UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

July 24, 1998

Mr. Lake H. Barrett
Acting Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
RW-1
Washington, DC 20585

Dear Mr. Barrett:

We have completed our review of material (11 reports) first submitted in summary form to the Nuclear Waste Technical Review Board (Board) by Mr. Jerry Szymanski at its January 1997 meeting in Pahrump. The Board also has reviewed additional reports provided by Mr. Harry Swainston of the Nevada Attorney General's office on possible future upwelling of water into the proposed nuclear waste repository at Yucca Mountain.[*]

As you know, this is not the first time that Mr. Szymanski has raised these questions. His ideas were thoroughly reviewed by outside experts, including a panel appointed by the National Research Council of the National Academy of Sciences (NAS). This prestigious and broadly based review was published in 1992 by the National Academy Press in a report titled *Ground Water at Yucca Mountain—How High Can It Rise?* As stated in the Board's December 1992 report to Congress and the Secretary of Energy, the Board saw no reason to disagree with the 17-person NAS panel's unanimous conclusion: "The panel concludes from the geological features observed in the field and geochemical data that there is no evidence to support the assertion [by Mr. Szymanski] that the water table has risen periodically hundreds of meters from deep within the crust." The Board's December 1992 report also noted that if significant new data or modifications were presented in the future, the Board would consider reviewing them at that time.

The Board examined the submitted material, and because some new information had been presented, the Board decided to evaluate the quality and significance of this information. For assistance in this evaluation, the Board contracted with four highly qualified scientists. The scientists were chosen as consultants because of their expertise in critical areas, their reputations among their peers (many of whom we spoke to), their lack of affiliation with the Yucca Mountain Project, and their lack of previous involvement in evaluating Mr. Szymanski's ideas.

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[*]A complete list of all the reports reviewed by the Board is in the reference list of the attached "Board Review."

The consultants were Dr. Robert J. Bodnar, C. C. Garvin Professor of Geochemistry and Director of the Fluids Research Laboratory, Department of Geological Sciences, Virginia Polytechnic Institute & State University (Dr. Bodnar's expertise is in fluid inclusions and the geology and geochemistry of ore deposits.); Dr. Patrick R. L. Browne, Associate Professor and Director of the Geothermal Institute, University of Auckland, New Zealand (Dr. Browne's expertise is in the hydrothermal alteration of volcanic rocks and fluid-rock interactions.); Dr. Stuart Rojstaczer, Associate Professor and Director of the Center for Hydrologic Science, Duke University (Dr. Rojstaczer's expertise is in the role of subsurface fluid flow in geologic and human-induced hazards and the hydrologic effects of earthquakes.); and Dr. John Valley, Professor and Chairman of the Department of Geology and Geophysics, University of Wisconsin-Madison (Dr. Valley's expertise is in metamorphic petrology and stable-isotope geochemistry.). Drs. Bodnar, Browne, and Valley were mentioned in our November 12, 1997, letter to you. Dr. Rojstaczer's assistance was obtained later.

The Board conducted its review, making use of its own expertise and that of its consultants. The report on the Board review and the consultants' letters are attached.

In addition to reviewing the 11 reports submitted to us by Mr. Szymanski, 3 additional reports provided by Mr. Swainston, and a number of other important documents referenced in these reports, our staff spoke directly to several of the reports' authors. A Board member, a Board staff member, and Dr. Bodnar also attended an international meeting in which fluid inclusion evidence for and against future hydrothermal upwelling at Yucca Mountain was presented and discussed. Following that meeting, Dr. Yuri Dublyansky (the lead author on several of the reports) spent several days with Dr. Bodnar at Dr. Bodnar's Fluids Research Laboratory at the Virginia Polytechnic Institute.

The Board has reached the following conclusions.

1. The material reviewed by the Board does not make a credible case for the assertion that there has been ongoing, intermittent hydrothermal activity at Yucca Mountain or that large earthquake-induced changes in the water table are likely at Yucca Mountain. This material does not significantly affect the conclusions of the 1992 NAS report.

2. There are several areas where additional research could be used to further evaluate the hypotheses of ongoing, intermittent hydrothermal activity and large earthquake-induced changes in the water table at Yucca Mountain. However, because of the lack of any substantive evidence supporting either of these hypotheses, the Board views additional research on these issues, if not already carried out, as generally having a lower priority than more important issues in the evaluation of repository performance.

3. However, some fluid inclusions found in mineral deposits at Yucca Mountain do provide direct evidence of the past presence of fluids at elevated temperatures (at least 72°C) in the vicinity of the proposed repository. This could be an indicator of some degree of past hydrothermal activity. The critical question is, "At what time in the past were such fluids present?" If fluids at elevated temperatures were present less than 100,000 years ago, as some of

the reviewed reports claim, this could lend credence to the hypothesis of ongoing hydrothermal activity at Yucca Mountain. On the other hand, if these fluids were present around 10,000,000 years ago or earlier, they could be associated with volcanic events related to the original formation of Yucca Mountain and would have no bearing on the hypothesis of ongoing hydrothermal activity. The Board believes that the ages of fluid inclusions should be determined. A joint program between federal and State of Nevada scientists for collecting, dating, and analyzing fluid inclusions would be one way to help eliminate some of the past disagreements associated with sample collection and handling.

We hope you will find this information helpful. If you have questions, please feel free to contact Dr. William Barnard, the Board's executive director, or Dr. Leon Reiter of the Board's senior professional staff at (703) 235-4473.

Sincerely,

(signed)

Jared L. Cohon
Chairman

Attachments

BOARD REVIEW

Introduction

Over the last 18 months, the Board has reviewed the 11 reports[1] submitted by Mr. Jerry Szymanski to the Board and the 3 reports that the Board considers as containing new data among the additional reports subsequently submitted by Mr. Harry Swainston of the State of Nevada Attorney General's office. These reports are identified in the attached reference list. They cover two main topics: (1) proposed evidence for ongoing, intermittent hydrothermal activity at Yucca Mountain and (2) proposed evidence that large, earthquake-induced changes in the water table are likely at Yucca Mountain. The first topic was addressed in 9 of the 11 reports submitted by Mr. Szymanski and in the 3 additional reports reviewed by the Board. The second topic was addressed in the two reports that were submitted by Mr. Szymanski and that were co-authored by Dr. John Davies and Dr. Charles Archambeau.

The Board conducted its review by making use of its own expertise and that of four consultants (Dr. Robert Bodnar, Dr. Patrick Browne, Dr. Stuart Rojstaczer, and Dr. John Valley).[2]

Four questions were posed to the consultants (Drs. Bodnar, Browne, and Valley for evidence of hydrothermal activity and Dr. Rojstaczer for earthquake-induced changes in the water table) that centered on the significance of the new information presented with respect to the conclusions drawn in the 1992 National Academy of Sciences (NAS) report, *Ground Water at Yucca Mountain—How High Can It Rise?* These questions[3] also are the focus of the Board's review:

1. Are there significant new data (and interpretations) since the 1992 NAS report?
2. What is the quality of these data (and interpretations)?
3. How much credence do these data (and interpretations) lend to the hypothesis of ongoing, intermittent hydrothermal activity (large earthquake-induced changes in the water table) at Yucca Mountain?
4. If these data (and interpretations) significantly affect the conclusions of the 1992 NAS report, how can the issue be resolved?

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[1] All of the material presented to the Board appeared as reports submitted to the Nevada Nuclear Waste Project Office. The reports that were eventually published in the professional literature are listed as such in the attached reference list.

[2] The institutional affiliation and area of expertise of each of these consultants are noted in the cover letter to this report.

[3] The original wording of these questions was posed to the consultants assisting in the review of evidence for ongoing, intermittent hydrothermal activity. The words in parentheses were used to modify the questions for the review of earthquake-induced changes in the water table to reflect differences in the subject and recognition of the critical role played by data interpretation.

We emphasize that the purpose of our review is to evaluate the information submitted to the Board, not to conduct a systematic review of all the information that has been collected on this topic, including the extensive work carried out for the U. S. Department of Energy's (DOE) Yucca Mountain Project by the U. S. Geological Survey and the national laboratories. A systematic review of all the information available by 1992 was carried out by the 17-person panel that prepared the 1992 NAS report. In addition to a published response (Stuckless and others 1998) to one of the reports submitted by Mr. Szymanski (Hill and others 1995), other outside information provided to the consultants was information that the consultants requested.

Following is the Board's review of the material presented in the two areas. In addition to the reports reviewed by the Board, other references cited in the Board's review are included in the attached reference list. Consultant letters are referred to by author and date and are attached in full to this review. Each of the three consultants who addressed the proposed evidence for ongoing, intermittent hydrothermal activity provided two letters. Their first letters review the reports submitted by Mr. Szymanski, and Dr. Browne's and Dr. Valley's second letters review two of the additional reports provided by Mr. Swainston in their areas of interest. Dr. Bodnar's second letter addresses Dr. Dublyansky's visit to his laboratory. The additional report on fluid inclusions provided by Mr. Swainston is addressed in Dr. Bodnar's first letter. The additional reports provided by Mr. Swainston do not include new information on earthquake-induced changes in the water table; we supplemented the two reports submitted by Mr. Szymanski on this issue with an additional paper (Kohl and Liang 1995) that includes much of the data analysis included in the two reports.

Review of Evidence Presented for Ongoing, Intermittent Hydrothermal Activity at Yucca Mountain

1. Are there significant new data since the 1992 NAS report?

There are new data since the 1992 NAS report, but their significance varies, depending on how directly the data bear on the hydrothermal hypothesis and how much one needs to rely on controversial and speculative interpretations to relate the data to hydrothermal activity. Thus, the data that posed the most potential for reflecting the postulated hydrothermal activity are the data determined from fluid inclusions. The stable-isotope data and the mineralogy and petrology data are generally of lesser significance.

2. What is the quality of these data?

The quality of the data in the reports generally appears to be high. Much of the analytical data (for example, stable-isotope analyses) has been provided by well-known and reputable laboratories or at least reflect well-established techniques (for example, homogenization temperatures of fluid inclusions). The quality of some of the data was confirmed during Dr. Dublyansky's visit to Dr. Bodnar's laboratory in June 1998 (Bodnar letter; July 8, 1998).

Although the data generally appear to be of good quality, often there is poor or insufficient documentation of important details. Examples of this deficiency include the lack of detailed information on the location of the study of Stagecoach Road fault stable isotopes discussed in Dublyansky (1995) and Dublyansky and Szymanski (1996); the lack of clear information on the locations of the fluid-inclusion sample sites in the underground exploratory studies facility (ESF) cited by Dublyansky and Reutsky (1995) and Dublyansky, Reutsky, and Shugurova (1996); the lack of adequate description of a proposed hydrothermal eruption breccia referred to in Szymanski (1996) and in Chepizhko and others (1996); and the lack of a clear and persuasive description by Dublyansky and Reutsky (1995) and Hill and others (1995) of how the critically important ages of fluid inclusions were determined.

Far more serious are the problems associated with the interpretation of the data, which is the critical part of many scientific analyses. Examples include the very tenuous fits of lines to scattered small data sets showing presumed stable-isotope changes with depth and with distance shown in Hill and others (1995), Dublyansky **(**1995), Dublyansky and Szymanski (1996), and Szymanski and Dublyansky (1996); photographs allegedly demonstrating the hydrothermal origin of zircon in Chepizhko and others (1996) that do not show the zircons growing on vein walls or fractures, the sort of evidence that would be required if this interpretation were true; the implication in Dublyansky and Lapin (1995) that relatively unimportant differences in chemical analyses of rocks imply large-scale alteration by hydrothermal processes (metasomatism); and the assumption in Hill and others (1995) and Dublyansky, Reutsky, and Shugurova (1996) that all fluid inclusions at depth were formed at the same time, permitting the determination of a paleo-geothermal gradient although their own very limited data show otherwise.

3. How much credence do the data lend to the hypothesis of ongoing, intermittent hydrothermal activity at Yucca Mountain?

Little credence is lent by the data to the hypothesis of ongoing, intermittent hydrothermal activity at Yucca Mountain. With the *possible* exception of the fluid inclusions (discussed below), the data presented do not pose a serious challenge either to findings reached in the 1992 NAS report or to the reasoning behind those findings. Above all, the reports can be criticized because of the pervasive presence of unsubstantiated interpretations, examples of which are given above. This is the primary reason for the criticism by the Board's consultants of the quality of the reports they were asked to review. The consultants cited the "… apparent selective use of information … with non-supporting data being ignored." (Bodnar letter; January 2, 1998); documents that are "… frustrating and confusing to review" and that "…rely heavily on unpublished documents, which are difficult to obtain and which are loosely interpreted, sometimes with a misleading effect. Important dissenting information … is not mentioned or discussed. In many instances, these documents make conclusions that are so strong as to seem divorced from the preceding data and discussion." (Valley letter; December 18, 1997); reports that are "… full of unsubstantiated conclusions, errors of fact and *ex cathedra* statements not supported by any, or dubious, evidence." (Browne letter; December 23, 1997); and "… full of non-sequiturs, special pleadings, reliance on dubious conclusions reported in the earlier reports and assertions presented as proofs." (Browne letter; June 16, 1998).

The fluid inclusion data show that there is little doubt that some of the calcite in the ESF was either formed by, or later exposed to, aqueous fluids at elevated temperatures (at least 72° C) under different conditions than those present in today's unsaturated environment (Bodnar letter; July 8, 1998). If the limited, poorly documented, and indirect estimates of young ages (less than 100,000 years) quoted by Hill and others (1995) and Dublyansky and Reutsky (1995) are correct,[4] this could lend credence to the hypotheses of ongoing, intermittent hydrothermal activity at Yucca Mountain. On the other hand, if the ages of these calcites are shown to be around 10,000,000 years or older, the presence of fluids at elevated temperatures could be associated with volcanic events related to the original formation of Yucca Mountain and would have no bearing on the hypothesis of ongoing hydrothermal activity.

Although the consultants were not asked specifically to do so, they cited some lines of evidence that argue *against* ongoing, intermittent hydrothermal activity. This evidence includes the oxygen-isotope composition of modern groundwater (Valley letter; December 13, 1997)[5] and the lack of documented subsurface textural features or surface morphological features associated with known hydrothermal activity (Browne letters; December 23, 1997, and June 16, 1998).[6] This last point is supported by the Board members' own observations in trips to excavated trenches in the Yucca Mountain vicinity.[7] What is clear is that the sequential layering (youngest on top, oldest on bottom) of calcium carbonate deposits, the continuation of these deposits both upslope and downslope of faults, the transitionary nature of boundaries between layers, and the correlation and parallel nature of individual layers all argue for these deposits being related to normal soil formation rather than to hydrothermal upwelling. These deposits are not similar to the known, ancient spring deposits in Crater Flat and Ash Meadows.

4. If these data significantly affect the conclusions of the 1992 NAS report, how can the issue be resolved?

Although the reports reviewed by the Board lend little credence to the hypothesis of ongoing hydrothermal activity, several lines of evidence, although poorly constrained or insufficiently documented, *if substantiated*, would be permissive of some ongoing hydrothermal activity. As cited by the consultants, these lines of evidence include the quoted young ages for some of the fluid-inclusion host rocks (Bodnar letters; January 2, 1998, and June 16, 1998) and the poorly constrained stable-isotope gradients in surface carbonate deposits (Valley letter; December 13, 1997). Reliable dating and petrographic and field investigations could help determine whether these data really are permissive of the hydrothermal hypothesis.

The consultants indicated a number of other areas where they think additional work might be helpful in further evaluating the credence of the hydrothermal hypothesis. They

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[4] Stuckless and others (1998), for example, dispute the young ^{14}C ages assigned to two of the inclusions, arguing that they were not determined from the same part of the calcite in which the fluid inclusions were found.

[5] Dr. Valley pointed out that this is the only stable-isotope evidence arguing against ongoing hydrothermal activity and urged that additional studies be carried out.

[6] As Dr. Browne stated in his letter of December 23, 1997: "In summary, there is no evidence in the reports, so far as I can see, that there have been either intermittent or recent thermal events at Yucca Mountain or hydrothermal eruptions there."

[7] Many of these observations also were documented in U. S. Geological Survey (1996).

include determination of how much Yucca Mountain has eroded since the fluid inclusions were formed (Bodnar letter; January 2, 1998); a search by a geologist experienced in studying geothermal and mineralized areas for possible hydrothermal breccias; chemical and isotope analysis of deep waters and pore waters in the ESF; more work for resolving contradictory findings with respect to geothermal gradients and the presence of root casts in breccias; mapping of supposedly younger volcanic rocks; a search for hydrothermally altered phenocrysts (large, conspicuous crystals), morphological evidence of surface degassing of rich thermal waters, and fossil evidence of microbiological activity related to surficial warm waters (Browne letters; December 23, 1997, and June 16, 1998); coordinated studies of carbonate cements from the surface and from drill holes involving analyses of fluid inclusions and stable isotopes, paragenetic studies, and determination of relative and absolute ages in the same carefully described samples (Valley letter of December 13, 1997; Bodnar letter of January 2, 1998); and testing of some stable-isotope samples for heterogeneity and isotope zoning (Valley letter of December 13, 1997; Browne letter of June 16, 1998).

As indicated previously, much additional work has been carried out for the DOE by the U.S. Geological Survey and others that bears on the issue of ongoing hydrothermal activity. Most recently, for example, detailed analysis of water-deposited secondary minerals (calcite and opal) in the ESF at the depth of the proposed repository by Paces and others (1998) shows distinct differences between these deposits in the unsaturated zone and those in the saturated zone at much greater depth. Although the secondary minerals in the saturated zone typically coat all surfaces, those found in the ESF occur generally on fracture footwalls or lithophysal cavity floors. The depositional geometry of these deposits, 28,000 years old and older, suggest formation under unsaturated conditions by downward-percolating water, not under the saturated conditions that would be expected if the deposits were formed by upward-moving hydrothermal water that could have formed seeps or springs at the surface. In the past, other analyses of the physical, chemical, biological, petrographic, isotopic, and mineralogical properties of secondary carbonate and silica in trenches exposing proposed hydrothermal deposits at the surface near Yucca Mountain suggest that these deposits also were formed by downward-percolating water (see, for example, Taylor and Huckins 1995).

Because of a lack of any substantive evidence of ongoing hydrothermal activity, the Board views additional research on this subject (if not already carried out) as generally having a lower priority than more important issues in the evaluation of repository performance.

However, because some fluid inclusions do provide direct evidence of the past presence of fluids at elevated temperatures in the vicinity of the proposed repository, the Board believes that the ages of fluid inclusions should be determined. Dr. Bodnar, in his July 8, 1998, letter, recommended a joint program between U. S. Geological Survey and State of Nevada scientists for collecting, dating, and analyzing fluid inclusions. Such a process would be one way to help eliminate some of the past disagreements associated with sample collection and handling.

Review of Evidence Presented that Large, Earthquake-Induced Changes in the Water Table are Likely at Yucca Mountain

1. Are there significant new data and interpretations since the 1992 NAS report?

Except for changes in water levels in wells associated with the magnitude 5.6 Little Skull Mountain (LSM) earthquake near Yucca Mountain in June 1992, no really new data have been presented that have become available since the 1992 NAS report. The bulk of the two reports (Davies and Archambeau 1997a and 1997b), however, present new and different interpretations of preexisting data.

2. What is the quality of these data and interpretations?

The quality of the new data on changes in four water-level recordings that are due to the LSM earthquake *as presented* in Figure 4 of Davies and Archambeau (1997a) is poor. The authors maintain that these recordings show evidence of "… relatively large [rises of up to 5 meters] water-table changes due to normal [faulting] earthquakes in an extensional tectonic environment … particularly relevant to the proposed Yucca Mountain repository…" Scrutiny of the source for the water-level recordings referenced in Davies and Archambeau (1997a) and the actual document itself indicates that the referenced source does not contain the information shown in Figure 4;[8] that the correct reference (O'Brien, Tucci, and Burkhardt 1995) for earthquake-induced changes at two of the wells shown in Figure 4 (J-11 and J-12) reveal essentially no rise in these wells; and that the correct reference (La Camera and Westenburg 1994) for the other two wells identified as AD-11 and AD-16[9] reveals that the well that was supposed to show an up-to-5-meter rise due to the LSM earthquake actually showed only a measured rise of less than 1 meter.

Many problems exist in the proposed models and the interpretation of data presented in Davies and Archambeau (1997a and 1997b). For example, the fundamental idea presented is that the large hydraulic gradient (LHG), a "steep"[10] change in the water-table level north of the proposed repository, is controlled by the stress field and that readjustments in that stress field due to earthquakes could cause open fractures south of the LHG to close, decreasing the permeability of the rocks and causing the proposed repository to flood. The assumption is that changes of about 30 to 40 bars in stress could cause large (two orders of magnitude) changes in permeability. The topology of fracture networks in rocks, however, is such that some fractures might close while others might open as a result of stress changes. Generally, the fractional change in permeability in rocks is much smaller and depends very much on confining stress (see, for example, Appendix E in Peters and others 1984, and Figure V.6 in Guðguen and Palciauskas 1994). The claim that the existing LHG separates two permeability regimes differing by one to three orders of magnitude is supported by only two data points.

[8] However, small increases and decreases in the water level due to the LSM earthquake were shown at several other wells.

[9] At least since 1994, AD-11 and AD-16 have been identified as AD-10 and AD-12 (personal communication from R. La Camera, 1998).

[10] Although Davies and Archambeau (1997a) describe the LHG as indicating "… a 'wall' of subsurface water, over 250 meters in height …" the slope of the LHG is actually less than about 10°.

Davies and Archambeau (1997b) go on to develop a theory and a technique for measuring the state of stress by inferring average fracture-opening pressures (also called "fracture-closing pressures") from existing bore-hole slug-test data at Yucca Mountain. Slug tests are not designed for state-of-stress measurements. The inferred average fracture-opening pressures could be simply a result of variability in the chosen test intervals. However, two of the fracture-opening pressures (USW G1 and USW G2) shown in Figure 2 of Davies and Archambeau (1997a) and Figure 1 of Davies and Archambeau (1997b) were not determined by the method proposed by Davies and Archambeau (1997b). Apparently, as indicated in Kohl and Liang (1995), a study that provides much of the analysis, estimates of fracture-opening pressure at USW G1 and USW G2 were determined from standard hydrofracture measurements presented in Stock and Healy (1988). The measurements at USW G1 and USW G2 and their significance are discussed below.

Finally, a key element in the model proposed by Archambeau and Davies (1997a) is the assumption that a 40 percent change in strain would be enough to cut off fracture network conductivity (permeability) in the region south of the LHG and cause the water table to rise. The cited basis for this assumption is Wang and Narasimhan (1993). Careful examination of this paper reveals that the 40 percent "change" assumed by Davies and Archambeau (1997a and 1997b) is estimated from the difference between fracture apertures derived from two very different models and has little to do with a cutoff in fracture network conductivity.[11]

Even assuming that the Davies and Archambeau (1997a) model is correct, the supposed trend of fracture-opening pressures (high north of the LHG and low south of the LHG) is suspect. For example, USW G2, where the water table elevation is 1029 meters, is the only borehole north of the LHG with an estimate of fracture-opening pressure. The fracture-opening pressure differs only by 5 bars from that of USW G1 south of the gradient, where the water table is 275 meters lower. In addition, Stock and Healy (1988) point out that because of the likely presence of preexisting fractures, three of the estimates at USW G2 shown in Kohl and Liang (1995) should be considered only *upper bounds* on the value of the minimum stresses. It also should be noted that, contrary to the supposed trend, the fracture-opening pressure shown at US H5 is 25 bars *lower* than that shown at USW G1, even though the water table at US H5 is 21 meters *higher* than at USW G1.

The rationale behind the choice of data points used by Davies and Archambeau (1997a and 1997b) remains unclear. The rationale appears to be based on using quantitatively unverifiable averages of selected data determined from visual inspection and curve fitting. The only direct comparison between their technique and that determined by standard hydrofracture measurements from Stock and Healy (1988) is at borehole UE 25p1 in the region of supposedly low fracture-opening pressures. As shown in Table 17 of Kohl and Liang (1995), the estimated fracture-opening pressure in the depth interval of 1554-1600 meters is 4.36 bars. Using Stock

[11] The 40 percent change is really only the difference between (a) an "effective" fracture aperture inferred from fitting a simple model to bulk permeability tests and (b) an indirect estimate of the fracture aperture below which parts of an assumed single "rough walled" fracture would be in contact under *in situ* stress. This latter value should not be used as a measure of the cutoff in fracture network conductivity, and there is no basis for assuming that a 40 percent change in strain could lead to such a cutoff.

and Healy (1988), we find that the fracture-opening pressure (minimum horizontal stress minus ambient fluid pressure) at a depth of 1573 meters is 91 bars. This discrepancy in the estimates of fracture-opening pressure at the same location is troubling and, furthermore, it exceeds the range of the fracture-opening pressures (10 to 55 bars) used by Davies and Archambeau (1997a) as evidence for two different stress regimes. This discrepancy was not discussed by the authors.

Several geologic observations are pertinent to the location of the LHG. The assumption is made in Archambeau and Davies (1997a) that the absence of mapped faults at the surface can be used to infer a lack of open fractures at depth and consequent low hydraulic conductivity. Although more-pervasive fracture development can be associated with faults, the lack of faults within bedrock strata of varying thickness and varying mechanical properties should not be used to infer the lack of fractures. No geologic evidence of a shifting, stress-induced LHG has been presented. There is, however, abundant evidence that LHGs exist at other locations near Yucca Mountain that simply can be explained by differences in hydraulic properties caused by geology. Winograd and Thordarson (1975), for example, discuss several of these LHGs, including two very steep gradients caused by the juxtaposition of Paleozoic and Precambrian clastic and carbonate rocks in the vicinity of Emigrant Valley.

Davies and Archambeau (1997a) did not pay adequate attention to alternative hypotheses for the cause of the LHG. A recent panel of eminent experts from outside the Yucca Mountain project was convened by DOE contractors to provide independent estimates of saturated zone flow and transport for use in assessing the performance of the proposed Yucca Mountain repository (see Geomatrix Consultants 1997). They provided several alternative explanations of the cause of the LHG, including topography, recharge patterns, and geology. The panelists were supplied with Davies and Archambeau (1997a), but they did not support Davies' and Archambeau's findings, concluding that the probability of any large transient changes in the configuration of LHGs that are due to earthquakes or other mechanisms is extremely low.

3. How much credence do these data and interpretations lends to the hypothesis of large, earthquake-induced changes in the water table at Yucca Mountain?

These data and interpretations lend little or no credence to the hypothesis of large, earthquake-induced changes in the water table at Yucca Mountain. The authors have taken three fairly well accepted, independent conclusions: (1) Earthquakes can cause changes in local stresses; (2) Stress changes can affect permeability; (3) Hydraulic gradients can be due to spatial variation in permeability. However, the authors have linked these conclusions and developed a model for which there is no reasonable evidence or theoretical justification. As the Board's consultant states in the attached letter (Rojstaczer letter; June 15, 1998), "The interpretations depend significantly upon theoretical models that have never been tested or previously used and run counter to observations in nature and in the laboratory."[12]

4. If these data and interpretations significantly affect the conclusions of the 1992 NAS report, how can the issue be resolved?

[12] In his letter, Dr. Rojstaczer describes numerous statements made by Davies and Archambeau as "science by assertion."

Although the data and interpretations do not significantly affect the conclusions of the 1992 NAS report, the Board's consultant (Rojstaczer letter; June 15, 1998) states that Davies' and Archambeau's interpretations "… are not completely falsifiable given the available data." and "Additional field work and data collection at Yucca Mountain would help in fully determining whether or not the interpretations and models employed have potential validity." He reminds us, however, that the likelihood of the interpretations being correct is "extremely remote."

In the Board's view, any additional work the DOE may undertake to address specifically the issues raised by these two papers is clearly of much lower priority than more important issues in the evaluation of repository performance.[13]

The DOE is drilling a new borehole into the LHG to help determine its cause. Useful information will very likely be obtained from this drillhole that will improve our understanding of the nature of the groundwater system in the vicinity of Yucca Mountain.

[13] Of interest is that Davies and Archambeau (1997a) casually, and incorrectly, dismiss the importance of *climate-induced* changes in the water table. Apparently, they misunderstood a modeling study (Czarnecki 1985) that concluded that there would be a large rise in the water table (but well below the proposed repository horizon) if rainfall doubled in the next 10,000 years.

REFERENCE LIST

Reports Submitted by Mr. Szymanski to the Nuclear Waste Technical Review Board

Chepizhko, A. V.; Y. V. Dublyansky; and J. Szymanski. 1996. *Hydrothermal accessory minerals in tuff, breccias, and calcite/opal; veins at Yucca Mountain: evidence for Plio-Quaternary hydrothermal eruptions.* Abstract submitted to 1995 Geological Society of America meeting and report submitted to Nevada Nuclear Waste Project Office (NWPO).

Davies, J. B., and C. B. Archambeau. 1997a. "Geohydrological models and earthquake effects at Yucca Mountain." *Environmental Geology*, v. 32, pp. 23-35.

Davies, J. B., and C. B. Archambeau. 1997b. "Analysis of high-pressure fluid flow in fractures with applications to Yucca Mountain, Nevada, slug test data." *Tectonophysics*, v. 277, pp. 83-98.

Dublyansky, Y. V.; V. Reutsky; and N. Shugurova. 1996. "Fluid inclusions in calcite from the Yucca Mountain exploratory tunnel: evidence for hydrothermal origin of the calcite." In P. E. Brown and S. G. Hagemann, eds., *Proceedings of the Pan-American Conference on Current Research on Fluid Inclusions*. May 1996. Madison, Wisconsin.

Dublyanski, Y. V., and J. S. Szymanski. 1996. "Carbonate deposits at Yucca Mountain (Nevada, USA) and the problem of high-level nuclear waste disposal." *Chemistry for Sustainable Development*, v. 4, pp. 149-161.

Hill, C. A.; Y. V. Dublyansky; R. S. Harmon; and C. M. Schluter. 1995. "Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada, USA: pedogenic, hypogene, or both?" *Environmental Geology*, v. 26, pp. 69-88.

Livingston, D. E., and J. S. Szymanski. 1996. *Chemical heterogeneity of the clinoptilolite heulandite fraction at Yucca Mountain, Nevada: evidence for polygenetic, hydrothermal alteration.* Report submitted to Nevada NWPO.

Szymanski, J. S. 1996. *Epithermal mineralization, alteration, and spring deposits at Yucca Mountain, Nevada - thermodynamic evolution of the geologic system.* Report submitted to Nevada NWPO.

Szymanski, J. S., and C. B. Archambeau. 1996. *The thermodynamic evolution and present state of the lithosphere at Yucca Mountain, Nevada*. Report submitted to Nevada NWPO.

Szymanski, J. S., and Y. V. Dublyansky. 1996. *Stable isotope gradients in slope calcretes at Yucca Mountain, Nevada: evidence for the involvement of carbonic gases in the*

hydrothermal discharges. Abstract submitted to 1995 Geological Society of America meeting and report submitted to Nevada NWPO.

Szymanski, J. S.; Y. V. Dublyansky; and D. E. Livingston. 1996. *Sr, C, and O isotopic profile from the USW VH-2 borehole, Crater Flat, Nevada: evidence for the intermittancy of the hydrothermal discharges and the Plio-Quaternary age of the ^{87}Sr metasomatism at Bare Mountain*. Abstract submitted to 1995 Geological Society of America meeting and report submitted to Nevada NWPO.

Additional Reports Submitted by Mr. Harry Swainston Containing New Material

Dublyansky, Y. V. 1995. *Stable isotope composition of carbonates exposed in trenches at the Stagecoach Road fault*. Report submitted to Nevada NWPO.

Dublyansky, Y. V., and B. Lapin. 1995. *Bedrock tuffs, mosaic breccias and young volcanic rocks at Yucca Mountain, Nevada.* Report submitted to Nevada NWPO.

Dublyansky, Y. V., and V. N. Reutsky. 1995. *Preliminary data on fluid inclusions in epigenetic minerals from tunnel excavated under Yucca Mountain*. Report submitted to Nevada NWPO.

Additional References

Czarnecki, J. B. 1985. "Simulated effects of increased recharge on the ground water flow system of Yucca Mountain and vicinity." *Water Resources Investigations Report 84-4344*. U. S. Geological Survey.

Geomatrix Consultants. 1997. *Saturated zone flow and transport expert elicitation project.* Report submitted to U. S. Department of Energy, Site Characterization Office.

Guðguen, Y., and V. Palciauskas. 1994. *Introduction to the Physics of Rocks.* Princeton University Press.

Kohl, B., and B. Liang. 1995. "Quantitative characterization of the role of flow through fractures in the groundwater system in the vicinity of Yucca Mountain". *TRAC-NA Quarterly Report,* No.5, Part II. Nuclear Waste Projects Office, State of Nevada. May (1995).

La Camera, R. J., and C. L. Westenburg. 1994. "Selected ground-water data for Yucca Mountain Region, southern Nevada and eastern California, through December 1992." *Open File Report 94-54*, U. S. Geological Survey.

O'Brien, G. M.; P. Tucci; and D. J. Burkhardt. 1995. "Water levels in the Yucca Mountain area, Nevada." *Open-File Report 94-311*, U. S. Geological Survey.

Paces, J.; L. A. Neymark; B. D. Marshall; J. F. Whelan; and Z. E. Peterman. 1998. "Inferences for Yucca Mountain unsaturated zone hydrology from secondary minerals." *Proceedings of the Eighth International Conference High-Level Radioactive Waste Management*, Las Vegas, Nevada, pp. 36-39.

Peters, R. R.; E. A. Klavetter; I. J. Hall; S. C. Blair; P. R. Heller; and G. W. Gee. 1984. Fracture and matrix hydrologic characteristics of tuffaceous materials from Yucca Mountain, Nye County, Nevada." *SAND84-1471,* Sandia National Laboratories.

Stock, J. M., and J. H. Healy. 1988. "Stress field at Yucca Mountain, Nevada." In M. D. Carr and J. C. Yount, eds. *Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada*. U. S. Geological Survey Bulletin 1790, pp. 87-93.

Stuckless, J. S.; B. D. Marshall; D. T. Vaniman; W. W. Dudley; Z. E. Peterman; J. B. Paces; J. F. Whelan; E. M. Taylor; R. M. Forester; and D. W. O'Leary. 1998. "Comments on 'Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada, USA: pedogenic, hypogene, or both?'" by C. A. Hill, Y. V. Dublyansky, R. S. Harmon, and C. M. Schluter. *Environmental Geology*, v. 34, pp. 70-78.

Taylor, E. M., and H. E. Huckins. 1995. "Lithology, fault displacement, and origin of secondary calcium carbonate and opaline silica at Trenches 14 and 14D on the Bow Ridge fault at Exile Hill, Nye County, Nevada." *Open-File Report 93-477*, U. S. Geological Survey.

U. S. Geological Survey 1996. "Quaternary paleoseismology and stratigraphy of the Yucca Mountain site area." J. W. Whitney and E. M. Taylor, eds. Chapter 4 in *Seismotectonic framework and characterization of faulting at Yucca Mountain, Nevada.* Report to U. S. Department of Energy.

Wang, J. S. Y., and T. N. Narasimhan. 1993. "Unsaturated flow in fractured porous media." In J. Bear, C. Tsang, and G. de Marsily, eds. *Flow and Contaminant Transport in Fractured Rock.* Academic Press, Inc. Pp. 325-394.

Winograd, I. J., and W. Thordarson. 1975. "Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site." *U. S. Geological Survey Professional Paper 712-C.*