PERFORMANCE ASSESSMENT ISSUES CONCERNING THE PARADOX BASIN ENVIRONMENTAL ASSESSMENTS

Benjamin Ross

Second Draft

prepared for:

Utah Office of Planning and Budget
116 State Capitol
Salt Lake City, UT 84114

November 2, 1984

disposal safety incorporated

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1 Introduction

This report describes long-term performance assessment issues which must be resolved before one could have confidence in the safety of a high-level waste repository built in the Paradox Basin. It addresses the case for safety made by the Environmental Assessments and their supporting documents, especially the two Status Reports issued by INTERA Environmental Consultants, Inc. The final draft of the EA's which is to be formally issued for public comment will, we understand, differ significantly in its discussion of performance assessment from the earlier versions now available. But there will be little immediate change in the data base from which the Department of Energy will draw its conclusions, and so a statement of issues as they stand now will be very useful in evaluating the EA's and at later stages of the siting process.

The focus of this discussion is necessarily on omissions, questionable assumptions, and possible errors to be found in the EA's and other Office of Nuclear Waste Isolation reports. This emphasis does not imply a prejudgment of the technical merits of the Paradox Basin sites. On the contrary, it is only through the fullest and most detailed criticism that the merits of a repository site can be determined. Some of the issues raised here will probably be dealt with even before the EA's appear in a final version. Indeed, we discuss some easily corrected problems only briefly because they are so likely to be resolved in the final EA. Other matters will certainly be setttled in the course of site characterization if one of the Paradox Basin sites is nominated for further study. Nonetheless, careful, early attention to potential weaknesses of the proposed sites is essential for the orderly and rational selection of a final repository site.

Because performance assessment, in the broadest sense, involves all evaluations of the effects of a repository on human health and on the environment, there will necessarily be considerable overlap between the matters discussed here and the subjects treated by other reviewers of the Environmental Assessments. The emphasis of this report, however, is on issues which can significantly affect future releases of radionuclides to the environment or which bear directly on compliance with safety criteria promulgated by the Nuclear Regulatory Commission and the Environmental Protection Agency. Special attention is also directed to computer modeling which has been conducted or is planned by ONWI.

The current version of this report is based on Draft 4 of the EA's. Later versions will be revised to reflect the recently released Draft 5.

2 Ground-water flow in the Leadville Limestone

Because existing ground-water heads imply that flow would be downward if the aquifers above and below the repository were connected, the most likely path of radionuclide transport from the repository is through the aquifers below the host salt rock. The most prolific and important of these is the Leadville Limestone. The EA's calculations indicate that ground water moves very slowly in this formation and that travel times are 100,000 years or greater. But the analysis of the Leadville presented by the EA is based on rather optimistic assumptions and does not convincingly establish the long travel times claimed.

Travel times in the Leadville are of extreme importance to repository performance and to compliance with regulatory criteria. The EA asserts that travel times from the repository down to the Leadville would be even longer than those calculated for the Leadville, but the times for vertical flow are difficult to establish and would probably change if the repository were disrupted. Scenarios leading to release of radionuclides from the repository usually involve massive fracturing or salt dissolution, either of which would allow rapid movement of contaminated water from the repository level to the underlying aquifer. Furthermore, uncertainty in definitions (see Section 8) makes it difficult to assess how much of the vertical flow path is within the "disturbed zone," as defined by NRC regulations. No credit can be taken for the time involved in flow downward through salt strata which are within the disturbed zone when determining compliance with NRC standards and DOE siting guidelines for pre-emplacement ground-water travel times. Demonstrations of compliance with ground-water criteria are therefore likely to rely heavily on the travel times in the Leadville Limestone.

The EA's analysis of the Leadville is based on ground-water flow modeling by INTERA Environmental Consultants, Inc. This work is presented by INTERA in the form of two status reports (ONWI-503 and INTERA, 1984) which describe the first phase of an ongoing modeling effort. In general, the INTERA work represents a very creditable first effort. However, it lacks the thoroughness necessary to firmly establish the conclusions asserted by DOE. The principal weakness of INTERA's analysis is its reliance on a computer model which assumes that aquifers have uniform properties within fairly large blocks and neglects the possible existence of small, highly transmissive features through which water moves quickly. Other issues which require attention include the assumption that water in the Leadville has the properties of fresh water when it is actually quite salty, and the treatment of faults as invariably transmissive zones rather than flow barriers, and the lack of attention to hydrochemical data.

2.1 Small permeable features

The INTERA analysis assumes that the Leadville and underlying carbonate formations form a thick homogeneous aquifer with an effective porosity of 10%. This picture is inconsistent with the usual behavior of carbonate aquifers and with the particular stratigraphic relationships of the Paradox Basin. Flow in carbonate aquifers usually proceeds predominantly through fractures and bedding planes, which often are widened by solution of the rock. As a consequence, the effective porosity of such formations tends to be a few percent or less (Freeze and Cherry, p. 156).

Solution channels can provide pathways for extremely rapid ground-water flow in carbonate aquifers. If they are present in the Leadville, ONWI-503's analysis of the formation as a uniform porous medium could greatly overestimate ground-water travel times.

The upper contact of the Leadville Limestone is a former erosion surface, on which Karst topography developed (ONWI-290, vol. 1, p. 4-4). In such terrain, extensive solution channels develop in the limestone, often leading to the formation of large systems of caverns. Merrill and Winar (1958) describe the upper contact of the Leadville where it crops out in the San Juan Mountains of Colorado. By their account, the solution features are generally filled with siltstone or mudstone identical in lithology to the overlying Molas Formation. However, Merrill and Winar do not directly address the hydrogeology of the contact zone, and it may be that some solution channels do remain open for flow.

It is likely that dissolution of the limestone would have occurred preferentially where the rock was weakened by faulting or other tectonically induced fracturing. This could potentially have created long, highly permeable linear features. ONWI-290 and ONWI-485 suggest that the Monument Upwarp was active during the period of erosion of the Leadville. Fracturing associated with this or other structures might have created a linear flow path leading away from the repository site.

In evaluating our present level of knowledge of the basin, the spatial distribution of data must be taken into account. Weir et al. (1983) point out that the petroleum exploration holes which compose the existing data base on subsurface hydraulic properties are all located on the Paradox Basin's anticlinal features. As the faults which control the anticlines were active during the time of Leadville erosion (Hite and Lohman, 1973, p. 13), the faults presumably controlled the topography of the Karst erosion surface. The distribution of solution features would be closely related to ancient topography and structure, and so the existing data base in the basin probably represents an unrepresentative sample of the buried Karst surface. The exposures in the San Juan Mountains would probably not display the same bias, but weathering limits their value in assessing hydraulic properties of the deeply buried portion of the formation.

A detailed study of the hydrogeology of the Leadville-Molas contact zone is badly needed. Relevant evidence might be obtained through a review of drill-stem tests, caliper logs, drilling reports, and other records from petroleum exploration holes. A highly permeable linear feature would probably not be detected by the drill-stem tests which comprise almost all of the existing regional data, but would be more likely to be apparent if large-scale regional pump tests are conducted as part of the repository exploration program. (An exploration program sufficient to explore for such features might, however, require drilling in Canyonlands National Park.) Further study of the exposures of the contact zone is also necessary, but as mentioned above weathering may limit the usefulness of outcrop studies.

Another phenomenon which leads to irregular distribution of permeability in limestone aquifers is the chemical transformation of the limestone to dolomite. The volume shrinkage associated with dolomitization tends to increase permeability.

Zones of dolomitization occur throughout the Leadville Limestone. The stratigraphic and hydraulic significance of this dolomitization are matters of controversy in the literature. ONWI-92 identifies randomly located dolomitized zones as the most permeable parts of the formation. Hanshaw and Hill (1969) state that the Leadville Limestone is less permeable than an underlying Mississippian dolomite, apparently corresponding to the lower portion of the Leadville as described by other authors. Hite and Lohman (1973), on the other hand, quote Baars (1966) to the effect that the upper part of the formation is the more permeable section. We have not yet been able to examine the most detailed report on dolomitization in the Leadville, by Parker and Roberts (1963).

To summarize, there is little basis for any estimate of travel times in the Leadville Limestone without some evaluation of the possible existence of local zones of permeability. Permeable features might be associated with dissolution, with dolomitization, or with the structure of the basin. Existing data are insufficient for a full evaluation of this issue, and additional site exploration activities will be necessary.

2.2 Salinity

A second limitation of the INTERA modeling work is its assumption that the water in the Leadville has the density and viscosity of fresh water. Density differences between brine with 5% to 20% salt content and fresh water could potentially produce major changes in the results of the INTERA analysis. Two different questions must be considered: first, changes in computed flow paths due to the differences in average properties between brine and fresh water and, second, the potential for gravity-driven flows due to variations in salinity. Errors will also be introduced by use of fresh-water viscosity, but they will be smaller than other uncertainties in the system and will change the magnitude but not the direction of flows.

The potentiometric maps developed by Woodward-Clyde (ONWI-290, ONWI-503, and Dunbar and Thackston, 1984) and Hanshaw and Hill (1969) show "fresh water heads." The head gradient on such a map indicates the net force that would be exerted on an element of fresh water by the combination of pressure gradients and gravity. Because brines are denser than fresh water, gravity exerts a stronger force on them, and the net force on brine is directed more toward the down-dip direction than the force on fresh water would be. The approximate magnitude of the correction in the vicinity of GD-1 can be found by a simple calculation. The dip of the upper contact of the Leadville is about 5% (ONWI-485, Figure A-6). Assume that the fluid is 5% heavier than fresh water. The correction to the fresh-water hydraulic gradient will then be about 0.05 x 0.05, or 0.0025. This is of the same order of magnitude as the fresh-water gradient itself in the vicinity of Borehole GD-1 (ONWI-503, Figure 2-29). Flow will therefore be directed significantly further toward the downdip, or northeastward, direction than the fresh-water potentiometric levels would suggest.

An additional complication is introduced by the large variability in salinity, as illustrated in ONWI-503, Figure 2-32. The complex pattern exhibited by this data and the sparsity of its geographic coverage make it of little use in a predictive model.

The above considerations deal with present ground-water flows. Probably of more significance is the flow after a hypothetical release of radioactivity from the repository. Scenarios that would introduce contamination from a repository into the Leadville usually involve mechanisms that would saturate the contaminated water with dissolved salt. Thus the contaminated water would be considerably denser than Leadville formation water, and would have a propensity to flow down-dip independently of the local hydraulic gradient. (A similar mechanism involving a heavier-than-water organic fluid has been observed at the S-Area Landfill in Niagara Falls, New York. While soluble contaminants flow northward through a dolomitic aquifer away from the nearby Niagara River, the immiscible phase moves southward toward the river along the contact between the dolomite and an underlying shale [Guswa and Faust, 1984].)

Salinity effects — at present, and even more so after a future release of radioactivity into the formation — appear in this very approximate analysis to imply that flow in the Leadville is directed more to the northeast than would be indicated by an analysis of fresh-water potentials. Such a flow direction would seem to direct contaminants away from possible discharge areas and perhaps imply greater safety. Such may well turn out to be the case, but a more detailed evaluation of salinity effects is required before any definite conclusions at all about flow in the Leadville can be drawn from modeling results.

2.3 Role of fault zones

In general, fault zones which intersect aquifers may act either as conduits for more rapid flow or as barriers to ground-water flow. The INTERA modeling work treats them as either enhancing permeability or having no effect. Hanshaw and Hill (1969) suggest that a buried fault zone corresponding to the Monument Upwarp acts as a ground-water barrier. This interpretation is offered as an explanation of the relatively low salinity of the waters to the west of that feature. It is not clear whether incorporating flow barriers into the INTERA model would increase or decrease flow times, but the possible existence of flow barriers must be addressed in any complete analysis of the basin.

2.4 Hydrochemical evidence

The interpretations of the flow system offered by both INTERA and Dunbar and Thackston (1984) make almost no use of hydrochemical evidence to elucidate flow paths (either for the Leadville Limestone or for shallower aquifers). McCulley et al. (1984) do discuss the implications of the hydrochemistry for the flow regime, but their discussion is based entirely on data from the one borehole GD-1, and few definite conclusions are reached. In a system with the structural and lithological complexity of the Paradox Basin, hydrochemistry would normally be a primary tool in understanding the flow system. The interpretation by Hanshaw and Hill cited in the previous paragraph is a good example of such use of chemical evidence.

Perhaps there is insufficient data to interpret the spatial distribution of any chemical parameter other than TDS. If this is the case, it indicates a major gap in the Paradox Basin data base, but even so the ONWI hydraulic interpretations make little use of either the available salinity data or the chemical evidence from GD-1.

3 Waste package release rates

NRC regulations (10 CFR 60.113) require that "The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

The EA (in Section 6.4.2.1) calculates the rate of radionuclide release from the waste package by assuming all the brine in contact with the waste immediately forms a saturated solution of all radioelements. The dissolution rate is then equal to the product of the solubility and the rate at which additional brine migrates to the package surface. For most radionuclides, the dissolution rates calculated in this way easily satisfy the NRC standard. However, violations occur, the least tractable of them for the long-lived nuclides iodine-129 and cesium-135. If water contacts the waste at 300 years after burial, these nuclides violate the one-part-in-100,000 standard by factors of 22,000 and 3,700, respectively, and the alternate standard by factors of 420 and 740 (p. 6-279). A 1,000-year canister lifetime would reduce brine inflow (using the more conservative of the curves on p. 6-262, as the EA apparently does) and therefore radionuclide release by less than an order of magnitude. At 10,000 years, brine inflow is apparently negligible.

The EA addresses this problem (p. 6-280) by arguing that radionuclides will dissolve no faster than the overall leaching rate of the waste form. A leach rate of 0.007 per year would enable cesium-135 and iodine-129 to meet the alternative release standard. "Clearly [!]," the EA concludes, "in the future when site-specific solubility data and leach rates become available for more exact calculations, the results will be lower than the bounding estimates made here and the 10 CFR 60 release rate criteria will be met easily."

There are several weaknesses in this line of reasoning. First of all, it assumes that no significant amount of liquid brine will be present at the time of canister failure. This condition follows from the assumption made in the canister corrosion analysis that the rate of uniform corrosion is limited by the water supply and local corrosion mechanisms are unimportant. It is entirely possible that the canister will be largely immune to uniform corrosion and will fail by stress crack corrosion or some other localized mechanism. If that were the case, brine would accumulate around the canister and come in contact with the waste at the time of failure.

Several mechanisms can be imagined which would prevent uniform corrosion. One is passivation, or the formation of protective metal oxide layers on the canister surface. Another is the precipitation of an insoluble scale over the canister. In the corrosion experiments described by McElroy and Powell (1984), the brine derived by dissolving Permian Basin salts formed precipitate on heating to 150 degrees C. It had to be replaced with another formulation in order to keep feedlines from plugging. It is easy to imagine that protective scales might be deposited on a metal canister by such a brine. Canisters could still fail by local corrosion mechanisms with very little water consumption.

Second, no reason is given by the EA to think that spent fuel will have an overall leach rate of 0.007 per year, and even if it were that small, the overall leach rate would probably not constrain the release of cesium or iodine. A considerable portion of the cesium formed in a nuclear reactor migrates out of the fuel pellets while the reactor is operating. As a result, its dissolution proceeds independently of the fuel pellets. KBS (1983, p. 11:2) reports that in experiments "in the case of undamaged fuel from normal operations, one or several per cent of the entire cesium inventory in the fuel can have leached out in a few weeks."

One remaining problem is the short-lived radionuclide cesium-137. With a 300-year canister, releases of this nuclide are calculated to exceed the NRC standard by a factor of 170,000. Two approaches are suggested that might overcome this difficulty. First, with a canister lifetime of 820 years, radioactive decay would diminish the inventory sufficiently to meet the standard. Second, if an "interim performance standard" allowing release of one part in 10,000 of the total inventory is applied, only a 350-year canister is needed.

However, the "interim performance specification" was promulgated by ONWI on its own and has not been approved by NRC. The document in which the specification is formulated (ONWI-462) clearly states that interim specifications were developed "because the technical criteria of the regulatory agencies have not been established" and indicates that they will be superseded by NRC regulations. The argument (presented in ONWI-286) upon which the ONWI specification is based, that repository sites are so good at containing high-level waste that high-performance waste packages are unnecessary, was rejected by NRC when it formulated 10 CFR 60. Instead, NRC adopted a "multiple barrier" approach aimed at securing redundancy in the isolation system. The NRC regulations, which are far more stringent than the ONWI specification for waste form releasees, are now in effect.

A discussion earlier in the EA (p. 6-189) suggests that the "interim performance specification" is a design goal for developers of waste forms rather than an alternate performance standard. If spent fuel is to be packaged to meet such a goal, it would presumably have to be embedded in a leach resistant matrix. The EA should then have assessed the leaching of the resulting aggregate. On pp. 5-35 and 6-255, only brief mention of fuel consolidation is made, and use of a leach-resistant matrix is not suggested.

These considerations suggest that the release rate standard of one part in 100,000 of each nuclide will be met only if the canister remains intact until brine inflow to the repository has ceased and all brine has been consumed by chemical reactions. At such a point, it is hard to see how corrosion could continue with any rapidity, and canister lifetime should be effectively unlimited.

Such an argument, if it could be firmly established, would raise an interesting question of regulatory policy. The current NRC regulations, which require waste form and canister to act as separate barriers, rest on the implicit assumption that neither can be engineered with absolute assurance. If it could be shown convincingly that a "perfect canister" has been developed, the need for multiple engineered barriers would presumably disappear. But for DOE to claim that it meets the release rate standard with an infinite-life canister would be contrary to the spirit of the present standards. DOE might seek an alternative numerical limit as permitted by the rule. If this is DOE's intention, it probably ought to be stated in the EA.

The above arguments are not specific to the Paradox Basin, and so they indicate that the existing NRC standard will be very hard to meet at any salt repository, or indeed any repository at all, with spent fuel as the waste form. This should not be surprising, as NRC seems to have had glass in mind when it wrote the regulation. In the manufacture of glass waste forms, the wastes are mixed uniformly into the glass matrix, and so an assumption that all nuclides will be released at the same rate is more easily satisfied. It would be no surprise if the likely use of spent fuel waste forms led NRC to change the regulation, or at least to be lenient in granting exceptions.

4 Localized canister corrosion

NRC regulations require that contact between the waste and ground water be prevented for at least 300 years. The EA proposes to accomplish this by surrounding the waste with a wrought steel canister about 12 cm (5 inches) thick. The performance of this canister is analyzed with uniform (general) corrosion treated as the primary failure mechanism. The EA derives corrosion rates from laboratory tests and extrapolates them to differing temperatures, radiation dose rates, and time scales. Failure is expected when the canister is too thin to withstand the imposed mechanical stresses.

The EA (in Section 6.4.2.1.3; a summary of this work has been published by Jansen et al., 1984) analyzes two different cases of corrosion failure, involving different package environments. In the first case, the fluid contacting the package originates from migration of brine inclusions in the salt bed under the influence of the thermal gradient. This brine is limited in quantity, but has a high magnesium content. The high-magnesium brine corrodes the steel relatively rapidly; if an unlimited quantity of this fluid were available, a spent fuel package would fail in a time calculated at 210 years and would not satisfy the NRC requirement. However, the limited amount of water in contact with the metal is consumed by the corrosion reaction before the package fails, and so the canister lifetime is infinite.

The second package environment is the consequence of a postulated flooding of the repository. In this case, the brine has a low magnesium content but is available in unlimited quantity. The extrapolated corrosion rate in low-magnesium brine is much slower and determines the time to failure, which exceeds 10,000 years.

There are considerable gaps in the arguments presented for both of these scenarios. The most important of these concern the assumption of uniform corrosion. There are numerous other corrosion mechanisms. The EA's rationales for not considering them (outside of a brief discussion of pitting) are some limited testing reported by Westerman et al. (1984) and McElroy and Powell (1984) and an assertion that, due to the use of a crushed salt backfill around the canister, the metal will be uniformly wetted.

Neither of these arguments for uniform corrosion is conclusive. First of all, the tests for stress corrosion cracking were not at all conclusive. McElroy and Powell, in particular, report that tests designed to give a qualitative indication of susceptibility to stress corrosion cracking were positive and rule out an alternative interpretation advanced by Westerman et al. to explain the results of similar tests. Furthermore, the tests used only low-magnesium brine; magnesium generally promotes this failure mechanism (Dayal et al., 1982). An additional consideration is that stress corrosion cracking causes sudden catastrophic failures and may not be evident in short-term tests.

The EA's statement that stress corrosion cracking has "not been observed to date... in the corrosion experiments" is misleading. According to McElroy and Powell, in the type of experiment that has been conducted one would not necessarily expect to actually observe the phenomenon; rather the aim is to provide an indirect indication of the material's susceptibility to it. Soo (1984) reviewed the issue for NRC and concluded that "it is clear that there is great uncertainty regarding the susceptibility of carbon steel containers to SCC when exposed to HLW repository conditions." Soo's review was completed prior to the most recent tests reported by Westerman (1984), but these tests fall very far short of the testing program Soo recommends.

Marsh et al. (1983) describe measurements made in Great Britain of propagation of cracks by stress corrosion cracking in canister materials. No such tests are reported by any of the ONWI documents; the British tests were carried out on alloys different from those ONWI intends to use and in a less aggressive environment. Marsh et al. conclude that one must search for an alloy that is immune to cracking under repository conditions, but in that search "the main problem area is likely to be the hard metallurgical structures produced in the locality of sealing welds." Neither the EA nor its references even mentions this issue.

Uniform wetting also has yet to be demonstrated. In the period soon after the repository is closed, the void spaces around the canisters will gradually fill with water. Wetting will certainly be non-uniform during this period. Localized boiling might occur next to a canister, leading to concentration of otherwise low-concentration ions which could promote stress corrosion cracking. Corrosion sites developed during this period might remain significant as centers of local corrosion even if the wetting later became uniform.

Furthermore, the uniform corrosion model asserts that all the brine will be consumed by the corrosion reaction. If this were to be the case, the emplacement hole might not be fully saturated with water. The canister would then be wetted wherever migrating brine droplets encountered it. The distribution of arriving brine droplets will likely reflect various mechanical and lithologic inhomogeneities in the salt (not to mention corrosion products which may spall off the canister) and thus be quite non-uniform.

The summary of the EA corrosion calculations published by the ONWI staff (Jansen et al., 1984) largely concedes these points. It concludes that:

> the low Mg dissolution brines used in intrusion scenarios are not expected to cause the waste package to fail unless pitting and stress corrosion cracking cause much greater penetration of the overpack than uniform corrosion.
>
> In the bedded salt formations, with high Mg thermally-migrating brines it is necessary to take credit for the ability of the overpack to react with and use up the water in the brine to prevent package failure within 1,000 years after burial. If the brine is uniformly distributed over the package surface, the brine will be used up before corrosion proceeds to package failure. However, more detailed modeling of the emplacement procedure and early package history will be necessary to determine whether the brine will actually be evenly distributed.

Another issue not addressed by the EA is the possible role of radiolysis of salt. One aspect of this issue is production of oxidants. The calculations by Levy and Kierstead (1984) seem to suggest that as long as shielding provided by a 12-cm canister is present, the amount of free chlorine generated by radiolysis would be small compared to the water introduced by brine migration. Another point is that any contact betwen the colloidal sodium metal inclusions formed in the salt by radiolysis and migrating brines would be expected to yield sodium hydroxide. This compound is another promoter of stress corrosion cracking (Soo, 1984) which has not been addressed in the testing program.

5 Magnesium and corrosion

As mentioned above, magnesium promotes corrosion. The one water sample taken from the Honaker Trail Formation, the nearest aquifer overlying the repository, in GD-1 had over 2,000 mg/l of magnesium (McCulley et al., 1984, Table 3-1), The numerous dolomite inclusions noted by McCulley et al. in the Paradox salt beds would probably be a major component of the rubble that would occupy any dissolution cavity, and through which any water entering the repository would most likely flow. This dolomite (chemically a magnesium calcium carbonate) could further add to the magnesium content of waters entering a flooded repository. The Paradox Formation also frequently contains the magnesium-bearing salt carnallite.

The EA asserts, however, that waters entering the repository after a hydraulic connection is somehow established with an adjacent aquifer would have a low magnesium content, on the order of 130 mg/l (Table 6.4.3.1-3 and p. 6-260). This is the magnesium content of the water that has been used in the only actual laboratory tests on the proposed canister material (Westerman et al., 1984). Consequently, the EA lacks experimental evidence bearing directly on package lifetime in the event the repository is flooded.

6 Migration in the Paradox Formation

The EA devotes much effort (pp. 6-293 through 6-302) to a discussion of transport of radionuclides in intact salt. This discussion has little point and could be quite misleading. It is generally conceded that if the salt is homogeneous and remains intact, a repository in bedded salt will not release any radioactivity. The issue is the initial uniformity and long-term stability of the salt, and the consequences of potential instability. One should not belabor the lack of significant water flow in intact salt beds and describe the result as an analysis of host rock performance.

The calculations of diffusional transport presented in the EA are based (McNulty et al., 1984) on an empirical diffusion constant obtained by fitting to the observed water content in salt surrounding a brine pocket in the Weeks Island salt dome. As the physical processes which put the water in the Weeks Island salt are unknown, there is no clear rationale for fitting the data to a diffusion equation. McNulty et al. refer to the classic work of Robertson (1974) on solute transport in ground water as justification, but the analogy is inappropriate. Robertson was dealing with a known physical phenomenon which there was a good experimental and theoretical basis for expecting to be governed by a diffusion-type equation. At Weeks Island, the physics of the situation appear to be unknown.

The analysis of ground-water flow times through interbeds in the salt on p. 6-113 of the EA is similarly dubious. The highly variable pressure conditions encountered in these beds by petroleum exploration holes strongly indicate that they are not hydraulically connected with the regional ground-water system. The calculation of extremely long travel times further indicates that the interbeds are not realistic migration pathways. Nevertheless, this calculation is relied upon (p. 6-115) in finding a favorable condition for long ground-water travel time.

7 Permeability of the Pinkerton Trail Formation

The Pinkerton Trail Formation lies directly under the Paradox Formation salt beds. Its transmissivity is important for two reasons. First, many scenarios for salt dissolution are more likely if a transmissive bed directly underlies the salt. This bed may serve as a source of water to dissolve the salt, a sink for the brines produced by dissolution, or both. Second, if the Pinkerton Trail is an aquifer, contaminated brines can pass directly from a dissolution cavity to an aquifer and will not be delayed in passing through intervening low-permeability beds.

In its hydrogeology section, the EA states that "the Pinkerton Trail Formation is composed of strata that have very low matrix permeability... and is probably an aquitard in the candidate area, except where it is fractured" (p. 3-110). This statement largely begs the question of the Pinkerton Trail's permeability. Nevertheless, ONWI-503 considered the Pinkerton Trail "to provide only a limited avenue for ground-water flow" and assigned it a horizontal hydraulic conductivity two orders of magnitude smaller than the regional aquifers.

The basis for this treatment of the Pinkerton Trail is unclear. The approach taken in the EA is to assume that formation properties measured in hydraulic tests at Borehole GD-1 apply at the candidate areas also (p. 6-112). However, the Pinkerton Trail at GD-1 was not tested "because of unstable conditions in the borehole" (ONWI-290, vol. 2, p. 9-13). Very possibly, these unstable conditions reflect fracturing, which would suggest that the rock does have a significant permeability. This conclusion is supported by the experience in Borehole ER-1. In that well, "substantial zones of lost circulation were encountered in the Pinkerton Trail Formation, precluding further drilling. All attempts to stop this lost circulation, using material that would not irreversibly plug the formation, were unsuccessful" (ONWI-491, p. 22). This experience obviously indicates that the Pinkerton Trail has a very substantial transmissivity at the ER-1 location.

Other writers on the Paradox Basin regard the Pinkerton Trail as an aquifer. The "Pinkerton Trail Aquifer" is one of the four major regional aquifers discussed by Hanshaw and Hill (1969) in their detailed survey paper. The modeling study for ONWI by Dunbar and Thackston also treated the Pinkerton Trail as a separate aquifer. Dunbar and Thackston give this layer a horizontal hydraulic conductivity about 300 times larger than ONWI-503. The strongest dissent from this description of the formation to be found in the literature is by Weir et al. (1983); however Weir et al. cite no evidence for their interpretation.

According to Hite and Lohman (1973), the Pinkerton Trail is relatively impervious over most of the basin, but thickens and becomes predominantly limestone near the southwest shelf of the basin. This is consistent with the experience in ER-1, which is close to the southwestern boundary of the basin. Because the Davis and Lavendar Canyon sites are well to the southwest of GD-1, extrapolation of GD-1 measurements to the repository sites would be called into question by Hite and Lohman's interpretation of the variability of the Pinkerton Trail.

8 Definitions

NRC standards involve ground-water travel times from the boundary of the "disturbed zone" to the "accessible environment." EPA requirements take effect at the accessible environment. The interpretation of these terms obviously can strongly influence the results of performance assessments. The disturbed zone, in particular, has a high potential to arouse controversy in view of the vagueness of the NRC definition.

The EA assumes that the disturbed zone around the repository will extend only 10 meters from the repository. This is based on a somewhat optimistic (from DOE's point of view) interpretation of the NRC definition. The ultimate definition will probably be clarified only by NRC rulemaking or in licensing hearings; at this early stage alternative interpretations are possible. To be safe, the consequences of a less optimistic definition should be evaluated in the siting process.

Furthermore, the method of calculating the disturbed zone presented on p. 6-291 is misleading even if a narrow definition is used. Here, the disturbed zone is taken to be equal to the distance water will travel from the repository under the influence of the thermal gradient. As defined by NRC, however, the concept of disturbed zone encompasses the entire region in which the thermal gradient has a significant effect; its size is independent of ground-water travel distances.

The EA calculates ground-water travel times to discharge points at the Colorado River. As these points are more than 10 kilometers from the repository, the accessible environment will be encountered under EPA's and NRC's definitions well before the discharge point.

These definitions could be discussed in considerably more detail, but a highly detailed analysis of this point would probably be of little value, because the final EA is likely to change greatly from Draft 4 in this regard.

9 Capabilities of ground-water models

The work reported in ONWI-503 and INTERA (1984) approaches the limits of the state of the art in ground-water flow modeling. The reports do not discuss the impact of numerical constraints, but the large grids and sharp contrasts in transmissivity between adjoining layers are likely to constrain the modeling effort. In particular, it appears that the model parameters may be such as to require the use of direct solution methods. In that case, the nine-layer model used by INTERA with approximately 2000 grid blocks would approach the capacity limits of many computer memories.

A more refined analysis of the structural features of the basin would require many more grid blocks, especially with a finite-difference model like SWENT. Solute transport or thermal modeling would place additional requirements on mesh spacing, in addition to greatly complicating calculations and imposing new numerical restrictions. For example, in a solute transport model one could not approximate the effects of a narrow Lockhart Fault by increasing the average hydraulic conductivity of a grid block nearly one kilometer wide. These problems could, at least to a degree, be overcome by using supercomputers, which are available to ONWI through the National Laboratories. But even if computations are within the theoretical capacity of available computers, cost and other practical considerations can limit what is done.

Furthermore, there is no complete mathematical theory which can predict the numerical accuracy of models as complex as SWENT. It is usual to verify accuracy by repeating a few runs with a finer mesh. That this was not done by INTERA is unsurprising when one considers that the "coarse" mesh already had up to 2000 grid blocks. But the problem will have to be faced with future simulations used in licensing proceedings.

The ONWI Performance Assessment Plan (BMI/ONWI-545) does not address these issues. The computer programs listed in this document (p. 128) as candidates for use by ONWI all suffer from limitations similar to those of SWENT. The current plans could leave ONWI without a method of reliably calculating ground-water flow and radionuclide transport around a proposed Paradox Basin repository.

10 Completeness of scenarios discussed

The discussion of potential disruptive events and processes (Section 6.4.2.6, apparently mistitled) addresses disruptions from three causes: human interference, climatic changes, and tectonic processes. These are certainly not the only, and probably not even the most important, causes of potential repository disruption at a salt repository site.

The most threatening scenarios at a salt site tend to involve either unanticipated processes connected with repository development, or features which provide flow pathways and are not detected in the repository exploration program. As an instance of the former, consider the possibility that repository heating could initiate a process of dissolution at the base of the salt beds that would propagate upward as a new breccia pipe. An example of an undetected feature might be a breccia pipe which does not reach the surface and is missed by seismic profiling. Both of these examples are quite speculative, but they suggest the type of issues that DOE should address. Another type of feature DOE should consider is an existing poorly sealed well. This is not at all speculative; Huntoon (1979) reports that water flows from an abandoned, poorly sealed drillhole near Taylor Canyon.

Undetected dissolution features are extremely important scenarios for salt repositories; they may even be the decisive ones in safety analysis. The EA addresses dissolution features only in Section 6.3.1.6. This discussion simply concludes that no evidence of dissolution has been detected. It does not address the likelihood that a small undetected feature does exist. Neither are the consequences of such a feature's existence evaluated anywhere in the performance assessment. The EA's neglect of possible undetected, but already existing, flaws is a major gap in its evaluation of the performance of the Paradox Basin sites.

11 Choice of scenarios for consequence analysis

Drawing on previous work (most notably the WIPP Safety Analysis Report), the EA (p. 6-308) argues that potential human interferences can be reduced to three main release pathways: solution mining, intrusion by a single borehole, and a U-tube connection of the repository with an overlying aquifer. This is an appropriate and useful way of approaching the problem of disruption scenarios in general. Disruption scenarios in a salt repository usually can be reduced to a simple network of flow pathways. The same flow network (for example, a single through-going conduit from an overlying to an underlying aquifer) can come about from many causes. The consequences usually depend only on the geometry, size, and permeability of the conduit; so only a single consequence analysis, in which the parameters describing the conduit may have to varied, is needed. For example, one analysis can serve for all single-conduit scenarios regardless of the cause of the conduit.

This type of analysis requires that the scenario which is used as the representative of a class of disruptions typify its class. Most commonly, the worst scenario in a class is analyzed, so that the calculated consequences can be regarded as an upper limit regardless of the cause. Such is not the case for the EA's single-borehole scenarios.

To be specific, two different single-borehole scenarios are analyzed in the EA. In the first, a flow conduit from overlying to underlying aquifers is created. In the second, a newly drilled borehole releases pressurized, contaminated brine.

The weakness in the through-going borehole scenario is the assumption that the conduit is a borehole. A borehole, with its very small diameter, is by no means the largest disruption that could be imagined. (True, the EA analyzes this scenario in a section devoted to human intrusion, but human intrusion is the only disruption whose consequences are calculated, and so this scenario must be regarded as a representative of a much larger category of disruptive events and processes. Because of the small diameter of a borehole (apparently — the description of the calculations in the EA is very sketchy), even if the borehole is infinitely permeable, the transmissivity of the adjoining aquifers sharply limits the amount of water that can pass through it. As a result, only a limited amount of water is transmitted through the repository, and the conduit is closed by salt flowage in fairly rapid order. This scenario might proceed quite differently if the conduit had a larger diameter and were filled with insoluble rubble.

There are limitations also to the scenario involving release of pressurized water. It is assumed that steam provides the pressure needed to drive water up the borehole. The EA shows that repository temperatures decline quickly enough that this particular version of the scenario is of very little concern. But there are at least two other processes that might generate significant pressures in brine pockets: transfer of lithostatic loads to the brine by salt flow, and radiolysis of water to form hydrogen and oxygen. The first of these processes is the generally accepted explanation for the pockets of naturally pressurized brine often encountered in salt formations (Baar, 1977). The second must also be a concern, as indicated by the findings of McElroy and Powell (1984) that radiolysis will produce an equilibrium gas pressure of 50 to 100 atmospheres.

Because the specific parameter values used to describe these scenarios are chosen on the assumption that the flow pathway is created by human intrusion, the consequence analyses do not bound the effects of similar scenarios arising from other causes. A full analysis of the consequences of repository disruption should also address scenarios arising from pre-existing flaws, effects of repository construction and operation, and future natural events and processes.

12 Detailed Comments

Environmental Assessment

P. 6-98 - No explicit discussion is presented of the second part of the qualifying condition, which requires that the geohydrologic system permit compliance with NRC waste package standards. While the discussion of the waste package in Section 6.4.2.1 asserts that the waste package can meet requirements, it does not so demonstrate, and it particularly fails to analyze package performance under the specific conditions of the Paradox Basin. See Sections 3, 4, and especially 5 of this report.

P. 6-120 - Some of the structural features in the geologic setting clearly make a major contribution to the difficulty of modeling the geohydrologic system. In the modeling studies by INTERA (ONWI-503) and Dunbar and Thackston (1984), most of the effort is devoted to understanding the hydraulic significance of faults, intrusive bodies, and other structural features. One cannot address the potentially adverse condition (3) without discussing these features.

P. 6-130 - There is a reference here to the salt at the repository site likely having lower levels of potash minerals than at GD-1. We did not notice any reference to potash minerals in McCulley et al. If there were potash present, it is hard to see how one could be confident that it would be less abundant at the repository site.

P. 6-260 - Permian Basin No. 2 brine is a low-magnesium brine, not high-magnesium as stated here. McElroy and Powell do not report any new tests of their own with high-magnesium brines, but they do summarize some previously published work. They comment that corrosion rates in the high-magnesium brine, as measured at 250 degrees C, "are plainly not tolerable in the current design concept... "

P. 6-265 - Contrary to the impression which the reader is given, the "reference" corrosion rates for high-magnesium brines are not obtained from either of the references and seem to be guesses. The corresponding Figure 6.4.2.1-12 appears not to represent experimental work either.

P. 6-270 - If pitting corrosion is possible, the effects of assuming a local penetration ratio should be shown for all cases and not only for those in which the results are favorable.

P. 6-314 - It is hard to see how the flow of ground-water through a borehole would rapidly become saturated if the flow were being replenished from a relatively low-salinity aquifer.

P. 6-315 - The reference given for the pressure release scenario (Lanner, 1983) is not on the reference list.

P. 6-316 - Section 6.4.2.1.3 does not, as asserted here, show that corrosion will consume most of the brine near a waste canister. What that section does is assume so in order to be conservative in its analysis of corrosion. The conservative assumption about corrosion is just the opposite when used to assess waste form leading. Protective scale or passivation might inhibit general corrosion and preserve the brine around a canister. (See Section 3 above.) The canister could nevertheless fail by a localized mechanism. Contaminated brine would then be available.

P. 6-321 - The assumption of no buoyancy effects in the U-tube interconnection scenario is highly non-conservative.

P. 6-326 - It is not at all clear that Shay Graben is downgradient from the site, especially if one uses salt-water rather than fresh-water heads. (See Section 2.2 of this report.) Even if all faults that interconnect aquifers were downgradient and subparallel to the regional flow direction, it does not automatically follow that they would have minimal effects on flow.

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Pp. 80-82 - The modeling assumes away any possible interconnection in Lockhart Basin. The Lockhart Fault is given a width of only 1.5 mm, effectively defining it into insignificance, and Lockhart Basin was not among the structural features examined in the sensitivity analysis.

P. 84 - Boundaries which are believed to lie along flow lines are treated as no-flow boundaries. This introduces a potential for error. Ideally, one should treat these boundaries as prescribed-head boundaries and one of the goals of the calibration process should be to make flow lines lie along them. This would probably be a difficult approach to carry out in practice, but some effort should be made at the end of the modeling exercise to verify that the results are consistent with the original assumptions concerning flow lines. Also, it is unusual to have two flow lines intersecting at right angles.

P. 109 - The recharge rate derived from the modeling is one-tenth that estimated by Weir et al. (1983). This discrepancy is at least worthy of discussion.

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P. 47 - High permeability in the Paradox Formation is found here to imply a lateral efflux at the northeast boundary of the model through the Leadville Limestone. Because the Leadville potentiometric surface indicates influx from the northeast, the conclusion is drawn that relatively high permeability in the Paradox is inconsistent with the potentiometric data. However, it is not clear whether flow at the northeast boundary is still found to be inward if salinity is taken into account in interpreting the data. (See Section 2.2 above.) Conclusions of the type presented here cannot be reliably drawn from fresh-water models.

13 References

ONWI reports:

ONWI-92: Woodward-Clyde Consultants, "Overview of the regional geology of the Paradox Basin study region," March 1983.

ONWI-286: H.C. Burkholder, "Engineered components for high-level radioactive waste isolation systems - are they technically justified?", 1982.

ONWI-290: Woodward-Clyde Consultants, "Geological characterization report for the Paradox Basin study region Utah study areas," January 1982.

ONWI-462: "Conceptual waste package interim performance specifications for waste forms for geologic isolation in salt repositories," June 1983.

ONWI-485: J. McCleary, T. Rogers, and R. Ely, "Stratigraphy, structure, and lithofacies relationships of Devonian through Permian sedimentary rocks: Paradox Basin and adjacent areas - southeastern Utah," August 1983.

ONWI-491: J.W. Thackston, L.M.Preslo, D.E. Hoexter, and N. Donnelly, "Results of hydraulic tests at Gibson Dome No. 1, Elk Ridge No. 1, and E.J. Kubat boreholes, Paradox Basin, Utah," March 1984.

ONWI-503: INTERA Environmental Consultants, "First status report on regional ground-water flow modeling for the Paradox Basin, Utah," May 1984.

BMI/ONWI-545: Office of Nuclear Waste Isolation, "Performance assessment plans and methods for the salt repository project," August 1984.

Other references:

C.A. Baar, Applied Salt-Rock Mechanics, Elsevier Scientific, Amsterdam, 1977.

D.L. Baars, ""Pre-Pennsylvanian paleotectonics - Key to basin evolution and petroleum occurrences in Paradox Basin, Utah and Colorado," American Association of Petroleum Geologists Bulletin, vol. 50, pp. 2082-2111 (1966).

R. Dayal, B.S. Lee, R.J. Wilke, K.J. Swyler, P. Soo, T.M. Ahn, N.S. McIntyre, and E. Veakis, "Nuclear waste management technical suppport in the development of nuclear waste form criteria for the NRC, volume 1, waste package overview," U.S. Nuclear Regulatory Commission Report NUREG/CR-2333, February 1982.

D.B. Dunbar and J.W. Thackston, "Status report: numerical modeling of ground-water flow in the Paleozoic formations, western Paradox Basin, Utah," to be published as ONWI report.

R.A. Freeze and J.A. Cherry, Groundwater, Prentice-Hall, Englewood Cliffs, NJ, 1979.

J. Guswa and C.R. Faust, "Evaluation of immiscible contaminant migration at S-Area Landfill, Niagara Falls, New York," presented to American Geophysical Union, Cincinnati, May 1984.

B.B. Hanshaw and G.A. Hill, "Geochemistry and hydrodynamics of the Paradox Basin region, Utah, Colorado, and New Mexico," Chemical Geology, vol. 4, pp. 263-294, 1969.

R.J. Hite and S.W. Lohman, "Geologic appraisal of Paradox Basin salt deposits for waste emplacement," U.S. Geological Survey Open-File Report 73-114, 1973.

P.W. Huntoon, "The occurrence of ground water in the Canyonlands area of Utah, with emphasis on water in the Permian section," in Permianland, 9th Field Conference Guidebook, Four Corners Geological Society, 1979.

G. Jansen, Jr., G.E. Raines, and J.F. Kircher, "Performance analysis of conceptual waste package designs in salt repositories," in G.L. McVay, ed., Scientific Basis for Nuclear Waste Management, vol. 7, pp. 445-454, 1984.

INTERA, "Second status report on regional ground-water flow modeling for the Paradox Basin, Utah," to be published as ONWI report, 1984.

KBS, Final storage of spent nuclear fuel - KBS 3, Kaernbraenslesaekerhet, Stockholm, 1983.

P.W. Levy and J.A. Kierstead, "Very rough preliminary estimate of the colloidal sodium induced in rock salt by radioactive waste canister radiation," in G.L. McVay, ed., Scientific Basis for Nuclear Waste Management, vol. 7, pp. 727-734, 1984.

C.P. Marsh, I.W. Bland, J.A. Desport, C. Naish, C. Westcott, and K.J. Taylor, "Corrosion assessment of metal overpacks for radioactive waste disposal," European Applied Research Reports - Nuclear Science and Technology, vol. 5, pp. 223-252 (1983).

B.L. McCulley, J.W. Thackston, and L.M. Preslo, "Status report: geochemical interactions between ground water and Paleozoic strata, Gibson Dome area, southeastern Utah," to be published as ONWI report.

J.L. McElroy and J.A. Powell, "Nuclear waste management semiannual progress report April 1983 through September 1983," Pacific Northwest Laboratory Report PNL-4250-4, January 1984.

E.G. McNulty, S.G. Bloom, G.E. Raines, and K. Vafai, "Diffusional radionuclide transport," in "Expected nuclear waste repository near-field performance at potential salt sites," to be published as ONWI report, August 1984.

W.M. Merrill and R.M. Winar, "Molas and associated formations in San Juan Basin-Needle Mountains area, southwestern Colorado," American Association of Petroleum Geologists Bulletin, vol. 42, pp. 2107-2132 (1958).

J.W. Parker and J.W. Roberts, "Devonian and Mississippian stratigraphy of the central part of Colorado Plateau," Four Corners Geol. Soc. Guidebook, Symposium -- Shelf Carbonates of the Paradox Basin, pp. 31-60, 1963.

J.B. Robertson, "Digital modeling of radioactive and chemical waste transport in the Snake River Plateau Aquifer at the National Reactor Testing Station, Idaho," U.S. Geological Survey Report IDO-22054, 1974.

P. Soo, ed., "Review of DOE waste package program," U.S. Nuclear Regulatory Commission Report NUREG/CR-2482, vol. 5, August 1984.

R.E. Westerman, J.L. Nelson, S.G. Pitman, W.L. Kuhn, S.J. Basham, and D.P. Moak, "Evaluation of iron-base materials for waste package containers in a salt repository," in G.L. McVay, ed., <u>Scientific Basis for Nuclear Waste Management</u>, vol. 7, pp. 427-436, 1984.

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