office of Scientific and Technical Information

3 Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37831
ATTN: T. M. Gilliam
E. McDaniel
R. Spence

ONSITE

2 DOE Richland Field Office

L. A. Huffman, S7-53
N. R. Brown, S7-53

4 Westinghouse Hanford Company

K. C. Burgard, G6-13
J. A. Voogd, G6-13
G. F. Williamson, G6-13
R. J. Murkowski, G6-13

No. of
Copies

20 Pacific Northwest Laboratory

L. M. Bagaasen, P7-43
K. A. Blanchard, K2-50
C. Franks, K9-72
H. D. Freeman, P8-38
J. H. Holbrook, K9-81
G. B. Mellinger, K6-51
E. V. Morrey, P7-19
R. J. Serne, K6-81
B. D. Slonecker, K9-80
J. H. Westsik, Jr., K9-80
G. A. Whyatt (5), P7-19
Technical Report Files (5)