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MEMORANDUM FOR: Malcolm R. Knapp
High-Level Waste Licensing
Management Branch
Division of Waste Management

FROM: Matthew J. Gordon
High-Level Waste Licensing
Management Branch
Division of Waste Management

SUBJECT: REVIEW OF DATA COLLECTION TO DATE AND FUTURE PLANS FOR SITE HYDROLOGY CHARACTERIZATION AS PRESENTED IN SCR

Enclosed is a report which analyzes the SCR's treatment of groundwater hydrology with particular emphasis on their past efforts and future plans for performance assessment of the geologic medium.

ORIGINAL SIGNED BY

Matthew J. Gordon
High-Level Waste Licensing
Management Branch
Division of Waste Management

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SCR - Groundwater

The Site Characterization Report, as intended by NRC, should be a presentation by DOE which describes the progress made and plans which they have for site characterization. The following report is a review of the data collection to date and the future plans which DOE has outlined to characterize the site hydrology to the satisfaction of the NRC. The review is summarized in this introduction and is followed by the detailed analysis of the site hydrology as presented in the SCR. The principal chapters of the SCR that address the site hydrology are Chapters 5, 12 and portions of 13 through 17.

The document does not detail the specifics of the testing procedures for each head, conductivity and transmissivity measurement. The testing procedures are given in a generalized form which does not specify, for example, which wells were drilled which way, or what kind of procedures were followed to avoid skin effects from drilling mud and to avoid measuring drilling transient effects rather than in-situ conditions. Only the results of the tests are given. Their future plans involve the drilling of three new holes and a cluster set around DC-16. It is questionable whether their testing plans would be appropriate for measuring bulk hydraulic properties.

The SCR goes into great detail in modeling of the site to show that the groundwater travel times to the accessible environment are sufficiently long to satisfy the EPA and NRC performance standards. The results from their preliminary analyses suggest that the minimum travel time is 30,000 years, which greatly exceeds the requirements imposed upon them. This estimate is not entirely consistent with their data. Also, the data available are insufficient to predict travel times with a sufficient degree of accuracy at this time. If these travel times were correct, DOE could conceivably convince the NRC that the multiple barrier approach is unnecessary. However, these travel times are not in agreement with those calculated by NRC using the data available in the SCR.

In the following pages, several selected topics which relate to the site hydrology performance assessment are discussed. In particular, questions are raised concerning the construction of a conceptual model of groundwater flow as developed in the SCR.

1. Review of Work to Date

1A. Data Collection

The validity of the data collected is of utmost importance in assessing the performance of the geologic barrier. Since the details of testing are not available, it is not known whether the data collected to date may be suspect due to drilling mud skin effects, open hole packer testing effects, or non-equilibration of drilling transients effects. Also, the testing procedures used apparently all assume laterally continuous hydrostratigraphic units (HSU's) and have been short term point tests which do not adequately measure bulk conductivities. There has been no in-situ testing, such as multiple well, large scale pump tests, which would indicate (at least qualitatively) the presence and effects of structures and discontinuities in the system.

Heads measured throughout the basin generally vary very little, on the order of 5% or less. The likely error bounds on the measurements are probably greater than the variation. Therefore, gradients calculated from these head measurements are not totally reliable because they can be increased, decreased or even reversed if the heads are varied within the likely error bounds. As an example, it is interesting to note that on page 5.1.63 areal head gradients in the Middle Sentinel Bluffs and Umtanum flow tops are calculated by comparing two sets of head data. One comparison is made between heads in RRL-2 and DC-15 and another comparison is made between heads DC-12 and DC-15. These comparisons suggest flow to the southeast with a gradient of about 10^{-4} in both units. However, if we compare heads in DC-12 to heads in RRL-2 (from the same table) we see a gradient of 10^{-4} towards the northwest in both units. Thus, even with the data they have presented, the gradient can be shown to be in a perfectly opposite direction than they have calculated. This exemplifies the uncertainty that is still present in the conceptual model.

Despite the multitude of wells on the site, there has not been a concerted effort to characterize the site in terms of bulk groundwater flow characteristics. While several structures throughout the Cold Creek Syncline are "known or inferred" (see page 2.7-29) the hydraulic effects of these structures are totally unknown. The positioning of wells has not been designed to determine the nature of these structures (whether they are impediments to flow or are of high permeability) nor have the pump tests been designed to determine their effects (whether they facilitate interaquifer communication). The nature and extent of faulting is ignored in modeling the site even though a microearthquake swarm has occurred in the basin as recently as 1979 (SCR, pg. 3.7-45).

Although in Chapter 6 DOE claims to have characterized fractures in the Grande Ronde basalt flows, they do not indicate how many cores they have examined so far, nor how they managed to characterize the fractures from these greatly disturbed cores.

Their conceptual model hinges on the assumption that the Grande Ronde Basalt represents a separate groundwater system with minimal communication with the upper aquifers. They contend that this system is recharged solely by a relatively small area hundreds of miles away. This contention needs to be checked with a regional water balance, as it is not intuitive, considering the high pressures and large quantities of flow encountered in the Grande Ronde. Their conceptual model also has water moving towards the southeast, under the Columbia River, and towards Wallula Gap. A few head measurements on the east side of the river, across from DB-1, DB-2 and DC-15, would be most helpful in checking this assumption but have not been proposed in DOE's future plans. If the heads continue to decrease east of these wells, their flow path assumption would be supported. If, however, the new wells indicated flow toward the river, DOE's position would have to be re-evaluated.

The most common criticism of DOE's work to date centers on the lack of any vertical conductivity measurements. This has been dealt with extensively in the works of Lehman and Quinn (1982) and Quinn (1982) and will be discussed in Chapter 4 of the Site Characterization Analysis (SCA). The lack of any vertical conductivity data makes all of the estimates of vertical conductivity, which are made frequently in the SCR, very preliminary in nature.

Horizontal hydraulic conductivities in the basalts are calculated from measured transmissivities in single hole pump tests. Aside from the aforementioned skin and transient effects which affect results, the choice of transmissive unit thickness from the test interval can have a significant impact on the calculated conductivity. In the Grande Ronde, where transmissive cores are claimed by DOE to be a small percentage of the total sequence, the calculated conductivity can vary over up to two orders of magnitude, depending on the effective thickness chosen. Since water will travel the least resistant paths, these effective thicknesses and actual conductivities are extremely important to travel time calculations. Since travel time depends inversely linearly on conductivity, the resultant travel time estimate could be decreased by up to two orders of magnitude.

Similarly, travel time depends directly linearly on porosity. Only one measurement of porosity has been made. This was calculated from tracer test results, yielding an estimated "range" between 10^{-2} and 10^{-4} (SCR, pg. 5.1-46). They explain that they could not obtain a finer resolution of the porosity measurement because the effective thicknesses of the transmissive horizons were not known. This two-order range was calculated based on the total thickness of the test interval, which should yield a conservative (small) estimate. It may be guessed that the lowest value (10^{-4}) is the value they determined based on total interval thickness. At any rate, the tracer test procedures and results should have been included so that NRC could independently deduce a porosity estimate. The importance of porosity on travel time is as great as conductivities and therefore the exact value should be known to within a small enough factor to show that the calculated minimum travel time will satisfy 10 CFR 60 and the EPA standard.

1B. Modeling of the Groundwater Flow System

Despite the wide ranges of values for each parameter that have been determined from testing at BWIP thus far and despite the latent uncertainties in each measurement, DOE's modeling efforts have all been deterministic exercises using "best estimates". In many cases even their best estimate appears to yield non-conservative results. In light of the inherent uncertainties which are often characterized as lognormal probability distributions on parameter values, travel times calculated from these distributions can be expected to be lognormally distributed. A lognormal distribution implies a wide (several order of magnitude) range of possibilities with lower travel times being particularly likely. For this reason it is critical that DOE provide the bounds and probability distributions on each parameter.

Not all of the data available was utilized in building conceptual models of the system. Particularly, older head and transmissivity data from DC-1 is abandoned in favor of more recent data which was performed under less reliable conditions (short term tests, insufficient equilibration times, inferior measurement instruments (larger error bounds can be expected from the more recent "drill-stem testing" than for the older piezometer tests)). Data from RRL-2 was leaned on most heavily, as would be expected, since it is closest to the repository location. However, the other two holes used most frequently in their analysis of the conceptual flow model were DC-14 (which gave the most anomalous head measurement in the system) and DC-15. DC-14 and DC-15 are practically the furthest DOE wells from the repository and are located on the river. They represent hydrologic and geochemical conditions that can be expected to be most different from the Cold Creek Syncline (repository) areas.

Modeling efforts in Chapter 12 were, in many cases, non-conservative. Conductivities for the fault scenarios and far field modeling were calculated for composite layers, which bias the vertical conductivities in favor of the lowest conductivities. For the fault scenario, DOE used a 1 meter fault width through the repository to the surface with a porosity = 0.10, and a hydraulic conductivity of 0.6 meters/sec. These assumptions can be considered conservative. However, in modeling this scenario on the computer, DOE calculate the flow using 4000 meter square grid blocks (which include the one meter fault), assigning a composite conductivity to the fault zone of 10^{-4} meters/sec. Thus the presence of the fault is artificially hidden. If they had used a streamtube to represent the fault alone, the hydraulic gradient necessary to duplicate their conclusion of a 12,700 year travel time for the 472 foot path from the Umtanum to the Mabton would be on the order of 10^{-10} instead of the (at least) 10^{-3} gradient present (before emplacement).

Throughout Chapter 12, various Kv/Kh ratios were utilized depending on the model used. The Kv/Kh ratio used to represent dense basalt varied from 10^{-4} in their MAGNUM3D (far-field) model to 10^{-1} in their PORFLO (near-field) model. Since no measurements of vertical conductivity have been made, these values are arbitrary and the results of modeling with these values must be considered preliminary and must be used with caution.

In the MAGNUM3D model (which has been previously critiqued by Lehman and Quinn, 1982) conductivities in the Grande Ronde Basalt were calculated by dividing the DC4 and DC7 pump test transmissivities by the entire test interval. This will yield non-conservative results as mentioned previously.

Also in the MAGNUM 3D model, data from DC-12, DC-14 and DC-15 was used to support the assumption of low vertical gradient. With these (low vertical conductivity and gradient) assumptions, the flow path was determined horizontal to Wallula Gap. They then calculated travel time using a thinner Grande Ronde layer of higher conductivity to "account for the fact that water flow is not through the entire thickness," but they used the horizontal flow path, found with the previous assumptions, as their flow path.

In all of their modeling efforts, porosities of basalt flow contacts were greater than or equal to 0.01. Porosities assigned to the dense interiors were similarly high, with the exception of one model which assigned a porosity of 0.001. As noted earlier, the only value measured was "in a range" of 10^{-2} to 10^{-4}, and was most likely nearer to 10^{-4}. Therefore, the porosities used in modeling are non-conservative. Their results cannot be considered to represent minimum groundwater travel times and might well overestimate the travel time by two orders of magnitude.

The MAGNUM3D model also uses a very high (335 m) head as a boundary condition in the northwest portion of the Pasco Basin. In Chapter 5 (page 5.1-54) it is inferred that this high head west of the repository is due to the presence of a structural barrier across which the head drops almost 80 m. However, in the model there is no barrier placed between the high head boundary and the repository. Therefore, the head is not attenuated and will tend to cause flow to be pushed out the eastern boundary before it gets a chance to travel vertically, since the horizontal gradient is so much greater than the vertical.

In their most recent model, PORFLO, travel times are also calculated using non-conservative parameters. In addition, instead of using maximum values of hydraulic conductivities and gradients, "average" and "most probable" values are used. This will not yield a conservative estimate.

For both PORFLO and MAGNUM 3D, the particle tracking program PATH (and its 3D variation, PATH3D) was used. Most particle tracking programs use a finite difference solution which calculates velocities from grid block to grid block based on the following equation:

$$\bar{V} = \frac{Q}{nA} = \frac{v}{n} = \frac{-K}{n}\frac{\partial h}{\partial l} \qquad (1)$$

where

$\bar{V}$ = average linear velocity in direction l
Q = volumetric flux
n = porosity
A = cross-sectional area
K = hydraulic conductivity
h = head
l = direction
v = Darcy velocity

However, Nelson (1968) and Ellis (1968) show that the physical characteristics of the porous medium (grain size, shape, tortuosity) can increase or decrease the average linear velocity by a factor E:

$$\bar{V} = \frac{v}{En} \qquad (2)$$

where E is generally near or slightly greater than 1.0 for granular media. For fractured media E can be expected to be less than 1, which increases the velocity and decreases travel time.

Since the value of E is not stated anywhere in the report, we can assume that PATH and PATH3D calculate streamlines in the common way, by equation (1), which will be non-conservative for fractured media.

2. Review of Plans

Chapter 13 describes the future plans for site characterization which would most likely impact the conceptualization of groundwater flow. Discussed below are the selected "Work Elements" as defined by DOE for which NRC questions the direction and completeness of the descriptions of DOE's future plans to resolve the issues.

Chapter 13: Work Element S.1.1.A

Their plans for better defining thickness and continuity of candidate repository horizons in the RRL area include the analyses of data from only one new hole (DC-18). There is no mention made of the recent anomalously low thickness measurement made of the Umtanum flow. The validity of their past testing and evaluation methods are questioned in Appendix H of the SCA and in a report by William & Associates that may become an appendix.

Work Element S.1.5.A

Plans for fracture characterization and location of discontinuities and heterogeneities in RRL area are insufficiently detailed. There is no description of how the integrity of core samples is maintained during drilling. Many of the cores to date have been severely disced. Also, discontinuties and heterogeneities cannot be determined from cores unless the holes have been placed to pass directly through a structure of anomalous material, which would be unlikely. Multiple well tests are not planned for this purpose, but would be the most fruitful.

Work Elements S.1.7.A, S.1.8.A, S.1.9.A

DOE intends to characterize the flows above and below the candidate horizons. Only two holes will be drilled deep enough to analyze the strata below. The does not sound sufficient, but perhaps extensive detail is not necessary. At any rate, the methodology for data analysis of the deep hole data is not presented in the SCR. Also, there are no plans presented for collection of head data in the deep strata. This head data could be helpful in understanding the flow regime at the Hanford Site.

Work Element S.1.10.A

To determine the presence and characteristics of possible anomalies that could serve as zones of greater permeability, DOE intends to drill three cores in the RRL, and perform one cluster pump test at DC-16. The pump test cluster holes are only a few meters apart and thus will not provide sufficient information about anomalies unless they are present between the cluster holes.

Work Element S.1.24.C

To determine the hydraulic properties of the groundwater flow system, DOE says it will use both single and multiple borehole testing under both high-and low-induced stresses. However, from the information given, it appears that the multiple well tests involve only the double and cluster wells which are too close together to shed any new information about conductivities, discontinuities and structures. However, there could be some useful porosity data from these tests.

Work Elements S.1.25.C and S.1.27.C

In their plans to determine the hydraulic heads and interaquifer communication in the groundwater flow systems, DOE plans to focus on the RRL area. None of their plans include testing outside the Hanford site except at RSH-1 which is at the southwest side of the site. In particular, no wells are planned on the east side of river above Richland. By focusing their plans on the repository location, they are implicity assuming that the regional- and Basin-scale flow patterns are well known. This is not supportable for the reasons specified in Part 1 of this report.

Work Element S.26.C

Appendix F of the SCA will demonstrate the uncertainty associated with attempts to use hydrochemistry to establish a conceptual flow model at BWIP.

Work Element S.1.28.C

To determine vertical groundwater movement, DOE plans several multiple well tests using the Neuman ratio method. This is certainly a step in the right direction. Details about the tests are necessary to give an informed analysis of the testing plans. Their results will depend on which units are tested and how closely the procedures used follow the assumptions inherent in the ratio method.

Work Element S.1.29.C

Once again, large scale multiple borehole tests are the only way that structure and discontinuities will be found. Single hole and closely spaced dual or cluster wells are not likely to uncover the presence and effects of structure.

Work Elements S.1.30.C, S.1.31.C, and S.1.33.C

DOE proposes to develop a conceptual model of the system by incorporating new data as it is collected. Therefore, the model can only be as good as the data collected.

Work Elements S.1.34.C and S.1.40.D

As evidenced by my report on statistical analysis of generic basalts determining the bounds of uncertainty on travel time and radionuclide transport is critical. Barring this, an absolute, ultra-conservative model of the worst case would be the only acceptable model. It should be required of DOE that they specify error bounds on all measurements, and ranges and distributions of all parameters for use in statistical modeling.

Work Element S.1.34.D

There are no specific plans stated for modeling radionuclide mass fluxes to the environment. Up to this point they have used PORFLO, which is undocumented. The references for PORFLO which are listed are abstracts only.

Chapter 14:

Deals with "credibly disruptive events" which could affect the flow pattern, such as faulting, shaft seal and borehole failure. These subjects are discussed in SCA Appendix D, in preparation.

Chapter 16:

Pulls many of the work elements from chapters 13-15 and puts them under the umbrella of "performance assessment plans." This report has already dealt with the most importance work elements on which groundwater flow conceptualization would be based from these chapters.

Chapter 17:

Describes the same work elements as they will be 'resolved' by the exploratory shaft. The problem is that the very near field conceptualization is no substitute for regional- and basin-scale conceptualization. The SCR seems to indicate that 90% or more of future effort towards groundwater flow data collection and conceptualization will be directed towards the very near field (exploratory shaft).

Summary Review of DOE's Plans in SCR

Insufficient detail has been provided in the SCR to give an intelligent, knowledgeable review of DOE's plans for data gathering and performance assessment of the groundwater flow regime. What information has been presented appears, in some pertinent areas, to be misdirected and may not result in a sufficient characterization of the site hydrology by the time of licensing.

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