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LYSIMETER DATA AS INPUT TO PERFORMANCE ASSESSMENT MODELS⁶

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ABSTRACT: The Field Lysimeter Investigations: Low-Level Waste Data Base Development Program is obtaining information on the performance of radioactive waste forms in a disposal environment. Waste forms fabricated using ion-exchange resins from EPICOR-II⁷ prefilters employed in the cleanup of the Three Mile Island (TMI) Nuclear Power Station are being tested to develop a low-level waste data base and to obtain information on survivability of waste forms in a disposal environment. The program includes reviewing radionuclide releases from those waste forms in the first 7 years of sampling and examining the relationship between code input parameters and lysimeter data. Also, lysimeter data are applied to performance assessment source term models, and initial results from use of data in two models are presented.

KEYWORDS: lysimeters, solidification, EPICOR-II, resins, liners

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INTRODUCTION

Concern over the practices associated with the disposal of low-level radioactive waste (LLW) has resulted in a very real need to obtain accurate data on the long-term field performance of these wastes. The U.S. Nuclear Regulatory Commission (NRC) has enacted regulations that link LLW acceptance criteria to the long-term satisfactory performance of the waste. Under Code of Federal Regulations (CFR) Licensing Requirements for Land Disposal of Radioactive Wastes (10 CFR 61), [1], commercially generated LLW is classified as Class A, B, or C. Wastes classified as either Class B or Class C must be stabilized for a minimum of 300 years.

To verify the 300-year stability of waste forms, the NRC originally specified the use of short-term standardized tests with the hope that such tests in principle could provide information relevant to near-surface disposal performance objectives. Those tests, which were initially published in the NRC Branch "Technical Position on Waste Form" [2] and have been revised in Revision 1 of the Technical Position [3], are currently undergoing critical review to determine their applicability to the 300-year stability requirements.

A central requirement in LLW disposal site design is the need for a detailed understanding of the waste form as the radionuclide source of the site and the effect of that source on site performance. A major requirement in any site licensing is the site performance assessment. The performance assessment is used to predict whether or not a proposed disposal site will meet the performance objectives. Correct assumptions regarding the performance of the buried waste form have a direct bearing on the outcome of the performance assessment. Conservative assumptions of radionuclide release rates will result in over-design of containment, while under estimating the release of especially mobile constituents will over-predict containment performance.

A useful experimental device that will provide hard data for determining waste form stability is the lysimeter. Lysimeters are ideal systems for obtaining field test data because, when properly designed and operated, they can be used to isolate soil/waste systems under actual environmental conditions. Such conditions cannot be duplicated by standard laboratory testing. Lysimeters lend themselves to instrumentation used for acquiring environmentally related data and for collecting and storing migrating precipitation and mobilized radionuclides.

The Field Lysimeter Investigations: Low-Level Waste Data Base Development Program, funded by the NRC, is obtaining information on the performance of radioactive waste in a disposal environment, and the requirements of 10 CFR 61 are being investigated. Waste forms are being field-tested to develop a LLW data base and to obtain information on survivability of waste forms.

The purpose of this paper is to present the experimental results of two instrumented, operational lysimeter arrays over 7 years of operation. This study was developed to field-test waste forms composed of solidified ion-exchange resin materials from EPICOR-II prefilters used in the cleanup of the TMI Nuclear Power Station Unit 2 (TMI-2) [4]. Waste used in the study is significant because it has a high loading of radionuclides and is comprised of ion-exchange media of the type used by the nuclear industry.

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METHODS AND MATERIALS

Wastes used in the experiment include a mixture of synthetic organic ion-exchange resins from prefilter PF-7 and a mixture of organic-exchange resins and an inorganic zeolite from prefilter PF-24. Solidification agents employed to produce the 4.8 x 7.6-cm cylindrical waste forms (Fig. 1) used in the study were Portland Type I-II cement and DOW vinyl ester-styrene (VES). Seven of the waste forms were stacked end-to-end and inserted into each lysimeter to provide a 1-L volume. Table 1 lists waste form description by lysimeter number. The PF-7 waste contained 89% of the radionuclides as cesium-137, while PF-24 contained 94% cesium-137. The PF-7 waste also contained 5% strontium-90, and PF-24 contained 1% strontium-90. There were also significant amounts of cesium-134 and trace amounts of cobalt-60 and antimony-125 found in those wastes. Details on waste-form formulations are given in Reference [5].

Ten lysimeters were used in this study--five at Oak Ridge National Laboratory (ORNL) in Tennessee and five at Argonne National Laboratory-East (ANL-E) in Illinois. The lysimeters were designed to be self-contained units that will be disposed at the termination of the study. Each lysimeter is a 0.91 x 3.12-m right-circular cylinder divided into an upper compartment that contains fill material, waste forms, and instrumentation, and an empty lower compartment for collecting leachate (Fig. 2). Four lysimeters at each site are filled with soil; a fifth, used as a control, is filled with inert silica oxide sand (Table 1). The lysimeters at ANL-E contain soil indigenous to the site, while the ORNL lysimeters contain soil taken from Savannah River Laboratory in South Carolina. The soil columns are 0.91 m in diameter 2.21 m deep.

Instrumentation in each lysimeter includes moisture cup soil-water samplers and soil moisture/temperature probes. The probes are connected to an onsite data acquisition system (DAS), which also collects data from a field meteorological station located at each site. Fine porous cup soil-water samplers and a lysimeter leachate collection compartment comprise the water sampling components of each lysimeter (Fig. 2). Incoming precipitation moves downward through the soils column to the waste form, then on to cups 3 and 1, and finally to the leachate collector at the bottom. Moisture entering the soil at the edge of the lysimeter encounters cups 5, 4, or 2 as it moves downward. Samples of moisture are withdrawn from the cups and the collector. Radial movement of waste form releases are detected in cups 5, 4, and 2, while vertical release is observed by cups 3 and 1. Lysimeter design, installation, instrumentation, operation, and data acquisition are provided in Reference [6].

Monitoring of the lysimeters at ANL-E and ORNL began with the collection of liquid samples in September 1985 (3 months from the time of placement) and has continued with sample collection on approximately a quarterly basis thereafter, except in FY-91, in which the winter sampling was skipped. Samples of liquids were taken from locations near the waste forms and from the leachate collectors to track the migration of radionuclides. The water samples were analyzed for beta and gamma-producing nuclides. Each month, data stored on a cassette tape in the DAS were retrieved and translated into an IBM PC-compatible disk file. Soil moisture and temperature at three elevations in each lysimeter, along with a complete weather history, were recorded on a continuing basis by the DAS. Testing results are presented in References [7-13], as well as in this paper.

FIG. 1--Example of a waste form.

TABLE 1--Lysimeter waste-form composition.

Lysimeter number	Fill material	Waste form description	Waste weight percent
1	Soil	Cement with PF-7 waste	24
2	Soil	Cement with PF-24 waste	24
3	Soil	VES with PF-7 waste	61
4	Soil	VES with PF-24 waste	61
5 ANL-E	Silica oxide	Cement with PF-7 waste	24
5 ORNL	Silica oxide	Cement with PF-24 waste	24

FIG. 2--Lysimeter vessel component locations. The base of the soil column is the zero elevation reference.

RESULTS AND DISCUSSION

Weather and Soil Data

Precipitation, air temperature, wind speed, and relative humidity are being recorded continuously by the ANL-E and ORNL DAS during the experiment. Fig. 3 shows the cumulative precipitation for each site since the initiation of field work. Examples of the lysimeter soil temperature and moisture data recorded at ANL-E and ORNL can be found in References [7-13]. Data recorded in FY-92 indicate that the lysimeter soil columns at both sites have remained moist during the last reporting period. The average soil moisture of ANL-E lysimeter soils was 54.7% of the soil moisture holding capacity; for ORNL, this value was 38.9%.

By using the cumulative rainfall data from each site since the time the lysimeters were placed in operation, it is possible to calculate the volume of water that has been received by the exposed lysimeter surfaces (6 489.5 cm³). The cumulative volume of precipitation received by each ANL-E lysimeter was 3 886.1 L; at ORNL, this value was 5 790.7 L. The total volumes of precipitation that have moved through the lysimeters represent an average 2.35 pore volumes for the ANL-E soil lysimeters and 7.32 pore volumes for soil lysimeters at ORNL, while the control lysimeters at ANL-E and ORNL were 8.60 and 9.28 pore volumes, respectively. It appears that the throughput is dependent on lysimeter fill material and on site conditions (e.g., the period of time that the soil surface was frozen and the amount of precipitation received as snow).

Radionuclide Data

Four samplings from moisture cups and leachate collectors were taken at each site every 12 months. Figs. 4 through 10 show the cumulative amounts of nuclides as determined in water samples obtained from number 3 moisture cups (22.4 cm below the waste form in the soil column) and leachate collectors (51.2 cm below the waste form and soil column) for all sampling periods.

These data show that not all nuclides consistently appeared in the water obtained from the moisture cups or the leachate collectors. The nuclide that appeared with the most regularity at both sites was strontium-90. Table 2 contains a comparison of the percent of inventory of strontium-90 and cesium-137 found in the moisture cups and leachate water. Consistent significant occurrences have been observed in all the number 3 cups at both ANL-E and ORNL. There are standout amounts of strontium-90 retrieved from moisture cup samples at both sites. Those include a cumulative total of 1 095 575 pCi from cup 3-3 at ANL-E (Fig. 4) and 104 434 pCi from cup 1-3 at ORNL (Fig. 5).

For the ORNL lysimeters, the total amount of the nuclide released in leachate water was comparable to or greater than that in the cups (Table 2). These data follow a trend seen over the past 18 months and make it appear that a pulse of strontium-90 could be moving through the soil columns of the ORNL lysimeters.

At ANL-E, recovery of strontium-90 in cups 3 and the leachate collectors indicates a uniformity of waste form performance (Table 2). More strontium-90 was found in ANL-E cups 3-3 and 4-3 (VES waste forms) than in the other ANL-E cups, but the effect appears to be moderated by the distance traveled in soil from the waste form to the leachate collector. Movement of the nuclide into the leachate collector of the inert, sand-filled control, ANL-E lysimeter 5, is much greater than that of the other lysimeters and thus provides evidence of the moderating effect of soil.

FIG. 3--ANL-E and ORNL cumulative precipitation.

TABLE 2--Percent of total strontium-90 and cesium-137 inventory per lysimeter in moisture cups and leachate water.

Lysimeter number	Solidification agent	Percent total inventory Sr-90 x 10 ⁶		Percent total inventory Cs-137 x 10 ⁶					
		Moisture cups		Leachate water		Moisture cups		Leachate water	
		ANL-E	ORNL	ANL-E	ORNL	ANL-E	ORNL	ANL-E	ORNL
1	Cement	59	545	27	1,078	...	...	...	2.0
2	Cement	181	406	53	493	0.9	...	...	0.1
3	VES	3,998	381	193	69	...	...	...	0.7
4	VES	289	35	69	469	...	...	...	0.1
5	Cement	89	384	7,581	45,356	15.0	0.1	...	86.0

FIG. 4--ANL-E cumulative strontium-90 collected in moisture cup 3.

FIG. 5--ORNL cumulative strontium-90 collected in moisture cup 3.

FIG. 6--ANL-E cumulative strontium-90 collected in lysimeter leachate collectors.

FIG. 7--ORNL cumulative strontium-90 collected in lysimeter leachate collectors.

FIG. 8--ANL-E cumulative cesium-137 collected in moisture cup 3.

FIG. 9--ORNL cumulative cesium-137 collected in moisture cup 3.

FIG. 10--ORNL cumulative cesium-137 collected in lysimeter leachate collectors.

During the past 12 months, leachate collector water from the control lysimeters at each site contained amounts of strontium-90 at least an order of magnitude larger than releases from the soil lysimeters (Figs. 6 and 7). This is comparable to the previous year's findings [7-13]. For leachate collectors, intersite-comparable quantities of strontium-90 were found in ANL-E and ORNL soil lysimeters (Table 2). The percent of total strontium-90 being measured in the leachate collector water and number 3 cups is somewhat inconsistent between the two sites (Table 2). Perhaps this represents a difference in how the environment at the two sites affects the movement of strontium-90 being released from the waste forms. This difference is also seen when the percent of total strontium-90 found in the leachate water from the two control lysimeters is examined. The percent passing through the ORNL control to the leachate collector has increased to six times that of the ANL-E control (Table 2). Greater quantities of strontium-90 are moving through the ORNL lysimeters than the ANL-E lysimeters. There appears to be no correlation between the type of waste form and the amount of nuclide recovered in the leachate collector. About 0.045% and 0.008% of the strontium-90 contained in lysimeters 5 at ORNL and ANL-E, respectively, has now been recovered in leachate from those lysimeters. Recovery of strontium-90 in the ORNL cups is comparable for those lysimeters containing the cement waste forms and one of the two containing VES waste forms. These data, together with those from ANL-E, continue to indicate that cement and VES have comparable releases for strontium-90, and more is being removed from the ORNL lysimeters.

Gamma-producing nuclides have occurred with regularity at both sites (Table 2). ANL-E cup 2-3, below a cement waste form containing large amounts of cesium-137, has received significant quantities of cesium-137 (Fig. 8). Since June of 1987, cesium-137 has been appearing in ANL-E

cup 5-3. The quantity of this nuclide abruptly increased in each of the sampling periods during the last 3 years (Fig. 8) [12]. There continues to be no sustained occurrence of cesium-137 in any ANL-E leachate collector water. Measurable amounts of cesium-137 began to occur in ORNL cup 5-3 during the May 1988 sampling and have continued in subsequent samplings for a total of 2 010 pCi (Fig. 9). Also, cesium-137 has been detected consistently in water from the ORNL lysimeter leachate collectors (Fig. 10). Breakthrough of cesium-137 into the ORNL lysimeter 5 leachate collector occurred in November 1988 (Fig. 9), and thus far, a total of 234 508 pCi have passed through the soil column of that lysimeter. A comparison of cesium-137 releases from cement and VES waste forms is difficult to make at this time due to the small releases. However, all waste forms at ORNL are releasing detectable amounts of cesium-137 to the leachate waters (Table 2).

MODELING LYSIMETER RELEASES

A past evaluation has shown that data obtained from the operation of the lysimeters does have a relationship with performance assessment code parameters [10]. These parameters have been calculated using data collected during the 48-month operation of the ANL-E and ORNL lysimeters (Table 3). The data can be used in codes to predict the stability of waste forms for a 300-year period of time. The operational lysimeters provide continuous data from the near-field (that area comprised of the waste form and surrounding soil). These data relate directly to waste form stability. Information obtained from the data includes the mass balance of released constituents, the solubility of radionuclides in a site-specific geochemical system, as well as an indication of the retardation or dispersion of released constituents during transport in the near-field. Also, soil-pore water chemistry (radioactive and inorganic constituents), soil mineralogy, soil water/mineral mass ratio, net infiltration rate, soil profile moisture and temperature, porosity,

TABLE 3--Performance assessment code parameters
derived from ANL-E and ORNL data.

Code parameters	ANL-E					ORNL				
	1	2	3	4	5	1	2	3	4	5
Annual percolation (P) (m/yr)	0.297	0.346	0.520	0.422	0.817	0.969	0.977	0.983	0.995	1.148
Vertical water velocity (V_v) (m/yr)	1.14	1.33	2.00	1.62	3.89	5.21	5.25	5.28	5.35	5.74
Inventory (Q) (pCi Sr-90 x 10^9)	18.2	3.3	27.4	4.5	18.2	18.2	3.3	27.4	4.5	3.3
Fraction of saturation (S) (average of past 3 years)	56.4	56.5	56.4	56.4	50	37.2	37.2	37.2	37.2	50
Soil bulk density (d_s) (g/cm ³)	1.42	1.39	1.42	1.48	1.55	1.30	1.34	1.30	1.30	1.60
Effective soil porosity (P_e)	0.46	0.48	0.46	0.44	0.42	0.51	0.49	0.51	0.51	0.42
Inventory release (I_r) (%Sr-90 x 10^{-6})	27	49	29	1	1,500	140	279	60	220	2,160
Radionuclide concentration (C_v) (average pCi Sr-90/L leachate)	6.6	1.9	5.8	0.1	128.2	10.6	3.9	7.1	4.1	25.8

and hydraulic conductivity are being or could be extracted from lysimeter output. Such data are invaluable as inputs into performance assessment and source term codes since they represent a field data set that contains complete information that characterizes environmental, hydrogeological, geochemical, and waste form effects.

As a first modelling approximation, the first 5 years of collected lysimeter data were used as inputs to a mixing cell model. This model is a precursor to the models used in the two-dimensional Breach, Leach, and Transport (BLT) code [14] and the one-dimensional Disposal Unit Source Term (DUST) code [15]. Both of these codes predict the release of nuclides from a waste form in a failed container surrounded by a porous medium containing a solute. In the mixing cell model, the solute is treated as a well-stirred fluid (i.e., a mixing bath), and the concentration is calculated using a mass balance that depends on the solute flow rate, the amount of partitioning between the porous medium (soil) and solute (leachant), the size of the mixing cell (lysimeter size), the radioactive decay rate, and the rate of radionuclide release from the waste form. The distance of movement of radionuclides in the soil was taken as 51.2 cm to the leachate collector and 22.4 cm to moisture cup number 3.

Releases of cesium-137 and strontium-90 from the waste forms were modeled using the mixing cell model. The most appropriate release process was considered to be diffusion from a cylinder (the shape of the waste forms). The waste form diffusion coefficients were available from data in Reference [16]. Calculations for the mass balance of the solute concentration required Darcy velocities (volumetric flow rate per area), which were calculated from lysimeter leachate collector analytical data [11]. Soil/water retardation (distribution) coefficients (K_d) were obtained from previous published work [17,18].

A comparison of the measured cumulative cesium-137 activity from ORNL lysimeter 3 to a simulation using the mixing cell model appears to give a reasonable match to the data (Fig. 11). The simulation used a Darcy velocity of $3.12\text{E-}6$ cm/s, a K_d of 1 000, and a waste form diffusion coefficient of $3.3\text{E-}14$ cm²/s. Although a match was obtained, the mixing cell model is limited in that it treats the entire lysimeter as being one cell at a single concentration and ignores dispersive transport. At the very low measured cumulative fractional releases from these lysimeters, dispersion can play a substantial role in transport. Also, requiring a uniform concentration within the lysimeter may not be an adequate approximation. This first approximation helped identify those areas in which additional data (soil retardation coefficients and dispersivities) will be required in order to use the lysimeter data effectively in performance assessment modeling.

To remove these limitations, the DUST code was used to model the release of the radionuclides cesium-137 and strontium-90 from the lysimeter waste forms. DUST is a one-dimensional code that accounts for container performance and waste form leaching (including diffusion-controlled release). Transport can be modeled through finite differences or by a multi-cell mixing cascade approach. The finite difference method was used in the simulations reported in this paper because it is more general than the mixing cell approach and permits modeling of dispersive transport. A further description of the models in the code is given in Reference [15].

The releases of cesium-137 and strontium-90 from Portland Type I-II cement located in the inert, sand-filled lysimeters 5 at ORNL and ANL-E were chosen because releases from other lysimeters were substantially lower and because the data were not yet sufficient to model. At ANL, lysimeter 5 contained resin waste from PF-7 solidified in Portland Type I-II cement; at ORNL, lysimeter 5 contained resin waste from PF-24,

FIG. 11--Comparison of cesium-137 cumulative activities for measured data at ORNL lysimeter 3 leachate collector (51.2 cm of soil) and mixing bath model prediction.

which was also solidified in cement (Table 2). The waste form diffusion coefficients for Portland Type I-II cement were presented in Reference [15]. Measured values were $9.6\text{E-}10 \text{ cm}^2/\text{s}$ for strontium-90 in Portland Type I-II cement and $5\text{E-}11 \text{ cm}^2/\text{s}$ for cesium-137 in Portland Type I-II cement. The Darcy velocities ranged from $2.59\text{E-}6 \text{ cm/s}$ at ANL-E to $3.6\text{E-}6 \text{ cm/s}$ at ORNL [11]. The soil bulk density values were 1.55 g/cm^3 at ANL-E and 1.60 g/cm^3 at ORNL [6]. Moisture content values were calculated using the effective soil porosity and the fraction of saturation values found in Reference [12]. In lysimeter 5 at both sites, the moisture content was calculated as 21%. The distribution coefficients have not been measured for strontium-90 or cesium-137; therefore, they were estimated (based on data in Reference [18]) and by fitting the model predictions to the data. The cumulative leachate activity collected from the lysimeters over the first 7 years of operation of the experiment, which was used to make comparisons to the DUST code predictions, represented about 0.045% and 0.008% of the total inventory of strontium-90 in lysimeter 5 at ORNL and ANL-E, respectively. At ORNL, the collected amount represented less than $8.6\text{E-}5\%$ of the cesium-137 inventory in lysimeter 5, while nothing has been collected in ANL-E lysimeter 5 (Table 2). Therefore, either the waste form release rates are much lower than anticipated or transport processes are controlling release through the soil column. At that level, it is possible that random fluctuations (noise) are being seen and release patterns may not develop for several more years.

Three parameters are known to strongly influence release through the soil column. They are waste form diffusion, which controls radionuclide release rates from the waste form, the soil retardation coefficient (K_d), and dispersivity, which together control transport from the waste form through the soil column. Several cases were modeled in which either K_d , dispersivity, or waste form diffusion coefficients were varied to best match the actual release data from the lysimeters.

The domain of the model was extended to 52 cm below the waste form, 1 cm below the bottom of the soil column. This ensures that boundary conditions (BCs) will not significantly affect the predicted concentrations. Therefore, the results in Figs. 12 and 13 are obtained using a bottom BC of zero dispersive flux.

As shown in Fig. 12, the actual data for strontium-90 from ORNL lysimeter 5 are compared with the DUST code predictions of releases using zero dispersive flux BC, $K_d = 24$, and dispersivity = 8.5. Also shown are predicted releases using zero concentration flux BC, $K_d = 10$, and dispersivity = 0.6. The measured waste form diffusion coefficient of $9.6E-10$ cm²/s was used. The predicted releases of zero dispersive flux BC show a very good fit to the actual data.

Fig. 13 shows the actual data for strontium-90 at ANL-E lysimeter 5. In addition, the DUST predictions of 20 years of cumulative leachate activity is plotted in two cases, using dispersive flux BCs. The measured waste form diffusion coefficient of $9.6E-10$ cm²/s was used. Case 1 has a dispersivity of 8.5 and a K_d of 24.5. Case 2 has a dispersivity of 0.6 and a K_d of 10. Case 2 releases less activity over 6 years than case 1; however, at 20 years, the amount of activity released by case 2 is an order of magnitude higher than the amount in case 1. Over 20 years, case 2 will have released 33% of the total strontium-90 inventory, whereas case 1 will have released 3.3% of the total strontium-90 inventory. Case 1 is a better fit to the actual data at 7 years, indicating a predicted higher dispersivity and K_d than previously thought.

CONCLUSIONS

A greater recovery of strontium-90 has occurred in terms of quantity and percent of inventory than for other nuclides. Next in abundance is cesium-137. Compared to strontium-90, the occurrence of cesium-137 appears insignificant. Cesium-137 continues to occur in the moisture cups at ORNL and has been found in moisture cup 2 at ANL-E (below 22.4 cm of soil) but not in any leachate waters (through 51.2 cm of soil).

On a cumulative basis, more strontium-90 is being removed from the ORNL lysimeters. During the past 60 months, strontium-90 continues to be found in higher concentrations in leachate water from the control lysimeters at both sites, with more found at ORNL. It seems that the limiting step in receiving strontium-90 in the leachate collector is not release of the nuclide from the waste forms (because strontium-90 is found in number 3 cups), but rather it is the soil characteristics (including soil and quantity of soil water) that limit movement.

On three occasions, these lysimeter data have been reviewed to determine the possibility of using the data to initiate limited performance assessment modeling. It was shown to be possible to model some of the lysimeter strontium-90 release data from the experiment using the DUST computer code. Data provided by these lysimeter experiments have been shown to be useful in computing many parameters used as input to performance assessment codes. Also, to limit model/prediction uncertainties, several parameters need to be measured. These are the site-specific soil retardation coefficients and dispersivities. The utility of this reliable source of data will be demonstrated through continued operation of the lysimeters.

The U.S. Department of Energy at the Idaho National Engineering Laboratory is investigating the use of lysimeter systems based on the design presented here. Those systems would provide data for calculating parameters to be used in performance assessment of a LLW disposal site and for verification of the codes used in that performance assessment in accordance with DOE orders governing the disposal of LLW.

FIG. 12--Cumulative release of strontium-90 at ORNL lysimeter 5 over 7 years, compared with DUST predictions using two sets of estimated K_d and dispersivity values over 20 years.

FIG. 13--Cumulative release of strontium-90 at ANL-E lysimeter 5 over 7 years, compared with DUST predictions using two sets of estimated K_d and dispersivity values over 20 years.

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