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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

IN THE MATTER OF KERR-McGEE CHEMICAL CORPORATION (West Chicago Rare Earths Facility)	Docket No. 40-2061-ML ASLBP No. 83-495-01-ML

TESTIMONY OF CHARLES W. FETTER, JR., JAMES L. GRANT, AND JOHN C. STAUTER IN RESPONSE TO THE BOARD'S ORDERS OF NOVEMBER 14, 1989, AND NOVEMBER 20, 1989

NUCLEAR REGULATORY COMMISSION

Docket No. 40-2061-ML Official Exh. No. Kerr McGee 2
In the matter of Kerr McGee Rare Earths
Staff
Applicant ✓ IDENTIFIED
Intervenor RECEIVED ✓
Cont'g Off'r REJECTED
Contractor Ann Riley DATE 12/5/89
Other Witness Fetter, et al.
Reporter Ron Le Grand

November 28, 1989

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On November 14, 1989, and on November 20, 1989, the Board issued orders directing the parties to submit testimony regarding certain groundwater-related issues. This testimony is submitted on behalf of Kerr-McGee Chemical Corporation ("Kerr-McGee") in response to the Board's orders.

This testimony is submitted by a panel composed of Charles W. Fetter, Jr., James L. Grant, and John C. Stauter. Professor Fetter is Chairman of the Department of Geology and Professor of Hydrogeology at the University of Wisconsin, Oshkosh. He is the author of a widely used textbook on hydrogeology and has had extensive experience in assessing environmental impacts on groundwater systems. Dr. James L. Grant is the President and Chief Executive Officer of James L. Grant & Associates. He has a Ph.D. in civil engineering from the Georgia Institute of Technology and has been extensively involved in preparing geohydrological assessments. Dr. John C. Stauter is Director, Environmental Affairs, for

Kerr-McGee Corporation. He is a Ph.D. in Chemical/Extractive Metallurgy from the University of Utah. Resumes for each of the witnesses are attached as Appendices 1 through 3.

The Board's November 14 order suggests that the Board perceives differences in the groundwater modeling that was performed by Kerr-McGee and by the NRC staff and the Board's questions seem designed to explore these differences. In order to put the answers in context, it is appropriate first to examine how Kerr-McGee and the NRC approached groundwater modeling. Thus, in Part I of this testimony, we address the Kerr-McGee and the NRC modeling, the results that were obtained, and the nature of and the reasons for the differences in approach. As will be seen, although the NRC and Kerr-McGee have approached the modeling in different ways, the results in fact complement each other.

In Part II, we explore the specific questions that the Board has raised with regard to Contention 4(a). In Part III, we turn to Contention 3(g)(2). Finally, in Part IV, we turn to the matters raised in the Board's order of November 20. It will be seen that the analyses submitted by Kerr-McGee and the NRC are reliable (indeed, conservative), and confirm that the proposed disposal cell will have a negligible impact on groundwater quality.

I. CHARACTERIZATION AND MODELING

A. Site Characterization.

The starting point in any modeling effort is the characterization of the hydrogeology of the site. Kerr-McGee has engaged in an extensive effort to collect the necessary hydrological information. The data are described in detail in Volume II of the Kerr-McGee Engineering Report (April 1986).[1]

Borings and wells were installed throughout the area to obtain data concerning a variety of different parameters. These parameters were measured at the location of the wells or borings, and then, using standard interpolation and extrapolation techniques, were projected to estimate the values throughout the site. For example, the stratigraphy at a point was determined by drilling a borehole and collecting samples at several depths as the drilling progressed. These samples were analyzed by a geologist and certain physical tests, such as analyses of grain size, were performed. Principles of stratigraphy and glacial geology were then used to project the probable position of the various strata in the areas between boreholes. Similarly, the elevation of the hydraulic head was determined in a number of wells screened in the same aquifer. Contouring techniques were used to create potentiometric surfaces for the various strata at the site.

The data that were collected at the site provide the basic information used in constructing a groundwater model to predict future impacts of the proposed cell. The stratigraphy of the site forms the physical framework for the development of the model. At the West Chicago site, the topmost

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[1] Citations to the Engineering Report are set out in the form "[volume] Eng. Rep. [page, figure, etc.]".

aquifer -- the aquifer within the 2-stratum -- is the aquifer that would be first and most directly affected by the cell. Hence the groundwater model is designed to assess potential impacts on that aquifer.

The driving force behind groundwater flow is the hydraulic head. The potentiometric surface thus provides an important input to the modeling. Similarly, various physical parameters were estimated based on site measurements. Certain parameters that vary over a narrow range, such as effective porosity, were assumed to be constant across the site. Other parameters that vary widely in glacial sediments, such as hydraulic conductivity, were estimated in the regions between wells by means of standard geostatistical techniques.

The basic data describing the site hydrogeology are shown in figures that appear in the Engineering Report, such as those showing the site and regional stratigraphy, potentiometric surface maps for the different aquifer units, maps showing the distribution of transmissivity for the various units, and isopach maps showing the thickness of the various strata.

B. Kerr-McGee Modeling.

The Kerr-McGee modeling of the possible impact of the disposal cell consists of three distinct elements. First, Kerr-McGee estimated the infiltration of water through the cover of the cell. The cell's cover is designed to minimize the intrusion of water into the wastes, which has the obvious beneficial impact of reducing the volume of contaminants that can escape to the groundwater. The infiltration of water into the cell was analyzed using a computer model.

Second, in order to assess the impacts of the cell on groundwater quality, it was necessary to estimate the concentration of contaminants that the infiltrating water will dissolve. This analysis serves to characterize the leachate that could be introduced into the groundwater system. Kerr-McGee determined the leachate quality on the basis of standard chemical analyses of the leachate actually generated from the various types of wastes.

Third, it is necessary to predict the impact of any leachate released by the cell on groundwater quality. This latter step was accomplished through the use of a detailed numerical computer model of the groundwater flow at the site. The model permits the estimation of the concentration of contaminants in groundwater at the site boundary.

1. Infiltration.

The U.S. Army Corps of Engineers' Waterways Experiment Station has developed a computer model, the Hydrologic Evaluation of Landfill Performance model ("HELP"), for the U.S. Environmental Protection Agency to evaluate the performance of landfill designs. The model uses climatological and soil data to calculate a moisture balance for the cover. It enables the estimation of the amount of runoff, evapotranspiration, lateral drainage (through any drainage layers which might be present), and infiltration through the cover. The HELP model is well documented;[2/] it is a standard and reliable model that is often used to design landfill covers.

Although the model was developed for purposes of cover design, it also enables the calculation of the amount of recharge percolating past the soil moisture zone in natural soils. The HELP model shows that under natural conditions in the West Chicago region, the amount of rainfall recharging the E-stratum is on the order of 3.7 inches (9.4 cm) per year. II Eng. Rep. 2-73. This is consistent with estimates of natural infiltration made by others.[3/]

Because of the design of the cover of the Kerr-McGee cell, infiltration will be considerably less than that through natural soils in the area. The HELP model was applied to determine the amount of rainfall that could be expected to infiltrate through the cell cover. The relevant specifications for the cover design are set out in the Engineering Report. II Eng. Rep. Table 2-29. The infiltration was estimated based on the actual observed precipitation for a recent five-year period, as well as from a simulation of precipitation generated by the model for the area over a 100-year period. The HELP model shows that a cover built

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[2/] Schroeder, P.R., J.M. Morgan, T.M. Walski, and A.C. Gibson, "The Hydrologic Evaluation of Landfill Performance (HELP) Model," (1984) (EPA/530-SW-84-009).

[3/] Law Engineering Testing Co., <u>Hydrologic Studies -- West Chicago Thorium Plant</u> (1981).

according to the Kerr-McGee design would allow infiltration of less than 0.001 inches (0.0025 cm) per year. II Eng. Rep. 2-74, App. D. The predicted results are set out as Table 1.

As explained in the Engineering Report, it is often observed that soil under field conditions may be more permeable than the laboratory measurements of soil properties would suggest. II Eng. Rep. 2-74. This is believed to result from weathering of the soils and from the effects of vegetative roots. In any event, adjustments are customarily made to account for this effect by increasing the assumed hydraulic conductivity in the principal root zone by a factor of 3. See Schroeder, et al., supra note 2. Kerr-McGee allowed for increased infiltration through the root zone into the cell by increasing the assumed hydraulic conductivity of the surface soil layer by a factor of 10 -- a very conservative adjustment that serves to overestimate predicted infiltration. Under these conditions, cell infiltration was calculated to be about 0.1 inches (0.254 cm) per year. II Eng. Rep. 2-74, App. D; see Table 1. Kerr-McGee used this estimate as a reasonably conservative best estimate of the infiltration into the cell.4/

4/ A more recent version of HELP was applied in order to examine certain issues raised by the Board's questions. See pp. 23-25 infra. This subsequent analysis confirms the estimate set out in the Engineering Report.

2. Leachate.

Any water that infiltrates through the cover can pass through the waste and dissolve constituents that are then carried downward to the groundwater. Kerr-McGee conducted chemical analyses to estimate the quality of the leachate.

The procedure used by Kerr-McGee is set out in the Engineering Report. II Eng. Rep. 2-77 to 2-79. In summary, Kerr-McGee used the procedures specified by U.S. EPA (the so-called "EP toxicity specification") to estimate the leachate that could be generated for each type of waste that will be placed in the disposal cell (e.g., tailings, sludges, pond 1 wastes). In conducting the tests, Kerr-McGee also examined the effects of neutralization of the wastes and the effects of the relative volumes of liquid and waste. Kerr-McGee made adjustments to compensate for these effects in estimating the leachate quality.

Kerr-McGee also examined the impact of waste placement on the expected leachate. The layering and areal segregation of the various types of waste created the possibility of heterogeneity that could yield differing leachate quality in various parts of the cell. Guided by estimates of where the types of wastes will be placed, Kerr-McGee developed an estimate of the leachate that would be produced in various portions of the cell. Because the variation in leachate quality across the cell proved not to be large, Kerr-McGee assumed that a uniform quality leachate would be released from the cell in its subsequent modeling. But Kerr-McGee used the "composite" leachate -- the largest concentration calculated for any portion of the cell -- in the modeling. The composite leachate is a reasonably conservative best estimate of the leachate quality.

In order to bound its analysis, Kerr-McGee also estimated the "maximum" leachate -- the highest concentration of a constituent that was observed from the analysis of the various waste types. Thus, for example, because the analysis of the leachate from the unneutralized sludge yields a higher leachate concentration for iron than observed in the leachate from the other waste types, the "maximum" leachate is based on the assumption that all the wastes yield concentrations of iron found in leachate from unneutralized sludge. For some constituents, the concentration of a constituent in the "maximum" leachate is many times greater than in the composite leachate. This "maximum" leachate is therefore a highly overstated and artificial estimate of the leachate actually likely to be generated in the cell.

The data from which the estimates of leachate quality were derived are presented in Tables 2-30 through 2-38 of Volume II of the Engineering Report. Some typographic errors have been discovered in some of these tables. The corrections are described as follows:

In Table 2-31 the concentration of copper in the neutralized tailings leachate is reported as 0.565. The correct value is 0.0565.

In Table 2-35, the concentration of Th232 in the neutralized sludge leachate is reported as 0.91 pCi/l. The correct value is 0.091 pCi/l.

In Table 2-36, "less-than" signs (<) should be placed before the neutralized tailings and sludge concentrations of Ag, Cd, and Hg.

In Table 2-37, a "less-than" sign should be placed before the un-neutralized tailings chloride value. The title of the last row in the table should be changed from "Neutralized Tailings used in Analyses:" to "Values Used in Analyses." The entry in this row for calcium should be changed to 291, the entry for magnesium to 33, and the entry for nitrate to 0.23. The values in this row were determined by the analyst based upon a review of groundwater and leachate data, and were not in all cases derived directly from the information in the earlier part of the table.

In Table 2-40, the entries for maximum leachate in Case 3 is a repeat of the maximum leachate for Case 2. These rows of the table should be changed as indicated on the markup.

Revised copies of these tables are attached as Appendix 4.

In the period since the Engineering Report was prepared, Kerr-McGee has conducted further analyses to evaluate the leachate that might be generated from the wastes. A large number of samples were collected from the various waste materials on the site. A master composite of the samples was prepared in rough proportion to the amount of wastes of each type on the site, as well as a composite of samples from just the tailings pile. Three batches of leachate were then prepared from both the master composite sample and from the tailings composite and were subjected to chemical analyses.[5] The large and random sample of materials enabled a more accurate determination of leachate quality than was possible at the time of the preparation of the Engineering Report. This leachate thus provides the most representative characterization of the leachate from the Kerr-McGee wastes that currently exists.

The concentrations of the various radioactive and potentially toxic species in the leachate generated in the recent tests are presented in Table 2. As shown by Table 3, the recent analyses confirm that the estimates of the character of the leachate in the Engineering Report were generally reasonable and conservative.

3. Groundwater Model.

Kerr-McGee conducted its groundwater modeling using a model developed by John Bredehoeft and Leonard Konikow of the United States Geological Survey. This model enables the prediction of the flow of groundwater and the rate of mass transport of dissolved solutes in the flowing water. The transport algorithm used in this model is the Method of Characteristics. The model has been well verified in the

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[5] The leachate was generated by stirring a mixture consisting of 20 percent solids and 80 percent water in covered polyethylene vessels, while maintaining the slurry pH between 8 and 9 with reagent grade calcium hydroxide. The stirring was continued for two to three weeks until the pH stabilized. Nitrogen was continuously sparged into the slurry to exclude air and prevent oxidation. The solids were allowed to settle, and the clear solution (leachate) was subjected to chemical analyses.

published literature.[6] It has been successfully employed in the evaluation of contaminant transport and is known to be accurate in actual applications.[7]

Because the subsurface conditions vary across the site, the values of various parameters projected from measured points will not be totally accurate. An adjustment process is used to obtain the best estimate of the distribution of these properties. This process starts with a calibration of the groundwater flow portion of the model. The Kerr-McGee model was calibrated using a known condition, the potentiometric surface in the E-stratum.

Preliminary values for the various parameters were entered into the model. The model was run to determine a map of the potentiometric surface across the site. Adjustments were then made in the initially assigned values of the aquifer transmissivity and the model was run again to predict the potentiometric surface. Through a trial-and-error process the transmissivities were varied until an acceptable match of the predicted and actual potentiometric surface was achieved.

6/ Konikow, L.F. and J.D. Bredehoeft, "Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water", Book 7, Chapter C2, in Techniques of Water Resources Investigations of the United States Geological Survey (1978).

7/ Konikow, L. F. and D. W. Thompson, "Groundwater Contamination and Reclamation at the Rocky Mountain Arsenal, Colorado," Groundwater Contamination 93-103 (National Academy Press, Washington, D.C., 1984).

Once the model was calibrated as a flow model, it was then ready to be applied as a mass-transport model. A new hydraulic parameter, the dispersivity, is needed to calculate mass transport. (Dispersivity is a parameter that characterizing the mixing of the infiltrating water with the water flowing in the groundwater system.) Various values of dispersivity were tested until the model predicted a distribution of total dissolved solids and sulfate in the aquifer that is similar to that actually observed.

The calibrated mass-transport model was then used to project the post-closure impact of the disposal cell on groundwater quality in the E-stratum. The source term -- the concentration of the chemical constituents and the volume of leachate entering the groundwater system -- was based on the calculated infiltration and the leaching tests discussed above. Although the movement of most of the chemical constituents will be retarded to some degree by absorption into or adsorption onto the soil and aquifer materials and radioisotopes will decay, Kerr-McGee did not consider these effects. It was conservatively assumed in the calculation that the only process that will act to reduce the concentration of a chemical parameter is dilution.

As with any modeling effort, there is some uncertainty in the results. An estimate of the groundwater impacts was first performed using reasonably conservative best estimates for the various parameters. Additional simulations were then performed with values that serve to bound the results. For example, as discussed above, the conservative best estimate for infiltration through the cell cover is 0.1 inches (0.25 cm). This value was bracketed by infiltration values of 0.01 inches (0.025 cm) per year and 5 inches (12.7 cm) per year in various other simulations. The latter value basically gives no credit whatsoever for the effectiveness of the cell cover in limiting infiltration.

The degree of dilution of chemical constituents in the leachate is dependent upon the volume of water flowing through the E-stratum beneath the cell. If there is more water flowing, then the concentration at the site boundary will be less, whereas, if there is less water flowing, the concentration at the boundary will be greater. With this in mind, the mass transport model was first run with the transmissivity values that resulted in the best calibration of the flow model. The model was then run on the assumption that the transmissivity values are reduced by a factor of ten. This in effect reduces the water available for dilution by a factor of ten. It was not necessary to run the model with transmissivity values greater than the best estimates because we know that the results would be much better (i.e., would show an even smaller impact on groundwater quality) than those obtained by any of the other model simulations.

The quality of the leachate that is released from the cell to the groundwater system will affect the concentrations that are observed at the cell boundary. As noted above, a conservative best estimate of cell performance is attained using the composite leachate. A conservative bound is determined by using the maximum concentration produced by any of the waste types for a particular constituent.

Table 2-40 of Volume II of the Engineering Report presents the results of the modeling.[8] (The corrected results are reproduced here in Table 4.)[9] As the table shows, if the best estimate of the cell and aquifer parameters are considered (Case 2), the cell will have nearly negligible impacts on groundwater quality at the site boundary. Indeed, even if significant adjustments are made to the model's parameters, the IEPA general use groundwater parameters are generally satisfied by very wide margins. In fact, the only chemical parameters that exceed the IEPA general use standards are silver and fluoride and then only under the extreme and improbable assumption that the wastes yield the maximum leachate concentration and that infiltration is 50 times greater than the conservative best estimate.

The methodology also enables the determination of the concentrations of radiological constituents at the site

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[8] Cases 1 through 3 set out simulations with infiltration of 0.01, 0.1, and 5 inches per year, respectively, for both the composite and the maximum leachate. Case 11 represents the effects of infiltration of 0.1 inches per year, but with transmissivity reduced by a factor of ten and with all the leachate released at a single point.

[9] The average of the three measurements of leachate both to master composite and the tailings pile were used in the analysis.

boundary. These results are set out in Table 5 for the various modeling assumptions. (The estimates do not include the effects of radioactive decay or sorption.) As is shown, any release of radiological materials from the waste poses no threat to the groundwater as there is an ample margin between the calculated concentrations and the relevant standards.

The calculated concentrations of chemical parameters are maximum values over time, but no information is provided as to when that maximum will occur. In order to estimate the time dependence of concentrations, it is necessary to include the effects of retardation. (Retardation serves to slow the rate of movement of the solute front, but does not affect the maximum concentrations unless the mass of absorbant material is large enough to absorb the total mass of solutes.) As shown by Appendix 5, however, retardation will serve to delay even the minimal impacts predicted by the model. For example, at the best estimate of infiltration (0.1 inches/year), radium will not enter the the groundwater system from the wastes for over 6,000 years and uranium will not enter the groundwater for 3,000 years.

In sum, the sophisticated and conservative groundwater modeling performed by Kerr-McGee demonstrates that the disposal cell will have negligible impact on the water quality in the E-stratum. Consideration of groundwater impacts cannot conceivably justify the movement of the wastes to an alternative site.

C. NRC Modeling.

The NRC staff also used a mass-transport model to estimate the concentrations of chemical species that might be observed at the site boundaries of the West Chicago site and the various alternatives. The model is not adaptable to site-specific conditions like that used by Kerr-McGee, but this is largely explained by the different purpose of the NRC modeling effort. The NRC sought in the SFES to compare the impacts on groundwater of the various alternative sites and thus the NRC sought to apply the same basic model for the different alternatives. Application of the same model provided assurance that the comparison of the results of the modeling for alternative sites reflects actual differences in the sites, rather than differences in modeling techniques. Because detailed hydrological data were available only for the Kerr-McGee site, a more simplified approach was necessary and appropriate for the NRC's study.

1. Infiltration.

The NRC assumed an infiltration into the cell of roughly 1 inch per year (3 cm per year). Unlike the Kerr-McGee estimate, the NRC estimate does not appear to be based on any analysis of the infiltration through the cover. Rather, it is a very conservative assumption: infiltration through the cover is assumed to be close to the infiltration through normal soil in the area. The NRC staff approach should be seen as an exceptionally conservative assumption.

2. Leachate.

As explained in Appendix E of the SFES, the NRC calculated the concentrations of various constituents in the leachate from the measurements of the concentrations in the waste. The NRC approach is very conservative, yielding estimates of concentrations in leachate that in some cases are an order of magnitude or more greater than those actually observed in chemical analyses of the leachate. The NRC approach is discussed further at pp. 42-43.

3. Groundwater Model.

The NRC staff applied a standard model -- the AT123D model -- developed at Oak Ridge National Laboratory.[10/] The model can not be tailored to site-specific conditions like the one applied by Kerr-McGee. It represents the application of an analytical solution to the groundwater flow equations. In order to allow the calculation of a closed-form solution, the model embodies certain simplifying assumptions. For example, the model assumes that aquifer permeability is constant in space, when, in reality, the parameter is variable. The NRC chose values for aquifer parameters that would provide a reasonable estimate of cell performance. (A comparison of the hydraulic parameters applied by Kerr-McGee and the staff is set out as Table 2.) In order to account for retardation by

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[10/] G.T. Yeh, "AT123D: Analytical Transient One-, Two-, and Three-Dimensional Simulation of Waste Transport in the Aquifer System" (Oak Ridge Nat'l Laboratory, Environmental Science Division, Pub. No. 1439, 1981) (ORNL-5602).

the passage of leachate through the unsaturated zone, the NRC made a minor modification of the source term that is used in the model. This modification is discussed further herein.

D. Differences Between The NRC And Kerr-McGee Approaches To Modeling.

There are several salient differences in the approach used by the NRC. First, and perhaps most significant, the NRC model is an analytic model that assumes that the hydrological parameters are homogeneous across the aquifer. The Kerr-McGee model, by contrast, is a numerical model that allows spatial variation in the parameters. Moreover, unlike the NRC model, the parameters of the Kerr-McGee model were calibrated to site-specific conditions so as to replicate the potentiometric surface and the distribution of constituents that are actually observed in the aquifer. The Kerr-McGee model thus allowed much more realistic modeling of the actual hydrological conditions at the site.

Second, the Kerr-McGee model was run as a steady-state model so as to calculate the maximum concentration of each chemical species at the site boundary. The NRC model, by contrast, included time dependence. The NRC model was run so as to simulate flow for several thousand years and thus provided an estimate of the change in concentration of a chemical species with time. In order to provide a picture of the time dependence, the NRC model was required to account for the retardation of constituents by the unsaturated and saturated zones. Because the Kerr-McGee model was run as a steady-state model, the Kerr-McGee model effectively ignored such retardation effects.

Third, as discussed further herein, the NRC model incorporates assumptions that serve to exaggerate the predicted adverse impacts of the Kerr-McGee cell. For example, the NRC assumed an infiltration rate that is much greater than that predicted by Kerr-McGee and leachate that is of much lower quality than is indicated by the actual chemical analyses.

Nonetheless, despite these significant differences in approach, the NRC model generally confirms the Kerr-McGee analyses. A comparison of the Kerr-McGee best-estimate values (Case 2; composite leachate) and the NRC results is set out in Table 7. Both models show that the IEPA general use standards are satisfied by wide margins.[11] The models complement each other in demonstrating the negligible effects of the Kerr-McGee proposed disposal plan on groundwater.

II. SPECIFIC ISSUES WITH REGARD TO CONTENTION 4(A).

The Board has raised several specific issues with regard to Contention 4(a). We address each in turn.

A. Infiltration.

The Board inquiry states:

> According to the Kerr-McGee Engineering Report, the estimate of cell infiltration is 0.025 cm per year. (Vol. II, p. 2-80). However, the solute transport analysis in the SFES assumes an infiltration rate of

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[11] Cyanide is discussed herein at pp. 43-45.

> 3 cm per year. (SFES, p. E10). We need to resolve this 100 fold difference in the estimated source strength in terms of a most probable value and its uncertainty.

Memorandum and Order, 3.

As explained above, Kerr-McGee used a detailed and standard computer model to estimate the infiltration through the cell cover. Although the specifications for the cover yielded estimates of infiltration of less than 0.001 inches per year, Kerr-McGee made adjustments of the hydraulic conductivity of the topsoil layer to account for weathering and the effects of vegetative roots. This analysis yielded an infiltration rate of roughly 0.1 inches per year (0.25 cm per year). Thus, Kerr-McGee used an infiltration of 0.1 inches as its conservative best estimate of infiltration.

The NRC assumed an infiltration rate of 3.0 centimeters per year in its modeling, which is roughly a factor of ten greater than Kerr-McGee's conservative best estimate. The source of the NRC estimate is unclear, but it does not appear to result from any analysis of the cell cover. Rather, the NRC estimate is of the same order of magnitude as infiltration through natural soils in the area. It can be justified only as an estimate of the rate of infiltration after total failure of the cell cover.

As discussed above, Kerr-McGee assessed the sensitivity of its results by performing the groundwater modeling with various assumed infiltration rates. The range of infiltration rates span from 0.01 inches per year to 5 inches per year. The maximum limit in effect gives no credit whatsoever for the effectiveness of the cell cover in isolating the wastes; it represents a highly implausible worst-case analysis. Nonetheless, even with the assumption of infiltration at a rate of 5 inches per year, the cell has only a slight impact on groundwater quality at the site boundary. See Table 4.

B. Hydrogeologic Properties.

The Board's order observes:

> Both the SFES and the Engineering Report analyses are predicated on similar values for the hydraulic gradient and hydraulic conductivity of the E-stratum groundwater zone. However, neither report clearly describes the uncertainty of these values. Moreover, neither report provides any insight as to the probable variations in the groundwater flow during the next several centuries, in response to period of either wet or dry climatic episodes.

Memorandum and Order, 3-4.

In point of fact, the Kerr-McGee modeling included analyses that serve to encompass the potential effects of climatic fluctuations over a period of centuries, as well as the potential effects of residual uncertainties or variations in the hydraulic properties of the site. The results illustrate that moderate changes in climate, such as have been experienced during the past several hundred years, will not change significantly the projections of contaminant concentrations in groundwater. Moreover, the results show that the cell poses no threat to groundwater even if there were significant alteration of the observed or predicted aquifer properties.

1. Climatic Variations

Climatic conditions can influence the potential for groundwater contamination because climate is an important factor in determining the amount of groundwater flow beneath the site, as well as the amount of leachate that might be generated within the cell by the infiltration of rainwater.

Rainwater that falls on the surface of the earth has several possible fates. The water can become surface water, flowing immediately over the ground's surface. Rainwater that does not become surface water infiltrates into the soil. Most of the infiltrating water eventually is returned to the atmosphere as water-vapor evaporation or transpiration.[12/] A fraction of the infiltrating water may move too deeply through the soil to be removed by evapotranspiration. This water becomes groundwater recharge.

Although most rainwater in heavy rains becomes surface runoff, rainwater from moderate to gentle rainfall typically infiltrates into the ground and then is returned to the atmosphere by evapotranspiration. Recharge typically represents a small fraction of the total annual rainfall, and usually is limited to the spring, when rainfall is plentiful, accumulated snow is melting, and evapotranspiration is low.

12/ Because the end effect of these two processes is identical, they usually are lumped together in hydrologic studies. The two processes together are described as evapotranspiration.

In the West Chicago area, total annual rainfall is about 31 inches, and groundwater recharge is about 3 to 5 inches.

As discussed above, the cover of the Kerr-McGee disposal cell is designed to minimize the amount of rainwater that infiltrates below the zone of evapotranspiration. Although the cell cover is designed to encourage surface run-off and prevent the ponding of water, the primary means by which infiltration is minimized is by maximizing evapotranspiration losses. The cell cover includes a thick soil-moisture storage zone within which water is available for evapotranspiration. Underlying low-permeability and capillary-barrier layers help keep moisture within the soil layer, and thus increase evapotranspiration losses.

In addition, as shown by the schematic cross-section (Figure 1), the cell cover also includes a drainage layer that will allow excess moisture to move through the interior of the cell cover to be discharged into the groundwater away from the disposal cell. This feature will further reduce the amount of water that percolates into the disposal cell.

Figure 2 is a plot of the probability of a given annual amount of infiltration into the disposal cell, based upon simulated weather conditions representative of the site area over a 100-year period. The data were generated using a recently revised version of the HELP model. The average annual percolation through the disposal cell is about 0.1 inches, the value which was used in the groundwater modeling analyses reported in the Engineering Report, and the maximum calculated annual infiltration over the 100-year period is about 0.14 inches.

The calculated cell infiltration set out in Figure 2 shows two distinct patterns of infiltration. During dryer years, the amount of percolation is controlled by evapotranspiration demands. Climatic changes cause noticeable changes in the amount of cell infiltration, but only until infiltration of about 0.1 inches per year is achieved. During wetter years, the amount of percolation is controlled by the low-permeability barriers in the cell's cover. Climatic changes in this regime cause little change in the amount of cell percolation, since the capacity of the low-permeability barriers and the drainage layer will not be exceeded by even extreme climatic fluctuations.

In short, the assumption that the cell will yield an infiltration of about 0.1 inches per year is robust; major increases in rainfall do not increase the infiltration through the cover significantly. Nonetheless, as discussed above, the Kerr-McGee analyses were not limited to this value. Performance evaluations using an infiltration rate of 5 inches per year -- i.e., assuming the total failure of the disposal cell's cover -- were also conducted and groundwater was still not adversely affected.

2. Hydraulic Parameters

The groundwater transport model was calibrated so that the behavior of the model adequately represented the behavior of groundwater at the site. As discussed above, the calibration process proceeded by selecting appropriate values of hydraulic parameters, and then adjusting those parameters within realistic ranges to improve the match between the model's output and the groundwater observation. Transmissivity was adjusted to reproduce the observed potentiometric surface. And then, after a satisfactory match was obtained, dispersivity was adjusted until observed and calculated contaminant plumes in the E-stratum were similar.

After model calibration was completed, the model was applied in a series of simulations of post-closure site behavior. These simulations provided information about the behavior of the closed facility under extreme climatic and cell conditions, and identified the parameters to which groundwater quality is most sensitive. For example, the simulations indicated that the predicted concentrations in the groundwater were sensitive to transmissivity. Smaller transmissivity resulted in larger concentrations of contaminants in the aquifer. Accordingly, simulations assuming an order-of-magnitude decrease in transmissivity were performed. In light of the extensive site evaluation and model-calibration efforts, however, it is highly improbable that the actual conductivity is so low. Nonetheless, even with this change, the cell does not seriously threaten groundwater quality.

One model parameter that was not varied during the simulations was the hydraulic gradient. At the West Chicago site, the hydraulic gradient is determined primarily by the geometry of the E-stratum, and not by variations in climatic conditions or reasonable variations in groundwater recharge. Ground water in the E-stratum flows from high elevations in West Chicago up-gradient from the site to Kress Creek. The depth of water in the E-stratum is determined by the position of the D-stratum, a low-permeability layer that underlies the E-stratum. Gradients in the E-stratum are thus controlled by the relative positions and elevations of the up-gradient recharge area and Kress Creek. Only minor changes in groundwater gradients will result from possible climatic fluctuations. In this sense, the groundwater flow in the E-stratum is similar to flow in a river: the amount of flow may fluctuate in response to variations in the amount of rainfall, but the slope of the water surface will change very little. Thus, the hydraulic gradient will not vary significantly because the physical circumstances do not permit significant variations.

In sum, Kerr-McGee used ranges of parameters in the simulations that encompass likely climatic variations over the next several centuries, and even inconceivable variations in the hydraulic parameters. Cell percolation, which is the parameter most directly related both to climatic conditions and cell condition, was varied over a range of 500. The range between the most probable and the most concentrated leachate was evaluated. Finally, flow in the aquifer was varied by a factor of 10 to account for seasonal or longer-term changes resulting from climatic fluctuations. The array of different analyses provide ample reason for confidence that the cell will not have an adverse impact on groundwater.

C. Fluoride Concentrations.

The Board observes:

> The staff view that there has been no decrease in fluoride concentrations with time (SFES, p. 4-99 and Figure 4.34) needs to be resolved with the Kerr-McGee Engineering Report, Volume II statement that fluoride concentrations are decreasing (p. 2.61).

Memorandum and Order, 4. The cited statements relate to concentrations observed in the glacial aquifer in samples taken from the so-called B-series wells.

Chemical analyses of groundwater samples taken from the network of monitoring wells permit a detailed characterization of the major ion chemistry of groundwater at the site and its change over time. In general, the wells in the glacial aquifer under the site continue to show lingering (albeit declining) effects from past operations at the site. These effects are the result of waste material that was introduced to the aquifer through the onsite disposal ponds. However, a time-dependent decline is observed in the concentration of the major chemical species. The decline arises from the continuous removal of constituents by natural leaching processes. In effect, the site is being cleansed of contaminants by natural processes involving infiltration and groundwater flow.

The average fluoride concentration in the B-series wells is about 13 mg/L and presumably is an artifact of the hydrofluoric acid that was used in the ore-refining process at the facility. The hydrofluoric acid in the discharged waste waters underwent a chemical reaction in the soil to produce substances such as calcium fluoride and magnesium fluoride. Compared with other mobile contaminants, the fluoride compounds are relatively insoluble and thus are expected to leach from the soil more slowly. The consideration of the chemical properties thus shows that fluoride should be flushed from the site more slowly than other constituents, and its decline in concentration in groundwater should proceed more slowly than the other more mobile constituents.

In general, the analyses of the B-well data set out in the Engineering Report and the SFES are consistent. The SFES correctly reports that:

> Taken as a whole, the concentration data are consistent with a scenario of removal by leaching and groundwater flow of the materials discarded at the site during the years of operation. The decrease with time of concentrations of the more mobile contaminants indicate that the site is slowly being cleaned by percolation of precipitation and groundwater movement. The less mobile contaminants are removed at a slower rate because they tend to be more tightly bound to the soil particles.

SFES, 4-104 (parenthetical information deleted).

As the Board has observed, however, the SFES reports that no "decrease with time occurs for the fluoride data." SFES, 4-99. Kerr-McGee, on the other hand, believes that the data do show a decline in at least some wells. Both the SFES and the Engineering Report rely on the same fluoride concentration data, and thus the discrepancy is due to differences in the way the data were analyzed.

The staff's observation as to the absence of a decline is based on the averaging of certain of the B-well data (wells B-1 through B-5) and the plotting of the averages. SFES, 4-99, Fig. 4.34. The staff's statement appears to be based on the observation that the data appear to be generally constant (with the exception of the first two data points). Because the data were plotted on a logarithmic concentration scale (SFES, Fig. 4.34), the plot tended to obscure small trends; the logarithmic presentation serves to flatten subtle deviations. If a linear regression analysis is performed on the average (including the first two points), the concentration of fluoride in fact does decline and the trend is statistically significant.

Kerr-McGee's observations as to the decline in fluoride concentration were not based, however, on an assessment of the B-well average. Fluoride wastes were not disposed of uniformly over the site and thus significant differences in fluoride concentration are expected and observed in wells in different locations. Kerr-McGee thus conducted a well-by-well analysis of fluoride concentrations. The data were analyzed using two widely accepted statistical methods (linear and exponential regression) to ascertain whether trends over time are statistically significant. The results of the statistical analysis are summarized in Table 8 for both linear and exponential regression. In both cases, fluoride concentrations were noted to decrease for all B-series wells, with the exception of well B-1. The downward trend is statistically significant in wells B-2, B-4, B-5, and B-7. The trend is indeterminate in wells B-3 and B-6. All of these results were reported in exactly this fashion in the Engineering Report. II Eng. Rep. 2-57; Tables 2-21, 2-22; Figs. 2-120, 2-121, 2-122, 2-123. Indeed, despite the passage noted by the Board, these observations were generally confirmed by the NRC.[13]

D. Groundwater Flow.

The Board's inquiry states:

> The reports do not describe what groundwater flow is indicated by the observed decrease with time in the sulfate, chloride and fluoride concentrations in the glacial drift strata.

Memorandum and Order, 4.

In order to use the observed data on solute concentration to estimate groundwater flow, two things must be known: the mass of the solute in the source and its rate of

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[13] The SFES states:

> In general, fluoride concentrations appear to have increased with time over the range of sampling dates for Well B-1, whereas no increases with time occurred for Well B-6 and decreases with time occurred for the other B wells. The rate of decrease with time appears to have been largest for Wells B-2 and B-5.

SFES, 4-100.

release. The concentrations that are observed today in the glacial aquifer are believed largely to be the lingering consequences of site operations. See supra p. 29. During past operations, when up to 500,000 gallons of waste water per day was released to the glacial aquifer (FES, 4-3), minerals precipitated in the aquifer as the highly mineralized acidic liquid waste water underwent a pH change. This material is now being redissolved as groundwater flows through the aquifer. Without knowledge of the strength and release rate of these materials, however, it is not possible to use the observed decline in concentrations as a tool to estimate groundwater flow.

E. Recharge Of The Silurian Aquifer.

The Board's inquiry states:

> The SFES states that "about 38% of recharge water enters the Silurian" dolomite aquifer (p. 4-91). In contrast, the Engineering Report states that "only a very small percentage of the water entering the glacial aquifer from the surface finds its way to the dolomite aquifer." (Vol. I, p. 5). The Board needs to understand the reasons for these discrepant statements.

Memorandum and Order, 4.

There is no discrepancy between the SFES and the Engineering Report with regard to the estimate of the amount of water that recharges the dolomite aquifer from the glacial drift aquifer. The SFES states:

> Using an average head difference between upper sand units (C and E strata) and the Silurian dolomite of 9.45 m (31 ft), an average B stratum thickness of 7.9 m (26 ft), and an approximate B stratum

> vertical conductivity value of 9 x 10^{-10} m/s, the vertical leakage of water from the glacial drift to the Silurian dolomite has been calculated to be about 3.4 cm/yr (1.33 in./yr) (Kerr-McGee 1986--Vol. II). This is almost identical to the rough estimate made for western DuPage County by Zeizel et al. (1962). If 9 cm of water recharges the glacial drift per year and 3.4 cm of that amount leaks downward to the Silurian dolomite, then about 38% of recharge water enters the Silurian and 62% is flowing laterally through the Pleistocene sand units to discharge areas outside the Kerr-McGee property. Likely discharge areas would be along Kress Creek and the West Branch DuPage River.

SFES, 4-91.

A nearly identical estimate is found in the Kerr-McGee Engineering Report. The Engineering Report states that "vertical leakage from the glacial drift aquifer to the Silurian dolomite aquifer would be about 1.33 inches per year." II Eng. Rep. 2-46. Moreover, the estimate of the rate of recharge to the glacial aquifer that is set out in the Engineering Report is 3.7 inches per year (9.4 cm per year). II Eng. Rep. 2-73. The Engineering Report thus reveals that the general recharge to the Silurian aquifer is about 36 percent of the recharge to the glacial drift aquifer. This is nearly identical to the estimate in the SFES. The statement in the Engineering Report that "a small percentage of the water entering the glacial aquifer finds its way to the dolomite aquifer" (I Eng. Rep. 5) is a qualitative characterization of this data.

It should be noted, however, that the estimate of recharge from the glacial aquifer to the dolomite aquifer in the general West Chicago area does not reflect the likely recharge to the dolomite from the surface of the West Chicago site. Under conditions of normal recharge, the groundwater in the E-stratum under the site is flowing predominantly in a horizontal direction for discharge into Kress Creek. This is the consequence of the fact that the site is near to Kress Creek and thus the horizontal component of groundwater flow is enhanced, as it is in the vicinity of any discharge point. II Eng. Rep. 2-46; C.W. Fetter, Applied Hydrogeology, Ch. 7 (1988). The tendency to horizontal flow is accentuated at the West Chicago site by the clay strata (B and D strata), which serve as a barrier to vertical flow. See generally SFES, H-540. Thus, although the average recharge to the dolomite from the glacial aquifer in the West Chicago area is estimated at 1.33 inches/year, much less water entering the glacial aquifer from the site itself enters the dolomite. Most of that recharge flows horizontally under the site and then is discharged into Kress Creek.

The fact that only a small portion of the water leaving the surface of the site moves downward to the dolomite aquifer provides additional reassurance of the negligible threat to groundwater that is presented by the cell. As discussed further herein, it is only the deeper aquifers that are used and will be used as a major source of water supply. Even if adverse impacts from the cell were to be found in the E-stratum aquifer, the pattern of groundwater flow at the site provides reassurance that the deeper aquifers would not be adversely affected.

F. Groundwater Usage.

The Board's inquiry states:

> The SFES states that 60 wells were identified within a 2 mile radius of the Kerr-McGee site (P. 4-91) but does not tell the reader how much water is being withdrawn nor is there any indication of the extent to which such withdrawal contributes to the movement of recharge surface waters down into the dolomite aquifer. Further, there is no discussion of possible and/or probable increases in the withdrawal and resulting effects on the groundwater kinematics. As a matter of first impression, we take this issue to be quite consequential for both the staff and Kerr-McGee analyses (modelling).

Memorandum and Order, 4-5.

The SFES in fact states that there are 64 wells within a 3-kilometer radius of the Kerr-McGee site. SFES, 4-91. Some 52 of these wells withdraw water from the Silurian dolomite aquifer, 7 withdraw water from the deeper Cambrian-Ordovician aquifer, and 4 withdraw water from Pleistocene sand-and-gravel aquifer, which is represented by the C- and E-strata at the site. Id. All wells in the Pleistocene sand-and-gravel aquifer were observed to be for private use and, as indicated by the FES (at 4-64), all of these wells are at least 4000 feet (1200 m) from the Kerr-McGee site

Any effects of these wells have been included in Kerr-McGee's groundwater modeling by the matching of the predicted potentiometric surface to the observed potentiometric surface in the process of model calibration. Moreover, contrary to the Board's impression, reasonable changes in pumping will not alter the modeling results significantly.

The E-stratum, the topmost sand-and-gravel layer, is the layer for which groundwater impacts were assessed by both Kerr-McGee and the NRC. It is separated from the Silurian aquifer by two confining layers in the Pleistocene, the B stratum and the D stratum (SFES, Fig. 4.14). The E-stratum is thus hydrologically separated from the Silurian aquifer. Moreover, the Cambrian-Ordovician aquifer in the West Chicago area is confined by the overlying Maquoketa shale. SFES, 4-37 and Fig. 4.10.[14] This aquifer is thus hydrologically separated both from the Silurian dolomite aquifer and from the glacial aquifer. Because of this hydrological isolation, changes in the pumping of the Silurian or the Cambrian-Ordovician aquifers will not have any meaningful impact on the flows in the glacial aquifer nor upon the modeling results.

The isolation of the E-stratum is demonstrated by the fact that the potentiometric surface of the E-stratum beneath the disposal site (SFES, Fig. 4.28) is 25 to 37 feet higher than the potentiometric surface of the Silurian dolomite aquifer (SFES, Fig. 4.29). In fact, the average head difference between the C-stratum and the Silurian dolomite aquifer is about 28 feet, while the B-stratum aquitard

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[14] See also Zeisel, A.J., Groundwater Resources of DuPage County, Illinois, Ill. State Water Serv. Coop. Ground-Water Rep. 2 (1962).

averages 26 feet thick. The downward hydraulic gradient across the B stratum is thus shown to be greater than unity. Any additional lowering of the potentiometric surface of the Silurian aquifer that might result from further pumping of that aquifer would have no further impact upon downward leakage from the either the C- or the E-stratum, because unity is the greatest vertical downward hydraulic gradient that can affect saturated groundwater flow.[15] Thus, the maximum rate of leakage from the E-stratum to the bedrock aquifers is already occurring. Moreover, if pumping were to be reduced in the future, the impacts of the shallow aquifer on the deeper aquifers could only be diminished.[16] Thus, the hydrodynamic circumstances at the site preclude the need to take into account any impacts of current or future rates of pumpage from either the Silurian dolomite or Cambrian-Ordovician aquifers.

As noted above, there are only four private wells in the glacial drift aquifer within 3 km of the Kerr-McGee

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[15] Groundwater flowing unimpeded in a vertical direction will have a gradient equal to unity, representing the pull of gravity on the water. Gradients greater than unity indicate a restriction to the free flow of water, that is, that the aquifers are separate. Gradients less than unity do not necessary mean that the aquifers are connected, since the smaller gradients may be controlled by conditions within the aquifers, and not by the interchange of water between the aquifers.

[16] Decreased pumping in the deeper aquifers will result in higher potentiometric surfaces in those aquifers. If the levels rise enough to decrease the gradient between the E-stratum and the deeper aquifers, leakage will decrease. Thus, decreased pumping from the deeper aquifers either will not affect leakage from the E-stratum, or will decrease it.

site, and all those wells are more than 1200 meters away. As shown by Appendix 6, none of these wells -- presuming for the moment that they are completed in the E-stratum -- will have any effect on the Kerr-McGee site. Moreover, because of the limited yield of the glacial aquifer, the widespread (and expected) contamination of that aquifer from a multitude of sources in an urban area,[17/] and the available alternative sources of supply, it is highly improbable that use of the glacial aquifer will grow. It is thus not reasonable to expect significant changes in the pumping of the glacial-drift aquifer in the West Chicago area that would affect the modeling results.

Indeed, reliance on groundwater supply in general will decline in the area. DuPage County is now constructing a pipeline to carry water from Lake Michigan to many communities in the county. It is expected that this pipeline will be completed in 1992.[18/] When the pipeline is finished, many communities now using groundwater will switch to the surface water source. This change should serve to alleviate reliance on groundwater supply and, if anything, reduce any possible impacts of the West Chicago disposal cell.

[17/] See, e.g., Sasman, R.T., et al., Verification of the Potential Yield and Chemical Quality of the Shallow Dolomite Aquifer in DuPage County, Illinois, Ill. State Water Surv. Circ. 149 (1981).

[18/] Illinois Department of Transportation, Dan Injerd, personal communication, 1989.

III. CONTENTION 3(g)(2).

Contention 3(g)(2) submitted by the State provides as follows:

> The modified solute transport analysis of the Proposed Action and Alternative D was not benchmarked.

As the Board has noted, this contention as originally submitted was aimed at challenging certain modifications of the NRC's groundwater model to account for flow across the unsaturated zone beneath the disposal cell. Memorandum and Order, 5. The results in the SFES reflect an adjustment of the AT123D model to include the travel time across the unsaturated zone. SFES, E-3 to E-5. In determining that the contention should be subject to a hearing, the Board observed that "neither the staff nor Kerr-McGee affiants validate the challenged equation from first principles or cite observational data that empirically confirm the equation." Memorandum and Order, 7.

Because dissolved materials can react physically or chemically with the soil matrix, they often do not move as rapidly as the water in which they are dissolved. The equation used by the staff allows the calculation of the resulting travel time for a particular constituent to pass through a multilayer system. It is readily derived from first principles, as shown by Appendix 7.

The staff's modification of the computer code to deal with flow through the unsaturated zone did not require any change whatsoever of the basic model reflected in the

AT123D code. In effect, the modification introduces time dependence into the source term to reflect the fact that dissolved constituents in the waste will have a delayed impact on groundwater. Moreover, the modification does not in any way affect the conclusions that should be drawn from the NRC modeling effort. The effect of the unsaturated zone is merely to delay the time at which the maximum concentrations of a constituent will be observed, not the maximum concentration level that will be predicted. Thus, if the model had been run for the proposed action without the modification, the same peak concentrations would have been calculated, only at earlier times. The modification is hardly profound, and field testing to "benchmark" the change was unnecessary. Indeed, as shown by Appendix ___, the retardation calculated by the staff's model can be shown to be reasonable by a simple calculation.

In his Affidavit of September 20, 1989, Dr. Warner states that "the modeling that was done [in the SFES] could be characterized as that which would be carried out for the preliminary site screening but <u>not</u> for purposes of judging the long-term behavior of a site such as the West Chicago one once it was under serious consideration for development." He also states, quoting Yeh, that a proper modeling effort should be one that is based on "'extensive investigation, including boring and pumping tests, physical models and <u>sophisticated numerical</u> models . . . .'" (emphasis in original).

The Warner affidavit thus raises issues relating not to the modification of the code, but rather on the propriety of the NRC's reliance on the model regardless of the modification. Although the affidavit thus does not relate to the admitted contention, Dr. Warner's claim is nonetheless misguided. Dr. Warner has lost sight of the fact that the AT123D computer model was used by the NRC staff so as to allow the comparison of the various alternative sites. As noted above, it was not appropriate to use a sophisticated numerical model for this comparison because the necessary hydrologic data were unavailable for all but the Kerr-McGee site. But, the use of a common code at all the sites was necessary so as to allow the comparison of sites on a common basis. Moreover, the NRC assumptions in the modeling were conservative, thus yielding results that overestimate the impacts of the site.

In any event, however, there was no need for the NRC to use a sophisticated numerical model for the West Chicago site, because such modeling had already been performed by Kerr-McGee. As discussed above, Kerr-McGee has applied one of the standard mass-transport models, the USGS MOC model, and calibrated it for the conditions of the West Chicago site. The modeling performed by Kerr-McGee provides exactly the information that Dr. Warner finds lacking in the NRC approach.

IV. NOVEMBER 20, 1989 ORDER.

The Board's order of November 20, 1989, raises two additional issues.

A. Leachate.

The Board observed that Kerr-McGee determined the concentrations of constituents in leachate through laboratory measurement. The NRC staff on the other hand calculated the concentrations of selected heavy metals and radionuclides in the leachate using only data as to the concentrations in the wastes. As the Board has noted, the approaches yield somewhat dissimilar results.

The concentration of a constituent in leachate can be defined as the mass rate at which the constituent is being leached (Ci/yr or kg/yr) divided by the volume rate of leaching fluid (l/yr). The mass rate may be calculated by multiplying the solute leach rate from Equation E.4 of the SFES by the mass of the constituent to be leached. The volume rate of leaching fluid is the product of the infiltration rate through the waste and the horizontal area of the waste pile. Thus, upon substituting Equations E.4 and E.13, the concentration of a particular chemical species or radionuclide can be written as

$$C_l = \frac{p\ C_w}{n\ R\ [1 + p\ K_d/n\ R)]}$$

where

C_l is the concentration of the constituent in the leachate leaving the waste;

p is the bulk density of the waste;

C_w is the concentration of the constituent in the waste;

n is the effective porosity of the waste;

R is the saturation ratio in the waste; and

K_d is the distribution coefficient.

Parameter values for the right side of the above equation are set out in Appendix E of the SFES for the selected chemical species and radionuclides. The resulting leachate concentrations can be compared to the Kerr-McGee values estimated in the Engineering Report and resulting from the more recent leachate tests. These comparisons are presented in Table 3.

In general, the NRC concentrations are about 10 to 100 times larger than the composite leachate and as much as 10 times larger than the "maximum" leachate. (The exceptions are silver, arsenic, and nickel.) All but two of the NRC concentrations (those of mercury and nickel) are larger than the leachate concentrations determined in the recent leachate tests. The differences presumably result from the conservative nature of the NRC estimates. Because of the complicated chemistry associated with the dissolution process and the consequent difficulty in calculating leachate concentrations from simple equations, Kerr-McGee believes that its actual measured values are likely to be more reliable than the values calculated by the NRC.

B. Cyanide.

As part of its waste characterization program, Kerr-McGee determined the concentrations of priority-pollutant metals in the waste materials at the West Chicago site. Seven borings were drilled at the site and a total of fourteen samples were selected from the borings for priority pollutant metal analyses. The results of these analyses were presented and summarized in Volume VIII of the Kerr-McGee Engineering Report.

The concentrations of cyanide in the wastes were generally found to be below the detection limits. However, a single sample from Pond 2 had a reported cyanide concentration of 2.2 parts per million (ppm). (The only other sample from pond 2 had a concentration of cyanide that was less than the detection limit of 1 ppm.) The staff's comments about cyanide in the waste is evidently based on this one reported detection of cyanide.

The NRC staff presented a summary of the Kerr-McGee data in Table 2.5 of the SFES. The staff included cyanide in the table, indicating a range of values for the pond 2 sediments from 1.1 to 1.6 parts per million (ppm).[19] Then, in its transport modeling, the NRC used the upper concentration value of 1.6 ppm as the source term for cyanide concentration. The staff assumed that the upper limit value represented the cyanide concentration for all the waste, not just the pond 2 sediments.

The sample with a reported concentration of cyanide above the detection limit probably represents a laboratory reporting error. Cyanide was not used to process ore

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[19] The staff's lower concentration limit was calculated by assuming that the sample with cyanide below the detection limit had no cyanide. The upper limit was calculated by assuming that the sample had cyanide present at the detection limit of 1 ppm.

materials at the West Chicago facility, and none of the processes would be expected to produce cyanide as a by-product. Moreover, if cyanide were present in the wastes or had been used in site processing, it presumably would be seen in groundwater samples collected in the glacial aquifer. Groundwater samples collected in August 1986 were analyzed for cyanide and the results are presented in Table 8. The data show that cyanide concentrations in ground water were either not detected (as indicated by "<0.04 mg/l") or were only slightly above the detection limit. (Measurements slightly above the detection limit may not represent real values.) These results are generally consistent with data collected by the State of Illinois which showed "nondetection of cyanide at the 0.001 mg/l level [groundwater] in samples taken earlier in February 1986." SFES, 4-97. The lack of any significant cyanide concentration in the groundwater at West Chicago demonstrates that cyanide is also not present in the waste materials at the site.

CONCLUSION

Kerr-McGee and the NRC have performed careful and thorough assessments of the possible impacts of the proposed disposal cell on groundwater quality. These assessments show convincingly that the cell poses a negligible threat to groundwater.

Indeed, the modeling assessments are confirmed by the consideration of the site history. For years, hundreds of thousands of gallons of contaminated water were discharged directly into the glacial aquifer on a daily basis. At that time, there could be no debate about infiltration rates or elemental solubilities -- the dissolved materials were discharged directly into the aquifer at rates far exceeding even the most extreme estimate of infiltration from the proposed disposed cell. Impacts on the glacial aquifer were limited to the general vicinity of the site and have diminished over time. Radionuclides have not been found in the shallow groundwater even as a result of the direct discharge. And any lingering effects upon the Silurian aquifer as a result of disposal practices are minor. In short, the past disposal practices did not have a significant adverse impact. This history provides a compelling demonstration that the presence of the disposal cell, which must have a far lesser impact than the past disposal practices, will not damage water resources in the site area.

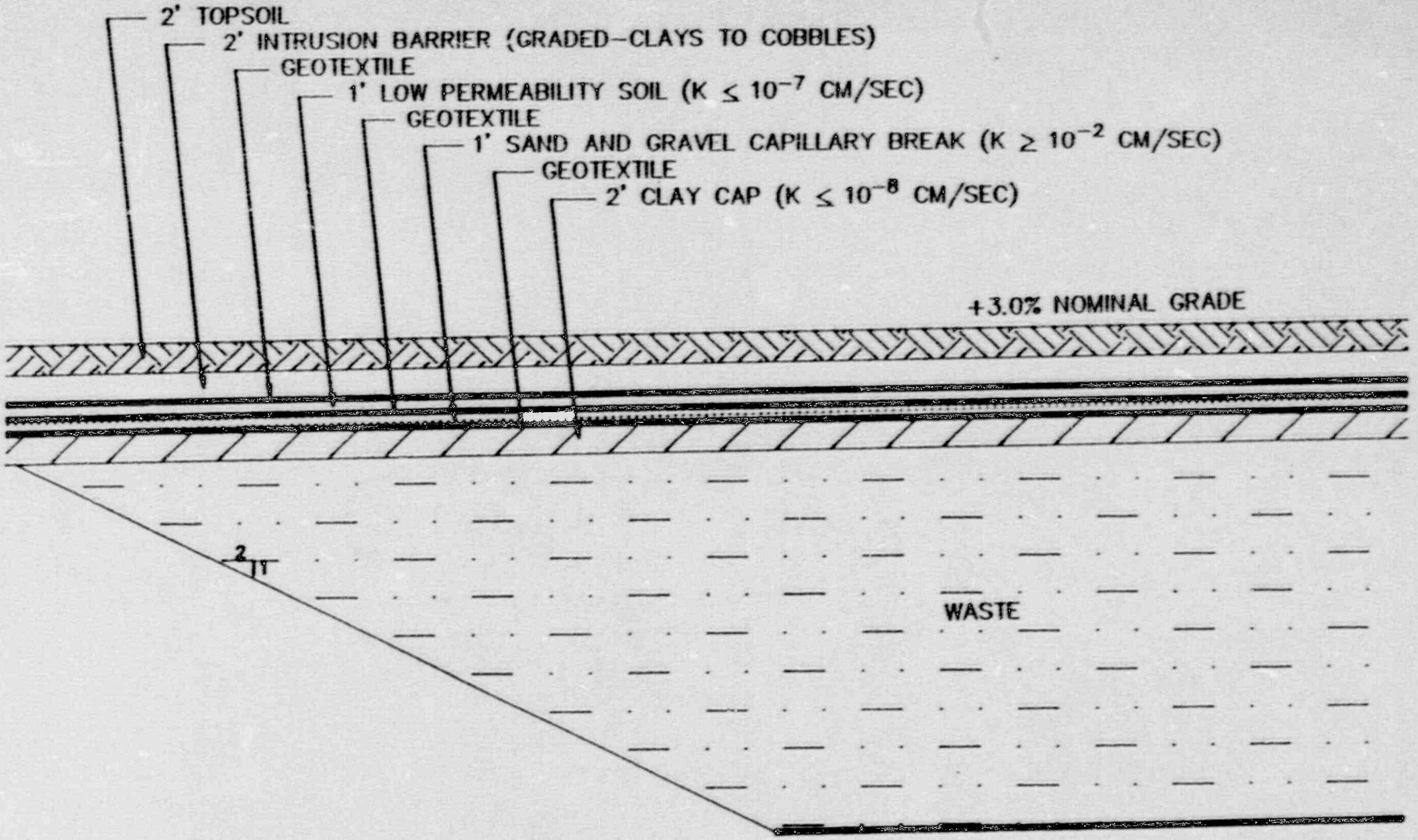
Respectfully submitted,

Charles W. Fetter, Jr.
University of Wisconsin
845 Elmwood Avenue
Harrington Hall
Oshkosh, WI 54901

James L. Grant
James L. Grant & Associates, Inc.
Denver Technological Center #30
8301 East Prentice Avenue, Suite 40
Englewood, CO 80111

John C. Stauter
Kerr-McGee Corporation
123 Robert S. Kerr Avenue
Oklahoma City, OK 73125

November 28, 1989



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JAMES L. GRANT & ASSOCIATES

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FIGURE 1

WEST CHICAGO FACILITY CLOSURE

DISPOSAL CELL COVER DESIGN

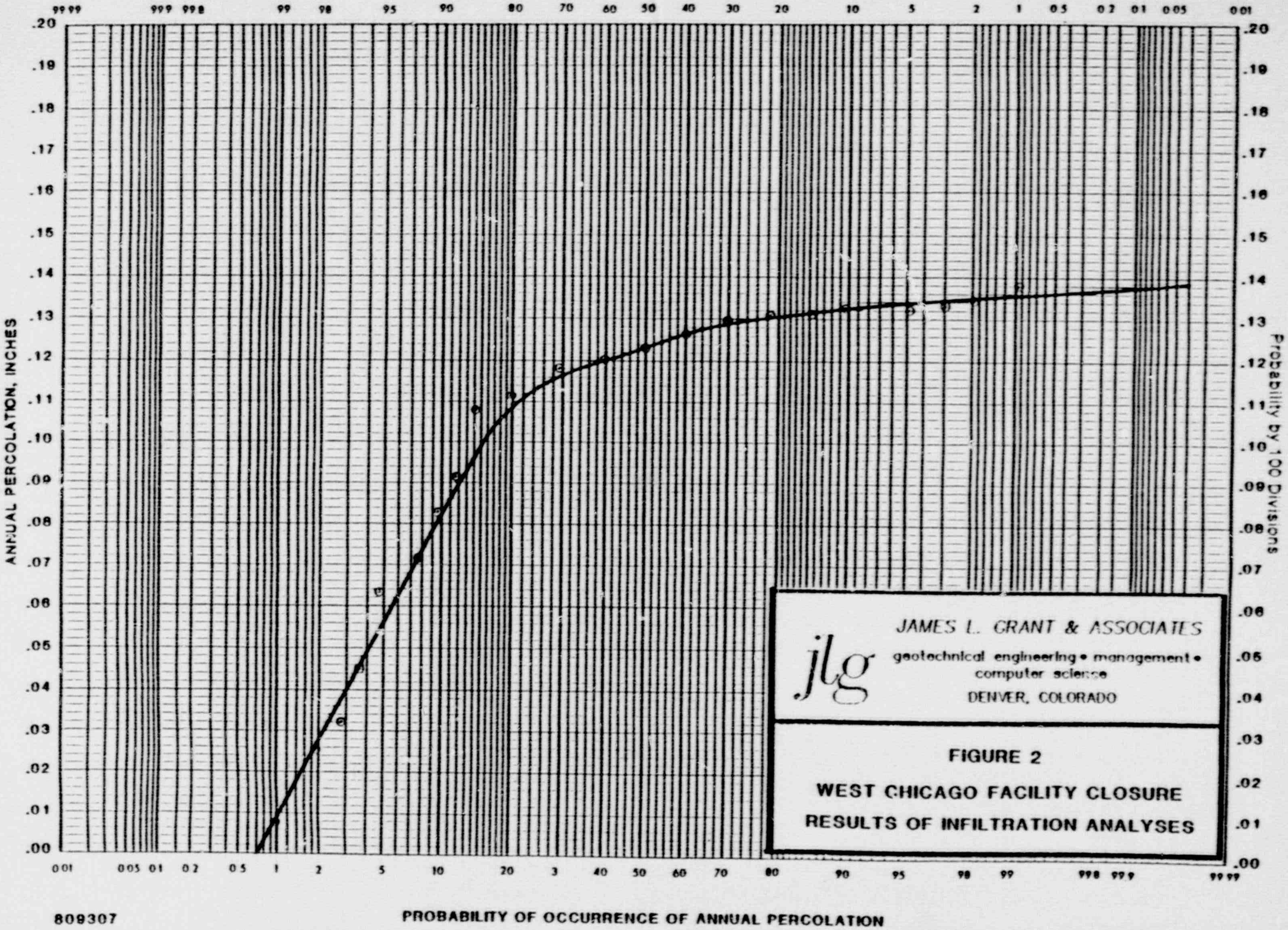

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FIGURE 2

WEST CHICAGO FACILITY CLOSURE

RESULTS OF INFILTRATION ANALYSES

TABLE 1

INFILTRATION RATE FOR CELL COVER AND MODIFIED CELL COVER[1]

SIMULATION RUN	PERIOD[2,3] (YRS)	AVERAGE MEAN PRECIPITATION (IN/YR)	CELL COVER INFILTRATION RATE (IN/YR)	MODIFIED CELL COVER[1] INFILTRATION RATE (IN/YR)
1	74-78	34.08	0.0005	0.0701
2	1-20	35.77	0.0001	0.0662
3	21-40	33.49	0.0001	--
4	41-60	34.56	0.0002	--
5	61-80	35.52	0.0001	--
6	81-100	34.14	0.0001	--

1) The hydraulic conductivity of the cover's surface soil layer was increased by a factor of ten.

2) Climatic data for a five-year period (1974-1978).

3) Mean average data for 20-year periods as derived from climatic simulation calculations.

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Table 2

Kerr-McGee Analyses of Leachates

		Tailings Pile Leachate			Master Composite Leachate		
Batch Number		1	2	3	1	2	3
SO_4	g/l	7.22	7.16	8.59	2.34	2.45	2.20
Na	g/l	2.73		1.98	0.45	0.48	0.50
Ca	g/l	0.43		0.45	0.54	0.55	0.56
Mg	g/l	0.16		0.13	0.13	0.13	0.14
Cl	g/l	0.20	0.16	0.15	0.18	0.18	0.18
K	mg/l	446		370	25	30	29
F	mg/l	10	11	<0.2	25	19	8.7
Ba	mg/l	0.042	0.021	0.055	0.016	0.039	0.028
Ag	mg/l	<0.018	<0.009	<0.008	<0.018	<0.009	<0.008
As	mg/l	<0.11	<0.09	<0.11	<0.11	<0.09	<0.11
Cd	mg/l	<0.015	<0.009	<0.005	<0.015	<0.009	<0.005
Cr	mg/l	<0.026	<0.007	<0.008	<0.026	<0.007	<0.008
Cu	mg/l	<0.015	<0.008	0.019	<0.015	<0.008	0.015
Fe	mg/l	<0.033	<0.008	0.021	<0.033	<0.008	0.031
Hg	mg/l	<0.040	<0.040	<0.04	<0.040	<0.040	<0.04
Ni	mg/l	<0.07	<0.08	0.022	<0.07	<0.08	<0.014
Pb	mg/l	<0.05	<0.13	<0.063	<0.05	<0.13	<0.063
Se	mg/l	<0.1	<0.065	<0.081	<0.1	<0.085	<0.081
Zn	mg/l	0.13	0.016	0.024	0.044	0.028	0.017
Ra 226	pCi/l 1/	13, 7.8	4.8, 3.8	5.6, 4.6	1.4, 9	0.37, 0.7	1.2, 1.8
Ra 228	pCi/l 1/	0, 8.0	7.5, 4.6	4.7, 4.0	0, 10	0.02, 0.6	0.28, 1.4
Th 228	pCi/l 1/	7.5, 1.5		0.58, 0.11	3.8, 1.2	0.05, 0.05	0.23, 0.07
Th 230	pCi/l 1/	14, 2.0		0.04, 0.03	5.1, 1.3	0.05, 0.05	0.12, 0.05
Th 232	pCi/l 1/	7.8, 1.5		0.02, 0.02	1.9, 0.9	0.19, 0.1	0.06, 0.04
U 238	mg/l	<0.005	0.58	<0.008	0.34	0.33	0.55

1/ First number is assay value, second number is +/- confidence value.

Table 3

		Recent Leachate Test[1]		Engineering Report		Staff	Ratios		
Element	Units	Tailings	Composite	Composite	Maximum		Recent Leachate Comp./Staff	ER Comp./Staff	ER Max/Staff
Ag	mg/l	<0.012	<0.012	0.025	0.080	0.042	<27.8%	59.5%	190.5%
As	mg/l	<0.103	<0.103	0.782	2.695	0.66	<15.7%	118.5%	408.3%
Cd	mg/l	<0.010	<0.010	0.021	0.077	0.25	<3.9%	8.2%	30.8%
Cr	mg/l	<0.014	<0.014	0.019	0.082	0.61	<2.2%	3.2%	13.4%
Cu	mg/l	<0.014	<0.013	0.029	0.057	1.14	<1.1%	2.5%	5.0%
Hg	mg/l	<0.040	<0.040	0.001	0.004	0.011	<363.6%	12.0%	37.3%
Ni	mg/l	<0.057	<0.055	0.131	0.392	0.0014	<3,904.8%	9,321.4%	28,028.6%
Pb	mg/l	<0.081	<0.081	0.205	0.345	7.4	<1.1%	2.8%	4.7%
Se	mg/l	<0.082	<0.082	0.805	3.189	21	<0.4%	3.8%	15.2%
Zn	mg/l	0.057	0.030	0.214	0.338	3.7	<0.8%	5.8%	9.1%
Sb	mg/l					5.3	NA	NA	NA
CN	mg/l					21	NA	NA	NA
Ra226	pCi/l	7.800	0.990	8.800		570	0.2%	1.5%	NA
U238	mg/l	<0.198	0.407			3.3	12.3%	NA	NA

1) Calculated by averaging the three analyses of tailings leachate and the three analyses of composite leachate.

Table 4

TABLE 2-40
ESTIMATES OF POST-CLOSURE GROUND-WATER CONCENTRATIONS

(all concentrations are in milligrams/liter (mg/l))

	Ag	Ba	Cd	Cr	As	Hg	Pb	Se	Cu**	Fe**	Ni**	Zn**	Ca	K	Mg	Na	SO4	Cl	F	NO3
IEPA General Use Standards	0.005	5	0.05	0.05	1	0.0005	0.1	1	0.02	1	1	1	NA	NA	NA	NA	500	500	1.4	NA
Composite Maximum	0.025	0.163	0.021	0.019	0.782	0.001	0.205	0.805	0.029	1.545	0.131	0.214	214	60	26	459	1759	6	16	0.231
Percent (%) of IEPA Standard	491	3	41	39	78	263	205	80	145	155	13	21	NA	NA	NA	NA	352	1	1114	NA
Maximum	0.08	0.313	0.077	0.082	2.695	0.0041	0.345	3.1884	0.0565	2.605	0.392	0.338	291	95	33	1529	2862	11	23	0.23
Percent (%) of IEPA Standard	1600	6	154	164	270	820	345	319	283	261	39	34	NA	NA	NA	NA	572	2	1629	NA
Case 1 Dilution Factor: 0.00017																				
Composite Maximum	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0003	0.000C	0.0000	0.036	0.010	0.004	0.078	0.299	0.001	0.003	0.00004
Percent (%) of IEPA Standard	0.083	0.001	0.007	0.007	C.013	0.045	0.035	[illegible]	0.025	0.025	0.002	0.004	NA	NA	NA	NA	0.06	0.00	0.19	NA
Maximum	0.00001	0.00005	0.00001	0.00001	0.00046	C.00000	0.00006	0.00054	0.00001	0.00044	0.00007	0.00006	0.049	0.016	0.006	0.260	0.487	0.002	0.004	0.00004
Percent (%) IEPA Standard	0.272	0.001	0.026	0.028	0.046	0.139	0.059	0.054	0.048	0.044	0.007	0.01	NA	NA	NA	NA	0.097	0.0004	0.277	NA
CASE 2 Dilution Factor: 0.00169																				
Composite Maximum	0.00004	0.00028	0.00003	0.00003	0.00132	0.00000	0.00035	0.00136	0.00005	0.00261	0.00022	0.00036	0.362	0.101	0.044	0.776	2.973	0.010	0.026	0.0004
Percent (%) of IEPA Standard	0.83	0.01	0.07	0.07	0.13	0.45	0.35	0.14	0.25	0.26	0.02	0.04	NA	NA	NA	NA	0.59	0.00	1.88	NA
Maximum																				

0.00014 0.00053 0.00013 0.00014 0.00455 0.00001 0.00058 0.00539 0.00010 0.00440 0.00056 0.00057 0.492 0.161 0.056 2.584 4.837 0.019 0.039 0.0004
Percent (%) of IEPA Standard
2.70 0.01 0.26 0.28 0.46 1.39 0.58 0.54 0.46 0.44 0.07 0.06 NA NA NA NA 0.97 0.00 2.75 NA

Case 3 **Dilution Factor: 0.08109**

Composite Maximum
0.00199 0.01323 0.00167 0.00157 0.08335 0.00011 0.01656 0.06520 0.00235 0.12520 0.01058 0.01732 17.340 4.862 2.103 37.195 142.554 0.471 1.264 0.019
Percent (%) of IEPA Standard
39.77 0.26 3.34 3.15 8.33 21.34 16.56 6.52 11.76 12.52 1.06 1.73 NA NA NA NA 28.51 0.09 90.31 NA

Maximum
0.00648 0.025 .006 .007 .218 .0003 .028 .258 .0046 .211 .032 .027 23.6 8 3 124 232 1 2 .02
Percent (%) of IEPA Standard
129.65 .5 12 14 22 60 28 26 23 21 3.2 2.7 NA NA NA NA 46 0.2 142

Case 11 **Dilution Factor: 0.04808**

Composite Maximum
0.00118 0.00785 0.00399 0.00093 0.03759 0.00006 0.00984 0.03869 0.00140 0.07429 0.00628 0.01027 10.29 2.88 1.25 22.07 84.59 0.28 0.75 0.01
Percent (%) of IEPA Standard
23.60 0.16 1.98 1.87 3.76 12.66 9.84 3.87 6.98 7.43 0.63 1.03 NA NA NA NA 16.92 0.06 53.58 NA

Maximum
0.00385 0.01505 0.00370 0.00394 0.12958 0.00620 0.01659 0.15330 0.00272 0.12525 0.01887 0.01625 13.99 4.57 1.59 73.51 137.60 0.53 1.10 0.01
Percent (%) of IEPA Standard
76.93 0.30 7.40 7.89 12.96 39.43 16.59 15.33 13.58 12.52 1.89 1.63 NA NA NA NA 27.52 0.11 78.30 NA

Table 5

Radionuclide Concentrations Using Engineering Report Composite Leachate

			Best Estimate (Case 2)	Infiltration .01 inches/yr. (Case 1)	Transmissivity 0.1 Calibrated (Case 11)	Infiltration 5 inches/year (Case 3)
Dilutional Factor			0.00169	0.000169	0.04808	0.08103
Isotope	Leachate Strength					
Th232	20.68	pCi/l	0.0349	0.0035	0.9943	1.6757
Th230	3.45	pCi/l	0.0058	0.0006	0.1659	0.2796
Th228	112.80	pCi/l	0.1906	0.0191	5.4234	9.1402
Ra226	8.80	pCi/l	0.0149	0.0015	0.4231	0.7131
Ra224	4.91	pCi/l	0.0083	0.0008	0.2361	0.3979

Radionuclide Concentrations Using Recent Leachate Analyses

Dilutional Factor			0.00169	0.000169	0.04808	0.08103
Isotope	Leachate Strength					
Th232	0.70	pCi/l	0.0012	0.0001	0.0337	0.5067
Th230	1.80	pCi/l	0.0030	0.0003	0.0865	0.1458
Th228	1.40	pCi/l	0.0024	0.0002	0.0673	0.1134
Ra226	1.00	pCi/l	0 0017	0.0002	0.0481	0.0810
Ra224	Not Available					
U238	133.2	pCi/l	0.2331	0.0333	6.3942	10.78

<u>NRC Limits</u> -- Th232: 2,000 pCi/l; Th230: 2,000 pCi/l; Th228: 7,000 pCi/l; Ra 226: 30 pCi/l; Ra224: 2,000 pCi/l; U238: 40,000 pCi/l.

<u>IEPA Limit</u> -- Ra226: 1 pCi/l.

Table 6

Hydraulic Parameters

	Kerr-McGee MOC Model	NRC AT123D Model
Hydraulic Gradient	0.01	0.01
Dispersivity	24 m	30 m
Hydraulic Conductivity	4.5×10^3 to 5.4×10^4 m/year	2.1×10^4 m/year
Effective porosity	0.20	0.25
Infiltration Rate	0.025 cm, 0.25 cm, and 12.7 cm	3.0 cm

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Table 7

Maximum Concentrations at Site Boundary (ug/L)

Chemical Species	IEPA Standard	Kerr-McGee Model (Case 2)	NRC Model
Antimony			8.0
Arsenic	1000	1.32	1.0
Cadmium	50	0.03	0.38
Chromium	50	0.03	0.92
Copper	20	0.05	1.7
Lead	100	0.35	11
Mercury	0.5	0.002	0.017
Selenium	1000	1.36	<32
Silver	5	0.04	0.063
Zinc	1000	0.36	5.5

Table 8

SUMMARY OF LINEAR REGRESSION OF FLUORIDE CONCENTRATION IN B-WELLS*

ell No.	Beta 0 (y-intercept)	Beta 1 (slope)	T Statistic	Critical T	Correlation Coefficient	Interpretation
-1	-33	0.0017	1.93	1.725	0.3955	increasing
-2	169	-0.0055	-3.56	-1.725	-0.6232	decreasing
-3	91	-0.0025	-1.56	-1.725	-0.3287	indeterminate
-4	72	-0.0018	-2.67	-1.725	-0.5130	decreasing
-5	179	-0.0053	-4.63	-1.729	-0.7280	decreasing
-6	0.66	-.0001	0.15	1.761	0.0402	indeterminate
-7	139	-0.0042	-4.02	-1.761	-0.7317	decreasing

*Taken from Volume II Engineering Report, Table 2-21

SUMMARY OF EXPONENTIAL REGRESSION OF FLUORIDE CONCENTRATION IN B-WELLS**

C = B0*EXP(B1*T) (T = TIME IN DAYS SINCE 1900)

Well No.	Beta 0 (y-intercept)	Beta 1 (slope)	T Statistic	Critical T	Interpretation
B-1	-0.25	1.034E-04	2.02	1.725	increasing
B-2	31.56	-1.028E-03	-4.15	-1.725	decreasing
B-3	3.95	-4.107E-05	-0.30	-1.725	indeterminate
B-4	5.37	-8.081E-05	-2.45	-1.725	decreasing
B-5	12.90	-3.349E-04	-2.93	-1.729	decreasing
B-6	2.56	-3.605E-05	-0.14	-1.761	indeterminate
B-7	13.82	-3.744E-04	-3.81	-1.761	decreasing

** Taken from Volume II Engineering Report, Table 2-22

Table 9

WELL NO.	DATE	CYANIDE CONCENTRATION (in mg/l)
B-01	8-20-86	0.04
B-02	8-19-86	0.04
B-03	8-20-86	0.04
B-04	8-21-86	< 0.04
B-05	8-22-86	0.04
B-06	8-19-86	0.06
B-07	8-18-86	< 0.04
B-08	8-19-86	< 0.04
B-09	8-28-86	< 0.04
B-10	8-18-86	0.04
B-11	8-20-86	0.04
B-12	8-21-86	0.05
B-13	8-19-86	0.05
B-14	8-20-86	0.04
B-15	8-22-86	< 0.04
B-16	8-21-86	< 0.04
F-01	8-23-86	0.04
F-02	8-23-86	< 0.04
F-03	8-25-86	0.04
F-04	8-23-86	< 0.04
F-05	8-23-86	< 0.04
F-06	8-22-86	< 0.04
F-07	8-23-86	< 0.04
F-08	8-25-86	0.04
F-09	8-21-86	< 0.04
I-01	8-28-86	0.04
KM-01	8-20-86	0.04
KM-02	8-19-86	< 0.04
KM-03	8-20-86	< 0.04
KM-04	8-21-86	< 0.04
KM-05	8-22-86	< 0.04
KM-06	8-19-86	< 0.04
KM-07	8-18-86	0.06
KMI-01	8-28-86	< 0.04
N-01	8-29-86	< 0.04
N-02	8-29-86	< 0.04
N-03	8-29-86	< 0.04
N-05	8-29-86	< 0.04
N-06	8-28-86	< 0.04
N-07	8-29-86	< 0.04
N-08	8-28-86	< 0.04

Charles W. Fetter, Jr.
Department of Geology
University of Wisconsin
Oshkosh, Wisconsin 54901
(414) 424-4460

EXPERIENCE

1984-present	Chairman, Department of Geology University of Wisconsin Oshkosh
1970-present	Consulting Hydrogeologist. Clients include attorneys, industries, municipalities, towns, engineering firms, state and federal Government. Responsibilities: Services to these clients include expert witness, groundwater exploration, water quality problems, well field layout, pumping tests, environmental studies, environmental impact analysis, computer models of ground water systems, general surface and geological and engineering geology site studies,especially of landfills and hazardous waste sites.
1971-present	Professor, Department of Geology University of Wisconsin Oshkosh Responsibilities: Courses taught include Environmental Geology, Hydrogeology, Ground Water Hydrology, Engineering Geology and Glacial Geology.
1983	Court-appointed expert witness by Judge Robert Pekowsky, Dane County, Wisconsin, Circuit Court in *Larson et al. v. Madison Metropolitan Sewerage District*. Responsibilities: Appointed by Judge Pekowsky as an impartial expert to aid him in interpreting very technical testimony and reports in case involving seepage of sewage effluent through an earthen dike. Reviewed case file, interviewed experts from both sides, evaluated raw data and reports and testified in court.
1982-present	Expert consultant, United States Environmental Protection Agency. Responsibilities: Designed and supervised a groundwater monitoring program and hydrogeology study for Seymour, Indiana hazardous waste site. Assisting in negotiating a settlement. Overseeing implementation of remedy.

RESUME - Charles W. Fetter, Jr.

EXPERIENCE (Cont'd)

1981-1982	Manager, Groundwater Resources Program Law Engineering Testing Company Marietta, Georgia Responsibilities: Business development and management of hydrogeology-related projects in water supply, hazardous and radioactive waste disposal and mining hydrology.
1978-1980	Senior expert witness, State of Wisconsin Department of Justice in Wisconsin et al. v. Illinois et al. Responsibilities: Urban runoff hydrology and computer modeling of regional groundwater flow. Prepared testimony for presentation to Special Master of U.S. Supreme Court. Assisted attorneys in preparation of Wisconsin's case-in-chief and in cross-examination of witnesses.
1970-1971	Teaching Assistant Indiana University
1966-1970	Staff Geologist. Holzmacher, McLendon & Murrell, Consulting Engineers, Melville, L.I., New York Responsibilities: Water resources studies. Supervision of test well drilling program. Design of municipal water wells and supervision of construction. General water resources engineering.

CONTINUING EDUCATION COURSES

March 1986	Sanitary Landfill Design University of Wisconsin Madison, Wisconsin
July 1982	Petroleum Reservoir Engineering Fundamentals American Association of Petroleum Geologists Jackson, Wyoming
June 1980	Hazardous Waste Management Practices University of Wisconsin Madison, Wisconsin
May 1980	Groundwater Computer Modeling University of Wisconsin Madison, Wisconsin

EDUCATION (Cont'd)

July 1978	Statistical Methods in Hydrology Colorado State University Fort Collins, Colorado

DEGREE PROGRAMS

1970-1971	Indiana University Ph.D. in Hydrogeology, Minor in Geochemistry Thesis: Hydrogeology of the South Fork of Long Island, New York
1964-1966	Indiana University M.A. in Geology
1960-1964	DePauw University (Phi Beta Kappa) B.A. in Chemistry, Minor in Geology

PROFESSIONAL REGISTRATION

Certified Professional Geologist, AIPG
Professional Engineer, Wisconsin

PROFESSIONAL MEMBERSHIPS

American Geophysical Union
American Water Resources Association
American Water Works Association
National Water Well Association
American Institute of Professional Geologists
Sigma Xi

HONORS

Phi Beta Kappa
Phy Eta Sigma
Sigma Xi, Past President,
  University of Wisconsin-Oshkosh Chapter
Past President, Minnesota-Wisconsin Section of
  American Institute of Professional Geologists
John McN Rosebush University Professor,
  University of Wisconsin Oshkosh
Listed in:
  American Men & Women of Science
  Who's Who in the Midwest
  Who's Who in Technology Today

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PUBLICATIONS

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RESUME

JAMES LUCIUS GRANT

EDUCATION:	Ph.D., Civil Engineering, (Hydraulics, Hydrology) Georgia Institute of Technology M.S., Applied Mathematics Georgia Institute of Technology B.E., Civil Engineering Georgia Institute of Technology B.S., Applied Mathematics Georgia Institute of Technology

PROFESSIONAL MEMBERSHIP:

American Geophysical Union
American Water Works Association
National Water Well Association
Sigma XI, Scientific Research Society

PROFESSIONAL REGISTRATION:

Professional Engineer in Georgia, Kentucky, Colorado, Wyoming, Nevada
Land Surveyor in Georgia

PROFESSIONAL EXPERIENCE:

1983-Present	President and Chief Executive Officer James L. Grant & Associates, Inc., Englewood, Colorado

Dr. Grant is currently president of a consulting engineering firm offering services in geology, geotechnical engineering, and waste disposal.

1979 - 1983	Corporate Consultant and Chief Hydrologist for Western Operations Law Engineering Testing Company, Denver, Colorado

Responsibilities included technical and management direction for projects in areas of waste management, mining, power plant sites, and development of other related siting investigations.

1978 - 1979 Chief Engineer
Nuclear Engineering Inc., Louisville, Kentucky

Responsibilities included engineering and construction activities at four low-level radioactive waste disposal sites and three industrial waste disposal sites; licensing and environmental monitoring at existing sites; and selection design, and licensing of new sites.

1973 - 1977 Senior Hydrologist and Geotechnical Engineer
Law Engineering Testing Company, Marietta, Georgia

Investigations included geotechnical, hydrologic, and water-resources engineering projects. Levels of responsibility included senior engineer, project management, consultation, and client development.

1967 - 1972 Design Engineer
Urban Engineers, Inc., Atlanta, Georgia

Served as project engineer on projects involving hydraulics, hydrology and storm drainage design; street and highway design; airport planning, design, and construction; residential and commercial design and construction; foundation design; land and construction surveys.

1964 - 1967 Mathematician
Lockheed-Georgia Company, Marietta, Georgia

Analyst on studies in strength analysis, advanced aerodynamic design, aircraft performance simulation, and command/control applications.

REPORTS:

"Closure Studies for Thorium Plant, West Chicago, Illinois," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project No. 804015, 1986.

"Longview (WA) Treated Wood Products Facility Ground-Water Assessment Program," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project No. 805046 and 806066, 1986.

"Joplin (MO) Treated Wood Products Facility Ground-Water Assessment Program," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project Nos. 804022, 804032, 805043 and 806070, 1986.

"Preparation of Responses to the U.S. EPA's Inquiries Regarding the Closure Plan and Part B Application for the Joplin (MO) Treated Wood Products Facility," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project Nos. 803011, 804025, 804029, 805041, 805051 and 806075, 1986.

"Closure Studies for the DeRidder (LA) Treated Wood Products Facility," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project Nos. 805039, 805045 and 806065.2343, 1986.

"Preparation of Closure Plan and Post-Closure Plan (Part B Application) for the Wiggins (MS) Treated Wood Products Facility," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project Nos. 804023, 804024, 805042 and 805044, 1985.

"Monitoring and Liner Waiver Design for the Beatty (NV) Chemical Facility," James L. Grant & Associates, Inc., Project Nos. 803001, 803008 and 805058, 1985.

"Preparation of a Model Debris Landfill Ordinance for Loudoun County, Virginia," James L. Grant & Associates, Inc., Project No. 805050, 1985.

"West Valley Closure Studies, James L. Grant & Associates, Inc., Project No. 805038, 1985.

"Development of a Ground-Water Monitoring Program for a Paper Mill Landfill in Bastrop, Louisiana," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project No. 805057, 1985.

"Landfarm Ground-Water Monitoring Design for the Southwestern Refining Company Land Treatment Facility, Corpus Christi, Texas," James L. Grant & Associates, Inc., Project No. 804028, 1984.

"Low-Level Nuclear Waste Site Study, Sheffield, Illinois," James L. Grant & Associates, Inc., Project Nos. 803010 and 804026, 1984.

"Ground Water Tracer Test Study, Seep Ridge Site, Utah," with W. E. Humphries, et al, James L. Grant & Associates, Inc., Project No. 804019, 1984.

"Preparation of Responses to the U.S. EPA's Inquiries Regarding the Closure Plan and Part B Application for the Longview (WA) Treated Wood Products Facility," with S.L Wampler, et al, James L. Grant & Associates, Inc., Project No. 804027, 1984.

"Surface Water Hydrologic Permit Section Preparation, Campbell County, Wyoming," with W.E. Humphries, et al, James L. Grant & Associates, Inc., Project No. 804020, 1984.

"Ground-Water Modeling Report for the Hazardous Waste Disposal Facility, Robstown, Texas," James L. Grant & Associates, Inc., Project No. 804035, 1984.

"Site Characterization Studies, Wiggins Treated Wood Products Facility," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project No. 804013, 1984.

"Site Characterization Studies, Joplin Treated Wood Products Facility," with S.L. Wampler, et al, James L. Grant & Associates, Inc., Project No. 803011, 1983.

"Maxey Flats Low-Level Nuclear Waste Disposal Site Closure Studies," with J.E. Razor, et al, 1983.

"Geological, Hydrological, and Geotechnical Engineering in Support of Operation of a Low-Level Radioactive/Chemical Waste Disposal Site at Beatty, Nevada," Law Engineering Testing Company, Project No. JLGA-803001, 1983.

"Geologic and Hydrologic Characterization for Oil Shale Project, Uintah County, Utah," with W.E. Humphries, et al, Law Engineering Testing Company, 1983.

"Hydrologic and Geochemical Investigation for Closure of Abandoned Modified In-Situ Retort, Rio Blanco County, Colorado," with Kyla D. Smith, et al, Law Engineering Testing Company, 1982.

"Soil and Ground-Water Investigation of the GCEP Landfill Pathways Analysis, Portsmouth, Ohio," with W.W. Bath, et al, Law Engineering Testing Company, 1982.

"Preparation of Hydrologic Sections of a Permit Application for a Proposed Oil Shale Operation Project in Uintah County, Utah," with S.L. Wampler, Law Engineering Testing Company, 1982.

"Tar Sand Development Water Supply Evaluation in Uintah County, Utah," with W.E. Humphries, Law Engineering Testing Company, 1982.

"Dam Feasibility Study in Douglas County, Colorado," Law Engineering Testing Company, 1982.

"Channel Modification Studies for Site Development, Arapahoe County, Colorado," with D.S. Bowles, Law Engineering Testing Company, 1982.

"Design of Operation, Construction and Closure Plans for Five Waste Disposal Sites," with W.E. Humphries, et al, Law Engineering Testing Company, 1982.

"Coal Mine Diversion and Impact Mitigation Design in Campbell County, Wyoming," with D.S. Bowles, et al, Law Engineering Testing Company, 1982.

"Geohydrologic Investigation of Surface Coal Mine, Colorado," Law Engineering Testing Company, 1981.

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"Preparation of a Water Management Plan to Permit the Rio Blanco Tract C-a Oil Shale Project," with W.E. Humphries, et al, Law Engineering Testing Company, 1980.

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"Report of Phase I Dam Safety Inspection, Hogback Dam, Little Hogback Creek, Jackson County, North Carolina," with C. H. Gardner and C. E. Sams, Law Engineering Testing Company, Job No. RA-982-B, August 1975.

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"Report of Phase I Dam Safety Inspection, Lake Toxaway Dam, Toxaway River, Transylvania County, North Carolina," with C. H. Gardner and C. E. Sams, Law Engineering Testing Company, Job No. RA-982-E, August 1975.

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"Report of Phase I Dam Safety Inspection, Ravenel Dam, Highland Falls Country Club, Cullasaja River, Macon County, North Carolina," with C. H. Gardner and C. E. Sams, Law Engineering Testing Company, Job No. RA-982-A, July 1975.

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PUBLICATIONS:

"Design and Impact Analysis for Diversion at Coal Creek Mine," with D. S. Bowles, W. E. Humphries, and A. P. O'Hayre, American Water Resources Association, Water Resources Bulletin, February 1986.

"Geotechnical Measurement at the Maxey Flats, Kentucky Low-Level Radioactive Waste Disposal Site--Lessons Learned," Proceedings of the Symposium on Low-Level Waste Disposal, Arlington, Virginia, June 16-17, 1982.

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"Chemical Migration of Radioactive Material in Soil," with F.L. Parker, Tutorial Session on Alternate Fuel Cycle, 25 Annual Meeting of the American Nuclear Society, June 5, 1979, Atlanta, Georgia.

"A Least Squares Method for Computing Statistical Tolerance Limits," with J. R. Wallace, Water Resources Research, 13(5) pp. 819-823, 1977.

"Statistical Frequency Analysis by Optimization of Density Functions to Histograms," Ph.D., Thesis, School of Civil Engineering, Georgia Institute of Technology, Atlanta, Georgia, 1973.

"A Hypercircle Method for Determining the Influence Coefficients of Thin Cylindrical Shells," M.S. Thesis, School of Mathematics, Georgia Institute of Technology, Atlanta, Georgia, 1967.

PRESENTATIONS:

"Seminar on the Development of Alternate Concentration Levels and Acceptable Exposure Limits - RCRA Permitting," with Carlos Stern, Dallas, Texas, September 10, 1985.

"Geologic Aspects of Hazardous Waste Management," Colorado Ground Water Society, 1982.

"Chemical Migration of Radioactive Material in Soil," with F.L. Parker, Tutorial Session on Alternate Fuel Cycle, 25 Annual Meeting of the American Nuclear Society, June 5, 1979, Atlanta, Georgia.

"Statistical Interpretation of Water Quality Data," Corps of Engineers Seminar on Water Quality Monitoring, May, 1978.

"Dewatering in the Piedmont," Raleigh Chapter, American Society of Civil Engineers, Raleigh, North Carolina, 1977.

"Hydrology of the Biscayne Aquifer," Florida Section, American Society of Civil Engineers Annual Meeting, Miami, Florida, 1976.

"A Least Squares Method for Computing Statistical Tolerance Limits," Fall Annual Meeting of the American Geophysical Union, San Francisco, California, 1974.

"Hydrologic Models," Georgia Section, American Society of Civil Engineers Annual Meeting, Atlanta, Georgia, 1974.

RESUME

John Clarke Stauter (405) 341-9374
909 South Dover Drive
Edmond, Oklahoma 73034

EDUCATION: B.S. Degree - Metallurgical Engineering, Michigan Technological University, 1966

M.S. Degree - Metallurgical Engineering, Michigan Technological University, 1967

Ph.D. - Metallurgy (Chemical/Extractive), University of Utah, 1970

WORK EXPERIENCE:

August, 1978 to Present: **KERR-MCGEE CORPORATION / OKLAHOMA CITY, OK**

10/84 - Present: Director, Environmental Affairs

3/84 - Present: Director, Nuclear Licensing and Regulation

CURRENT RESPONSIBILITIES: Direct a staff of seven professionals and two secretaries in assisting Corporate Staff and Operations Division personnel in solving environmental problems and assuring compliance.

Duties range full spectrum from hazardous and solid wastes, nuclear, ground and surface water quality and air quality issues.

Inform operations of new rules, comment on proposed rules, assist operations in writing permits, negotiations with regulatory agencies (federal, state, local), represent and support operations concerning response to Notices of Violation, Compliance Plans and litigation. Provide engineering evaluation, assist in selection of consultants. Visit all facilities and respond on-site when called upon during emergencies or site inspections. Provide expert support to operations to assure achievement of corporate and regulatory objectives.

5/81 - 3/84: Senior Environmental Scientist Nuclear Licensing and Regulation and Environmental Affairs Sections in Environment and Health Management Division Sections; Provide technical and administrative support related to nuclear and environmental RCRA & Superfund related issues.

(RESUME)

8/78 - 5/81: Senior Project Metallurgist, Technology Division; Direct process chemistry research for mineral and environmental control systems.

7/74 - 8/78: UOP INC. / DES PLAINES, IL

Group Leader (Research): Direct fundamental and applied process development research into new mineral processing systems and technology areas, precious metal recovery from catalysts.

2/70 - 7/74: CONOCO / PONCA CITY, OK

Research Scientist: Develop and prove processing flow sheets for Conoco Minerals (uranium, copper, precious metals) and Consolidation Coal (Fine Coal Cleaning Operations).

PERSONAL ACHIEVEMENTS:

(1) Member, AIME - Society of Mining Engineers

(2) Member, Alpha Sigma Mu Metallurgical Honors Fraternity, Chapter President - Michigan Technological University.

(3) Member Curriculum Advisory Committee, Department of Chemical and Nuclear Engineering, University of New Mexico, Albuquerque, New Mexico.

(4) Guest Lecturer: Process Chemical Metallurgy Seminar, Northwestern University, Evanston, Illinois, February, 1978.

(5) Three published technical papers. Seven presented papers at technical and trade society meetings.

(6) Several U.S. patents in Metallurgical and Chemical Processing area. Some corresponding foreign patents.

PUBLICATIONS:

1. Direct Electrowinning of Copper from Synthetic Leach Solutions Utilizing SO_2 and Graphite Anodes - Pilot Plant Results; G.F. Pace and J.C. Stauter; The Canadian Mining and Metallurgical Bulletin, January, 1974.

PUBLICATIONS (CONTINUED):

2. Leaching of Oxide Copper Ore With Ammonium Hydrogen Sulfate: Bench Scale Testing; J.C. Stauter and A.G. Fonseca; The Canadian Mining and Metallurgical Bulletin; February, 1974.

3. The Recovery of Lead from Sulfide Concentrates Using a Chlorination/Brine Leach/Electrolysis Process; R.T. Um, W.K. Tolley, and J.C. Stauter; Process and Fundamental Considerations of Selected Hydrometallurgical Systems, Chapter 10, p. 109, Edited by Martin C. Kuhn, AIME Publication.

PAPERS:

1. The Electrowinning of Copper Utilizing SO_2 and Graphite Electrodes; G.F. Pace and J.C. Stauter; Presented at 75th General Meeting of the Canadian Institute of Mining and Metallurgy, Vancouver, B.C., Canada; April 15-18, 1973.

2. Direct Electrowinning of Copper From Synthetic Pregnant Leach Solutions Utilizing SO_2 and Graphite Anodes - Pilot Plant Results; G.F. Pace and J.C. Stauter; Presented at 3rd Meeting of the Hydrometallurgy Group of CIM, Edmonton, Alberta, Canada; October 1-2, 1973.

3. Leaching of Oxide Copper Ore with Ammonium Hydrogen Sulfate - Bench Scale Testing; J.C. Stauter and A.G. Fonseca; Presented at the 12th Annual Conference of Metallurgists - CIM; Quebec, Canada; August 26-29, 1973.

4. Vat Leaching of Oxide Copper Ore; J.C. Stauter and G.F. Pace; Presented at 76th Annual Meeting of the Canadian Institute of Mining; Montreal, Quebec, Canada; April 21-25, 1974.

5. The Recovery of Lead From Sulfide Concentrates Using A Chlorination/Brine Leach/Electrolysis Process; J.C. Stauter, W.K. Tolley and R.T. Um; Presented at American Chemical Society Meeting; Anaheim, California; March 16, 1978.

6. Radon Daughters Research and Litigation Issues; E.T. Still and J.C. Stauter; Presented at Annual American Mining Congress Meeting; Phoenix, Arizona; September 23-26, 1984.

(RESUME)

PAPERS (CONTINUED):

7. Mining Waste Charaterization - The PEDCo Study; J.C. Stauter and E.T. Still; Presented at the Atomic Industrial Forum Uranium Seminar; Keystone, Colorado; October 3, 1984.

PATENTS:

1. Patent #3,834,533; Concentration Of Oxide Copper Ores By Flotation Separation; September 10, 1974.
2. Patent #3,845,862; Concentration Of Oxide Copper Ores By Flotation Separation; November 5, 1974.
3. Patent #3,919,080; Pyrite Depression In Coal Flotation By The Addition Of Sodium Sulfite; November 11, 1975.
4. Patent #3,966,567; Electrolysis Process And Apparatus; June 29, 1976.
5. Patent #3,972,,790; Production Of Metallic Lead; August 3, 1976.
6. Patent #3,981,784; Electrolysis Process And Apparatus; September 21, 1976.
7. Patent #4,013,754; Static Leaching Copper Ore; March 22, 1977.
8. Patent #4,028,463; Recovery Of Manganese Values; June 7, 1977.
9. Patent #4,029,734; Recovery Of Chromium Values; June 14, 1977.
10. Patent #4,087,340; Production Of Metallic Lead; May 2, 1978.
11. Patent #4,124,457; Production Of Metallic Lead; November 7, 1978.
12. Patent #4,124,461; Production Of Metallic Lead; November 7, 1978.
13. Patent #4,135,997; Electrolytic Production Of Metallic Lead; January 23, 1979.
14. Patent #4,149,947; Production Of Metallic Lead; April 17, 1979.

PATENTS (CONTINUED):

15. Patent #4,187,281; Hydrometallurgical Recovery Of Cobalt & Nickel; February 5, 1980.

16. Patent #4,197,276; Recovery Of Titanium Metal Values; April 8, 1980.

17. Patent #4,200,455; Hydrometallurgical Recovery Of Metal Values; April 29, 1980.

18. Patent #4,237,104; Flue Gas Treatment For Sulfur Dioxide Removal; December 2, 1980.

19. Patent #4,405,464; Process For The Removal Of Selenium From Aqueous Solutions; September 20, 1983.

20. Patent #4,519,913; Process For The Removal And Recovery Of Selenium From Aqueous Solutions; May 28, 1985.

RESUME

John Clarke Stauter
909 South Dover Drive
Edmond, Oklahoma 73034
(405) 341-9374

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CURRENT RESPONSIBILITIES: Direct a staff of seven professionals and two secretaries in assisting Corporate Staff and Operations Division personnel in solving environmental problems and assuring compliance.

Duties range full spectrum from hazardous and solid wastes, nuclear, ground and surface water quality and air quality issues.

Inform operations of new rules, comment on proposed rules, assist operations in writing permits, negotiations with regulatory agencies (federal, state, local), represent and support operations concerning response to Notices of Violation, Compliance Plans and litigation. Provide engineering evaluation, assist in selection of consultants. Visit all facilities and respond on-site when called upon during emergencies or site inspections. Provide expert support to operations to assure achievement of corporate and regulatory objectives.

5/81 - 3/84: Senior Environmental Scientist Nuclear Licensing and Regulation and Environmental Affairs Sections in Environment and Health Management Division Sections; Provide technical and administrative support related to nuclear and environmental RCRA & Superfund related issues.

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3. The Recovery of Lead from Sulfide Concentrates Using a Chlorination/Brine Leach/Electrolysis Process; R.T. Um, W.K. Tolley, and J.C. Stauter; Process and Fundamental Considerations of Selected Hydrometallurgical Systems, Chapter 10, p. 109, Edited by Martin C. Kuhn, AIME Publication.

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2. Direct Electrowinning of Copper From Synthetic Pregnant Leach Solutions Utilizing SO_2 and Graphite Anodes - Pilot Plant Results; G.F. Pace and J.C. Stauter; Presented at 3rd Meeting of the Hydrometallurgy Group of CIM, Edmonton, Alberta, Canada; October 1-2, 1973.

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4. Vat Leaching of Oxide Copper Ore; J.C. Stauter and G.F. Pace; Presented at 76th Annual Meeting of the Canadian Institute of Mining; Montreal, Quebec, Canada; April 21-25, 1974.

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2. Patent #3,845,862; Concentration Of Oxide Copper Ores By Flotation Separation; November 5, 1974.
3. Patent #3,919,080; Pyrite Depression In Coal Flotation By The Addition Of Sodium Sulfite; November 11, 1975.
4. Patent #3,966,567; Electrolysis Process And Apparatus; June 29, 1976.
5. Patent #3,972,,790; Production Of Metallic Lead; August 3, 1976.
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8. Patent #4,028,463; Recovery Of Manganese Values; June 7, 1977.
9. Patent #4,029,734; Recovery Of Chromium Values; June 14, 1977.
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14. Patent #4,149,947; Production Of Metallic Lead; April 17, 1979.

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17. Patent #4,200,455; Hydrometallurgical Recovery Of Metal Values; April 29, 1980.

18. Patent #4,237,104; Flue Gas Treatment For Sulfur Dioxide Removal; December 2, 1980.

19. Patent #4,405,464; Process For The Removal Of Selenium From Aqueous Solutions; September 20, 1983.

20. Patent #4,519,913; Process For The Removal And Recovery Of Selenium From Aqueous Solutions; May 28, 1985.

TABLE 2-31

SUMMARY OF

HEAVY-METALS LEACHATE CONCENTRATIONS

	Ag (mg/l)	Ba (mg/l)	Cd (mg/l)	Cr (mg/l)	As (mg/l)	Hg (mg/l)	Pb (mg/l)	Se (mg/l)	Cu* (mg/l)	Fe* (mg/l)	Ni* (mg/l)	Zn* (mg/l)
Neutralized:												
Tailings	0.044	0.313	0.046	0.0414	2.695	0.0041	0.0303	3.1884	0.0565	0.7987	0.3924	0.2628
Un-neutralized:												
Sludge	0.08	0.094	0.012	0.015	0.384	0.0002	0.345	0.098	0.036	2.605	0.088	0.338
Soils:												
E S&G	0.0153	0.076	0.015	0.013	0.211	0.00044	0.211	0.094	0.013	0.959	0.033	0.124
Fines	0.0285	0.163	0.023	0.021	0.249	0.00057	0.195	0.097	0.013	0.936	0.032	0.122
Ponds:												
1	0.0116	0.1543	0.0063	0.012	0.1967	0.0006	0.1973	0.0907	0.020	1.490	0.051	0.193
2-5	0.007	0.1779	0.0048	0.0133	0.164	0.0005	0.1276	0.0908	0.013	0.964	0.033	0.125

* Missing values estimated from metal/lead ratio in un-neutralized tailing and sludge analyses from Stabilization Plan

TABLE 2-35

SLUDGE AND TAILINGS LEACHATE TEST RESULTS

Material	Th232 (pCi/l)	Th230 (pCi/l)	Th228 (pCi/l)	Ra226 (pCi/l)	Ra224 (pCi/l)	U (mg/l)
Un-neutralized:						
Tailings	71	12	284	6.7	263	27
Sludge	435	71	2996	7.3	40.6	46
Neutralized:						
Tailings	0.045	0.06	1.37			
Sludge	0.091	0.06	0.65	1	1.74	

LEACHATE FACTORS

Material	Th232 (conver.)	Th230 (ratio)	Th228 (ratio)	Ra226 (conver.)	Ra224 (ratio)	U (conver.)
Un-neutralized:						
Tailings	0.052329	0.169014	4.000000	0.008175	39.253731	0.435483
Sludge	0.101360	0.163218	6.887356	0.003646	5.561644	0.060288
Average	0.076845	0.166116	5.443678	0.005911	22.407688	0.247886
Neutralized:						
Tailings	0.000630	0.005000	0.004800			
Sludge	0.002090	0.000850	0.000220			
Average	0.001360	0.002925	0.002510			

$$\text{Leachate Factor} = \frac{\text{Un-neutralized leachate concentration (pCi/l)}}{\text{Total Concentration (pCi/g)}}$$

TABLE 2-36

SUMMARY OF

HEAVY-METALS LEACHATE CONCENTRATIONS

	Ag (mg/l)	Ba (mg/l)	Cd (mg/l)	Cr (mg/l)	As (mg/l)	Hg (mg/l)	Pb (mg/l)	Se (mg/l)	Cu* (mg/l)	Fe* (mg/l)	Ni* (mg/l)	Zn* (mg/l)
Neutralized:												
Tailings	< 0.001	0.100	< 0.001	0.0020	0.0060	< 0.001	0.0040	0.0130	0.0020	0.0030	0.0070	0.0050
Sludge	< 0.001	0.016	< 0.001	0.006	0.002	< 0.001	0.002	0.006	0.016	0.006	0.002	0.025
Un-neutralized:												
Tailings	1.629	0.765	0.092	0.207	2.695	0.0041	3.333	0.1266	NA	NA	NA	NA
Sludge	0.08	0.094	0.012	0.015	0.384	0.0002	0.345	0.098	NA	NA	NA	NA
Soils:												
E S&G	0.005	0.033	0.075	0.082	0.102	0.001	0.127	0.094	NA	NA	NA	NA
Fines	0.027	0.134	0.077	0.027	0.166	0.001	0.124	0.097	NA	NA	NA	NA
Ponds:												
1	0.0116	0.1543	0.0063	0.012	0.1967	0.0006	0.1973	0.0907	NA	NA	NA	NA
2-5	0.007	0.1779	0.0048	0.0133	0.164	0.0005	0.1276	0.0908	NA	NA	NA	NA

* Missing values estimated from metal/lead ratio in un-neutralized tailing and sludge analyses from Stabilization Plan

Note: Neutralized tests taken from the Site Stabilization Plan
Un-neutralized data taken from Volume VIII of the Engineering Report

TABLE 2-37

SUMMARY OF

LIGHT METAL AND ANION LEACHATE ANALYSES

	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	SO4 (mg/l)	Cl (mg/l)	F (mg/l)	NO3 (mg/l)
Un-neutralized:								
Tailings	291	12.3	18.9	136	1504	< 2	8.7	0.2
Sludge	235	10.4	33	140	1512	6.2	13.3	0.23
Average	263	11.35	25.95	138	1508	4.1	11	0.215
Neutralized:								
Tailings	100	31	1.5	210	1400	< 1	0.12	< 0.1
Sludge	24	4.2	15	160	305	6.5	49	0.6
Average	62	17.6	8.3	185	853	< 3.8	24.56	< 0.3
Values Used in Analyses:								
Tailings	291	95	33	1529	2862	11	22.8	0.23

TABLE 2-40
ESTIMATES OF POST-CLOSURE GROUND-WATER CONCENTRATIONS

(all concentrations are in milligrams/liter (mg/l))

Ag	Ba	Cd	Cr	As	Hg	Pb	Se	Cu**	Fe**	Mn**	Zn**	Ca	K	Mg	Na	SO4	Cl	F	NO3
IEPA General Use Standards																			
0.005	5	0.05	0.05	1	0.0005	0.1	1	0.02	1	1	1	NA	NA	NA	NA	500	500	1.4	NA
Composite Maximum																			
0.025	0.163	0.021	0.019	0.782	0.001	0.205	0.805	0.029	1.545	0.131	0.214	214	80	28	459	1759	6	16	0.231
Percent (%) of IEPA Standard																			
491	3	41	39	78	283	205	80	145	155	13	21	NA	NA	NA	NA	352	1	1114	NA
Maximum																			
0.08	0.313	0.077	0.082	2.695	0.0041	0.345	3.1884	0.0565	2.805	0.392	0.338	291	95	33	1529	2862	11	23	0.23
Percent (%) of IEPA Standard																			
1600	6	154	164	270	820	345	319	283	281	39	34	NA	NA	NA	NA	572	2	1629	NA
Case 1		Dilution Factor: 0.00817																	
Composite Maximum																			
0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0003	0.0000	0.0000	0.038	0.010	0.004	0.078	0.299	0.001	0.003	0.00004
Percent (%) of IEPA Standard																			
0.083	0.001	0.007	0.007	0.013	0.049	0.035	0.014	0.025	0.029	0.002	0.004	NA	NA	NA	NA	0.06	0.00	0.19	NA
Maximum																			
0.00001	0.00005	0.00001	0.00001	0.00048	0.00000	0.00006	0.00054	0.00001	0.00044	0.00007	0.00008	0.049	0.018	0.003	0.280	0.487	0.002	0.004	0.00004
Percent (%) IEPA Standard																			
0.272	0.001	0.026	0.028	0.048	0.139	0.059	0.054	0.048	0.044	0.007	0.01	NA	NA	NA	NA	0.0973	0.0004	0.2789	NA
CASE 2		Dilution Factor: 0.00189																	
Composite Maximum																			
0.00004	0.00028	0.00003	0.00003	0.00132	0.00000	0.00035	0.00138	0.00005	0.00281	0.00022	0.00038	0.382	0.101	0.044	0.778	2.973	0.010	0.026	0.0004
Percent (%) of IEPA Standard																			
0.83	0.01	0.07	0.07	0.13	0.45	0.35	0.14	0.25	0.28	0.02	0.04	NA	NA	NA	NA	0.59	0.00	1.86	NA
Maximum																			
0.00014	0.00053	0.00013	0.00014	0.00455	0.00001	0.00058	0.00539	0.00010	0.00440	0.00068	0.00057	0.492	0.191	0.058	2.584	4.837	0.019	0.039	0.0004
Percent (%) of IEPA Standard																			
2.70	0.01	0.26	0.28	0.46	1.39	0.58	0.54	0.48	0.44	0.07	0.06	NA	NA	NA	NA	0.97	0.00	2.75	NA
Case 3		Dilution Factor: 0.08103																	
Composite Maximum																			
0.00199	0.01323	0.00167	0.00157	0.06335	0.00011	0.01658	0.09820	0.00235	0.12520	0.01058	0.01732	17.340	4.922	2.103	37.195	142.954	0.471	1.294	0.019
Percent (%) of IEPA Standard																			
39.77	0.26	3.34	3.15	6.33	21.34	16.58	9.82	11.76	12.52	1.06	1.73	NA	NA	NA	NA	28.51	0.09	90.31	NA
Maximum																			
0.00648	0.025	.006	.007	.218	.0003	.028	.238	.0048	.211	.032	.027	23.8	9	3	124	232	1	2	.02
Percent (%) of IEPA Standard																			
129.65	.5	12	14	22	60	28	28	23	21	3.2	2.7	NA	NA	NA	NA	46	0.2	142	NA
Case 11		Dilution Factor: 0.04508																	
Composite Maximum																			
0.00118	0.00785	0.00099	0.00093	0.03759	0.00006	0.00984	0.03869	0.00140	0.07429	0.00828	0.01027	10.29	2.58	1.25	22.07	84.59	0.29	0.75	0.01
Percent (%) of IEPA Standard																			
23.60	0.16	1.98	1.87	3.76	12.66	9.84	3.87	6.98	7.43	0.83	1.03	NA	NA	NA	NA	16.92	0.03	53.59	NA
Maximum																			
0.00385	0.01505	0.00370	0.00394	0.12958	0.00020	0.01659	0.15330	0.00272	0.12525	0.01887	0.01925	13.99	4.57	1.59	73.51	137.60	0.33	1.10	0.01
Percent (%) of IEPA Standard																			
76.93	6.30	7.40	7.99	12.96	39.43	16.59	15.33	13.58	12.52	1.89	1.93	NA	NA	NA	NA	27.52	0.11	78.30	NA

Appendix 5

The effect of retardation can be estimated by considering the movement of various chemical constituents through the two-foot thick clay liner that will form the bottom of the waste disposal cell. Retardation of anions and cations due to adsorption is a well-known phenomenon. The retardation factor is defined by the following expression:

$$R_d = 1 + \frac{pK_d}{n}$$

Where R_d is the retardation factor, p is the bulk density of the clay, K_d is the distribution coefficient, and n is the porosity.[1/] When the retardation factor is multiplied by the travel time for ground water flow through the clay liner, the result is the travel time for the solute front.

The bulk density of the compacted clay to be used in the clay liner is about 1.64 gm/cm^3, and the porosity is 0.38. The retardation factor for the clay liner is thus:

$$R_d = 1 + \frac{1.64}{0.38} K_d$$

or

$$R_d = 1 + 4.32\ K_d$$

The rate of movement of water through the clay liner is controlled by the rate of leakage of water through the

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[1/] R. Freeze, J.A. Cherry, Groundwater 404 (1979).

cover. With a probable infiltration rate of 0.1 inch (0.25 cm) per year and an effective porosity of 0.06, the rate of movement of water through the liner is 4.17 cm/year. At this rate it would take 14.6 years for a drop of water to pass through the 60.9 cm thick clay liner.

The SFES includes estimates of K_d for a number of compounds. These range from 3 for some mobile metals, to 100 for radium. With a distribution coefficient of 3, the retardation factor is 13.96. These mobile compounds would thus require 204 years to pass through the clay liner. The retardation factor for radium is 433 and it would thus take 6,321 years for the radium to pass through the clay liner. Similarly, the retardation factor for uranium is 217 and it would thus take 3,168 years for uranium to pass through the liner.

The same approach may be used to assess the NRC's results. With a recharge rate of 3 cm/yr -- the NRC's conservative assumption of infiltration -- the rate of movement of ground water through the clay liner is 50 cm/year. It would thus require roughly 1.2 years for water to pass through the liner. If the retardation factor is applied, it would require about 520 years for radium to pass through the liner, and about 260 years for uranium to pass through the liner. This simple calculation is consistent with the NRC's estimate that the peak concentration of radium will be seen at the site boundary in 860 years and of uranium in 430 years.

Appendix 6

There are only four wells in the Pleistocene sand and gravel aquifer within a three kilometer radius of the site and they are all at least 1200 meters away. They are used for private, presumably domestic purposes. The effects of withdrawals from these wells on groundwater flow at the site can be shown to be neglible.

Water use for domestic purposes is typically about 50 gallons per day per capita. To be conservative, a domestic well can be conservatively assumed to pump roughly 500 gallons per day (100 gallons per capita per day for a 5-person household) for domestic use. If the well is also used to water a lawn for three hours a day at a rate of 5 gallons per minute, which is about the maximum output of a domestic well, the additional usage is about 900 gallons per day. The maximum water usage from the well is thus roughly 1,400 gallons per day, or about 1 gallon per minute.

The radius of influence of a well in a water table aquifer can be estimated by the determining the surface area that is needed to supply sufficient recharge from precipitation to replenish the water captured by the cone of depression of the well. If all four wells in the Pleistocene sand-and-gravel aquifer use water at a rate of 1400 gallons per day during a five-month growing season and at a rate of 500 gallons per day for the remaining seven months of the year, the total water withdrawal from the Pleistocene sand-and-gravel aquifer would be 1.288 x 10^6 gallons per year (1.722 x 10^5 cubic feet per year). With a recharge rate of 3.7 inches per year (0.308 feet per year), a total surface area of 5.59 x 10^5 square feet of land area would be needed for recharge. If all four wells were located at the same spot, the area of influence would only extend a radial distance of 422 feet away from the wells. Because the closest well is at least 4,000 feet from the site, these wells can have no influence on the hydrodynamics of ground water flow at the site. Moreover, it is very unlikely that the number of domestic wells in the glacial aquifer will increase in the future because this unit is not used for municipal or industrial wells.

Appendix 7

Equation E.2 in the SFES can be derived in a straightforward manner from first principles. Assume that water is moving vertically downward through a multilayer system. The velocity with which the water moves through the j^{th} layer is given by:[1/]

$$v_j = \frac{Q}{nA} = \frac{q}{n_j} \qquad (1)$$

Where Q is the discharge rate or volumetric flux, A is cross-sectional area of flow, q is the specific discharge or Darcian velocity, and n_j is the effective or connected porosity.

Dissolved materials which react chemically or physically with the soil matrix may not move as rapidly as the water. The difference between the rate of movement of a solute and rate of movement of the water in which it is dissolved is called the retardation factor. The retardation factor for the j^{th} layer is defined (Freeze and Cherry, page 404) as:

$$R_{dj} = v_j/v_{dj} \qquad (2)$$

or, equivalently,

[1/] R.A. Freeze, J.A. Cherry, Groundwater 71 (1979).

$$v_{dj} = v_j/R_{dj}$$

where v_{dj} is the average velocity with which a dissolved substance travels through the layer j. The time for the contaminant to travel through the j^{th} layer is therefore readily given:

$$T_{dj} = L_j/v_{dj} = L_jR_{dj}/v_j = L_jR_{dj}n_j/q_j \qquad (3)$$

When T_{dj} is the time for the contaminant to move through the j^{th} layer and L_j is the thickness of the j^{th} layer. Under steady-state infiltration conditions, q_j is equal to the infiltration rate (I).

For the sites evaluated by the NRC, the water table is close to the ground and the climate is relatively humid. In such cases, the moisture content of the material in the unsaturated zone below a disposal cell will be nearly equal to or greater than the field capacity of the soil. Thus, in the unsaturated zone, the effective porosity in equation (3) can be approximated by the effective moisture content of the soil (Θ_{ej}), which is the percentage of the moisture that can readily move in the unsaturated zone.2/ This is a

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2/ Corey, A. T., "Mechanics of Hetrogeneous Fluids in Porous Media", Water Resources Publication, Fort Collins, Colorado, (1977).

conservative replacement because Θ_{ej} is always smaller than the effective porosity n_j.

Substituting for q_j and n_j, equation (3) may be written as

$$T_{dj} \quad = \quad L_j R_{dj} \Theta_{2ej}/I$$

The total travel time through a series of soil layers is therefore

$$T_d = \sum_{j=1}^{n} T_{dj} \quad = \quad \sum_{j=1}^{n} L_j \Theta_{ej} R_{dj}/I$$

This is Equation E.2 in the SFES.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of Kerr-McGee Chemical Corporation (West Chicago Rare Earths Facility)	Docket No. 40-2061-ML ASLBP No. 83-495-01-ML

CERTIFICATE OF SERVICE

I hereby certify that I have caused copies of the foregoing Testimony of Charles W. Fetter, Jr., James L. Grant, and John C. Stauter in Response to the Board's Orders of November 14, 1989, and November 20, 1989 to be served by express mail (or, as indicated by an asterisk, by first class mail), postage pre-paid, on this 28th day of November, 1989, as follows:

John H. Frye, III, Chairman
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
4350 East-West Highway
4th Floor
Bethesda, MD 20814

Dr. James H. Carpenter
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
4350 East-West Highway
4th Floor
Bethesda, MD 20814

Dr. Jerry R. Kline
Atomic Safety and Licensing Board Panel
4350 East-West Highway
4th Floor
Bethesda, MD 20814

Stephen H. Lewis, Esq.
Ann P. Hodgdon, Esq.
Office of the General Counsel
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Steven J. England, Esq.
Illinois Department of Nuclear Safety
1035 Outer Park Drive
Springfield, Illinois 62704

Carla D. Davis (also by FAX)
Douglas Rathe
J. Jerome Sisul
Assistant Attorney General
Environmental Control Division
State of Illinois Building
100 W. Randolph Street
12th Floor
Chicago, Illinois 60601

Adjudicatory File (2)*
Atomic Safety and Licensing Board Panel Docket
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Docketing & Service Section (3)*
Office of the Secretary
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Atomic Safety and Licensing Appeal Board Panel*
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Richard A. Meserve