U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

Report to The U.S. Congress And The Secretary of Energy

January to December 2000

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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April 2001

The Honorable J. Dennis Hastert
Speaker of the House
United States House of Representatives
Washington, D.C. 20515

The Honorable J. Strom Thurmond
President Pro Tempore
United States Senate
Washington, D.C. 20510

The Honorable E. Spencer Abraham
Secretary
U.S. Department of Energy
Washington, D.C. 20585

Dear Speaker Hastert, Senator Thurmond, and Secretary Abraham:

The Nuclear Waste Technical Review Board submits this *Report to The U.S. Congress and The Secretary of Energy* in accordance with provisions of the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203, which requires the Board to report its findings and recommendations to Congress and the Secretary of Energy at least two times each year.

Congress created the Board to evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy in characterizing a site at Yucca Mountain, Nevada, for its suitability as the location of a permanent repository for disposing of spent nuclear fuel and high-level radioactive waste. The Board also reviews the Department of Energy's (DOE) work that is related to the design of the repository and to the packaging and transport of spent nuclear fuel and high-level radioactive waste. In this report, the Board summarizes its major activities in calendar year 2000.

During 2000, the Board identified four priority areas for evaluating the potential repository at Yucca Mountain. As summarized by Chairman Jared Cohon at the Board's January 2001 meeting in Amargosa Valley, Nevada, the areas are the following:

- meaningful quantification of conservatisms and uncertainties in the DOE's performance assessments
- progress in understanding the underlying fundamental processes involved in predicting the rate of waste package corrosion

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- an evaluation and a comparison of the base-case repository design with a low-temperature design
- development of multiple lines of evidence to support the safety case of the proposed repository, the lines of evidence being derived independently of performance assessment and thus not being subject to the limitations of performance assessment.

This report summarizes the Board's views on each priority area. More-detailed discussions of these areas, as well as of other technical issues, were transmitted to the DOE by letter during the year. The letters are presented in Appendix E of this report.

We believe that the information in this report will be useful to policy-makers as well as to DOE managers and staff when they make important decisions on the status of the Yucca Mountain site and the research priorities of the civilian radioactive waste management program.

We thank you for this opportunity to present the Board's views.

Sincerely,

Jared L. Cohon
Chairman

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Board Activities in 2000

During 2000, the U.S. Department of Energy (DOE) continued characterizing Yucca Mountain in Nevada to evaluate the suitability of the site for constructing a mined geologic repository for the permanent disposal of spent nuclear fuel and high-level radioactive waste. The DOE continued preparing designs of the packages for disposing of the waste and a design of the subsurface repository facilities. An updated total system performance assessment was completed, and testing continues inside the tunnels of Yucca Mountain.

The U.S. Nuclear Waste Technical Review Board (Board) is charged under the Nuclear Waste Policy Amendments Act of 1987 (U.S. Congress 1987) with evaluating the technical and scientific validity of the work undertaken by the DOE to develop a system for disposing of spent nuclear fuel and high-level radioactive waste. In this report, the Board summarizes its activities in 2000. During the year, the Board identified four priority areas. As summarized by Chairman Jared Cohon at the Boards January 2001 meeting in Amargosa Valley, Nevada, the areas are the following:

meaningful quantification of conservatisms and uncertainties in the DOEs performance assessments

progress in understanding the underlying fundamental processes involved in predicting the rate of waste package corrosion

an evaluation and a comparison of the base-case repository design with a low-temperature design

development of multiple lines of evidence to support the safety case of the proposed repository, the lines of evidence being derived independently of performance assessment and thus not being subject to the limitations of performance assessment.

Section I of the report summarizes the Boards views on each priority area. More-detailed discussions of these areas, as well as of other technical issues, were transmitted to the DOE by letter during the year. The letters are presented in Appendix E of this report.

I. Board Priorities

A. Meaningful Quantification of Uncertainties

The Board believes that meaningful quantification of the uncertainties associated with estimates of repository performance, presented clearly and understandably, is essential to give policy-makers who are deciding on a site recommendation critical information on trade-offs between projected performance and uncertainty in the projections. The Board made several suggestions in 2000 to assist the DOE in this task. The Board was encouraged by the efforts made by the DOE during the year but cautions that additional efforts are needed before a case can be made that uncertainties have been estimated in a technically credible manner.

A closely related issue requiring further thought is the adoption of a mix of conservative, realistic, and optimistic assumptions in models and parameters. Determining the overall level of conservatism for a mix of conservative, realistic, and optimistic assumptions will be very difficult. If the DOE believes that a performance assessment is conservative, an

effort must be made to provide a defensible estimate of the overall level of conservatism.

The Board realizes that any projection of long-term performance of a potential repository at Yucca Mountain is inherently uncertain; eliminating all the uncertainties will never be possible (although they can be reduced). The Board also realizes that policy-makers can make a decision on whether to recommend the site at any time, depending in part on how much uncertainty they find acceptable. The Board believes, however, that developing methods for quantifying uncertainties in the DOEs performance assessments should be a priority area of work for the Yucca Mountain Project so that policy-makers will have a clearer basis for making their decisions.

B. Understanding Fundamental Corrosion Processes

Sensitivity and neutralization studies indicate that the waste package may be the most important barrier for containing and isolating radioactive waste. Therefore, the data, models, and assumptions pertaining to waste package performance deserve special scrutiny.

There have been significant improvements in waste package data and models since the performance assessment for the DOEs 1998 Viability Assessment (DOE 1998). For example, a major advance is the model relating the presence or absence of water on the outer surface of the waste package to relative humidity at temperatures above the boiling point. Similarly, the long-term-corrosion testing facility at Lawrence Livermore National Laboratory has improved the data set from which corrosion rates are estimated. Nevertheless, extrapolation of corrosion rates determined from short-term (a few years) experiments to predict waste package performance over tens of thousand of years is a subject of considerable uncertainty. Long-term extrapolations may be suspect if they are made with little or no understanding of the fundamental mechanisms that either preserve or dissolve the passive layer that is critical to the corrosion resistance of Alloy 22. If possible, such understanding should be accompanied by examples of long-term (in a geological sense) protection by passive layers in aggressive environments. Processes that could affect the long-term viability of the passive layer include the following:

Passive layer defect accumulation: Will the passive layer encounter microscopic defects as it sweeps into metal?

Passive layer debris accumulation: Will corrosion products have long-term effects on the passive layer?

(Quasi)transpassive dissolution: If the open-circuit potential creeps up over time, will transpassive regimes be approached, promoted by the high molybdenum content of Alloy 22?

Progress in understanding these fundamental processes is needed to support long-term predictions of waste package corrosion.

C. Comparison of Base-Case and Lower-Temperature Repository Designs

Some of the current large uncertainties about waste package and repository performance are directly or indirectly related to the high (above-boiling) repository temperatures associated with the DOEs current base-case repository design. High temperatures increase the level, extent, and significance of the combined, or coupled, effects of thermal, hydrologic, mechanical, and chemical processes. Furthermore, the waste packages may be more vulnerable to corrosion at higher temperatures if water is present. The Board believes that it will be very difficult for the DOE to improve substantially its current understanding of these high-temperature effects during the next year or two. However, it may be possible over several months to reduce some uncertaintiesfor example, by developing and evaluating a lower-temperature repository design.

The Board is interested in obtaining an evaluation and a comparison of the base-case, high-temperature repository design with a low-temperature, ventilated design. Evaluating a possible low-temperature, ventilated design could clarify the advantages and disadvantages associated with keeping waste package temperatures below, say, 85°C. In particular, the Board believes that the DOE should use performance assessment to evalu-

ate a low-temperature, ventilated design concept. If necessary, performance assessment models should be modified to portray accurately the effects of temperature changes on performance. Associated levels of uncertainty in repository performance should be developed for both high- and low-temperature design concepts. The Board realizes that the DOE also may want to examine other design-related considerations, including licensability, operations and logistics, flexibility, cost, etc. The more technically defensible and quantitative the evaluation and comparison, the more useful it will be for policy-makers.

D. Development of Multiple Lines of Evidence

Although demonstrating, in a conventional sense, how a repository will behave thousands of years into the future may not be possible, steps can be taken to increase confidence in estimates of future performance. The Board has strongly endorsed the DOEs efforts to develop multiple lines of evidence supporting a safety case for the proposed repository. During 2000, a fourth iteration of Repository Safety Strategy (RSS) (CRWMS 2000) was prepared that describes a safety case for a Yucca Mountain repository.

The DOEs safety case rests on key elements, or pillars: performance-assessment calculations, safety margins and defense-in-depth, evaluation of potentially disruptive events, insights from natural analogs, and performance confirmation. In the Boards view, the pillars of the RSS do not yet satisfy the goal of providing multiple lines of evidence and therefore do not substantially increase confidence that a repository at Yucca Mountain will perform as anticipated. Some of the pillarsperformance- assessment calculations, safety margins and defense-in-depth, and analyses of disruptive eventsas currently presented are all dependent on performance assessment. Thus, if one lacks confidence in the DOEs performance assessment, one is not likely to have much confidence in the other pillars that depend on it. The last two pillars of the repository safety casenatural analogs and performance confirmationare independent of performance-assessment calculations. However, the DOEs evaluation of natural analogs so far has been minimal, and performance confirmation is simply a plan of activities that will be subject to future budget and time constraints. The performance assessment plan should detail how any testing after repository closure would occur, including relevant monitoring activities. Additional development of multiple lines of evidence supporting the safety case of the proposed repository should be a high priority for the Yucca Mountain Project.

II. DOE Progress in Priority Areas

The DOE was responsive to the Boards recommendations in 2000, and progress was evident in each of the priority areas identified by the Board.

The DOE initiated an effort to quantify conservatisms and uncertainties that had not been quantified previously.

Waste package corrosion issues were to be examined in an external peer review beginning in 2001, and plans were developed for studies of fundamental corrosion mechanisms.

For its existing repository design, the DOE developed a low-temperature operating mode that can maintain repository temperatures below boiling indefinitely. (The Board remains concerned, however, that a comparison of high- and low-temperature designs is needed.)

Finally, the DOE participated in a Board meeting in April 2001 to review multiple lines of evidence for projecting repository performance, including the degree to which such lines of evidence that are independent of performance assessment can be found.

III. International Activities

Since its inception, the Board has sought to increase its knowledge and understanding of the problems shared by other nations as they try to find safe ways to dispose of spent nuclear fuel and high-level radioactive waste. The knowledge gained by the Board from its interactions with those involved in other programs and with counterpart entities hav-

ing responsibilities similar to the Boards in other countries has been very valuable in enhancing the Boards bases for evaluating the scientific and technical work of the DOE at Yucca Mountain, Nevada.

The Board hosted the mayor of Oskarshamn, Sweden, and two representatives of the municipality at the Boards May 2000 meeting in Pahrump, Nevada, and at meetings in Washington, D.C. The municipality is considering whether to proceed to the third step in repository site selection under way in Sweden. The process consists of three phases. After volunteering for consideration, communities may withdraw during the first two phases. Once a community decides to move forward to phase three, however, it is indicating its willingness to serve as the permanent repository site.

In June 2000, two representatives of the Board traveled to Finland and Sweden to discuss the status of corrosion research with scientists and engineers who are working on the repository development programs of those countries. The Board delegation met with representatives of ÅF-Energikonsult AB; the Swedish Nuclear Waste Management Company (SKBa company wholly owned by Swedish nuclear utilities and responsible for all spent-fuel storage and disposal in Sweden); the Swedish Council for Nuclear Waste (KASAMthe Boards counterpart in Sweden); Posiva Oy (Finlands repository development agency); and VTT Manufacturing Technology in Helsinki.

As the time for a site recommendation decision approaches in the United States, the Board sees a continued need to benefit from the experience and work of other programs and to keep the international community informed of work here.

IV. Evaluation of the Boards Performance in 2000

The Board believes that measuring its effectiveness by directly correlating improvements in the DOE program with Board actions and recommendations would be ideal. However, the Board has no implementing authority, so it cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome for the DOE program is, in most cases, (a) subjective and (b) an imprecise indicator of Board performance because implementation of Board recommendations by the DOE is outside the Boards direct control. Therefore, to measure its performance in a given year, the Board has developed the following performance measures for each annual performance goal.

1. Were the reviews, evaluations, and other activities undertaken under the auspices of the goal completed?

2. Were the results of the reviews, evaluations, and other Board activities communicated in a timely, understandable, and appropriate way to Congress and the Secretary of Energy?

If both measures are met, the Boards performance in meeting the annual goal will be judged effective. If only one measure is met, the Boards performance in achieving that goal will be judged minimally effective. Failing to meet either performance measure, without sufficient and compelling explanation, will result in a judgment that the Board has been ineffective in achieving that performance goal.

On the basis of these performance measures and the evaluation included in the appendices to this report, the Boards performance for fiscal year 2000 was found effective. For a more detailed discussion of the Boards evaluation, see Appendix H.

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Appendices

Appendix A
U.S. Nuclear Waste Technical Review Board Members: Curricula Vitae

Jared L. Cohon, Ph.D.; Chairman

On June 29, 1995, President Bill Clinton appointed Jared Cohon to the Nuclear Waste Technical Review Board. President Clinton appointed Dr. Cohon chairman on January 17, 1997.

Dr. Cohon is president of Carnegie Mellon University in Pittsburgh, Pennsylvania. He has more than 25 years of teaching and research experience, has written one book, and is author, coauthor, or editor of more than 80 professional publications. Among the awards that Dr. Cohon has received is the 1996 Joan Hodges Queneau Medal for outstanding engineering achievement in environmental conservation, awarded jointly by the American Association of Engineering Societies and the National Audubon Society. He is a member of Tau Beta Pi (National Engineering Honor Society) and of Sigma Xi (Scientific Research Society). Dr. Cohon is a registered Professional Engineer.

Dr. Cohon brings to the Board special expertise as a national authority on environmental and water resource systems analysis. His research interests focus on multiobjective programming, a technique for decision-making in situations with multiple conflicting objectives. He also has focused on water resources planning and management in the United States, South America, and Asia and on energy facility siting, including nuclear waste shipping and storage. In addition to his academic experience, he served as legislative assistant for energy and the environment to the Honorable Daniel P. Moynihan, United States Senator from New York, from 1977 to 1978.

Dr. Cohon is a member of the American Geophysical Union, the Institute for Operations Research and Management Science, the American Water Resources Association, and the American Society of Civil Engineers. He has served on several committees for the National Research Council, chairing the studies on the probabilities of extreme floods and on measuring and improving infrastructure.

In 1969, Dr. Cohon earned a bachelor of science degree in civil engineering from the University of Pennsylvania. He worked as a construction inspector in Philadelphia and as an engineering assistant for the Philadelphia Water Department before attending the Massachusetts Institute of Technology, where he earned a master's degree in civil engineering in 1972 and a Ph.D. in civil engineering in 1973. Dr. Cohon began his teaching career in 1973 at Johns Hopkins University, where he served as assistant, associate, and full professor in the Department of Geography and Environmental Engineering and as Assistant and Associate Dean of Engineering and Vice Provost for Research. In 1992, he became dean of the School of Forestry and Environmental Studies and professor of environmental systems analysis at Yale University. Dr. Cohon assumed his duties as president of Carnegie Mellon University in July 1997.

Dr. Cohon resides in Pittsburgh, Pennsylvania.

John W. Arendt, P.E.

On June 11, 1999, President Bill Clinton reappointed John Arendt to serve on the Nuclear Waste Technical Review Board. Mr. Arendt was first appointed to the Board in 1995.

John W. Arendt is senior consultant and founder of John W. Arendt Associates, Inc. Created in 1986, the firm offers consultation on program and project management, safety assessments and investigations, quality assurance, standards and regulations for uranium handling and processing, chemical safety audits, and safeguards and accountability. Mr. Arendt is a registered Professional Engineer and a certified nuclear materials manager.

Mr. Arendt brings to the Board five decades of experience in various phases of the nuclear fuel cycle, especially uranium processing, handling, safeguards and accountability, packaging, and transportation. He has extensive experience in the management of engineering projects, including uranium processing facilities and their quality assurance, quality control, and inspection. He is chairman of American National Standards Institute (ANSI) Accredited Standards Committee N14 on packaging and transportation of radioactive materials and nonnuclear hazardous wastes.

Mr. Arendt earned a bachelor of science degree in chemical engineering from Marquette University in 1943 and was a research engineer for the Manhattan Project at the University of Chicago from 1943 to 1945. He gained the bulk of his experience at Union Carbide Corporation's Nuclear Division in Oak Ridge, Tennessee, where he began as a production supervisor in 1945 and served in various department and project management positions through 1984. Before founding John W. Arendt Associates, Inc., in 1986, Mr. Arendt was a senior engineer with JBF Associates, Inc., where he provided technical and management assistance in uranium enrichment, standards and regulations, waste management, packaging and shipping, reactor activities, quality assurance, and safety.

Mr. Arendt resides in Oak Ridge, Tennessee.

Daniel B. Bullen, Ph.D.

On January 17, 1997, President Bill Clinton appointed Daniel Bullen to the Nuclear Waste Technical Review Board.

Dr. Daniel B. Bullen is associate professor of mechanical engineering, Department of Mechanical Engineering, at Iowa State University in Ames, Iowa. He has been teaching since 1989, and he served as Nuclear Engineering Program Coordinator at Iowa State University from 1993 to 1996 and as director of the Iowa State University Nuclear Reactor Laboratory from 1993 to 2001. He has 12 years of industry experience in nuclear engineering and materials science. He has edited and reviewed articles for such professional publications as Nuclear Technology, Journal of the American Ceramic Society, American Nuclear Society Transactions, and Encyclopedia of Chemical Technology. He has written or co-written more than 65 technical publications and reports and has contributed to three books. He is a registered Professional Engineer in mechanical, metallurgical, and nuclear engineering. Dr. Bullen's honors and awards include Tau Beta Pi (National Engineering Honor Society), Phi Kappa Phi, Sigma Xi (Scientific Research Society), Alpha Nu Sigma (Nuclear Engineering Scholastic Honor Society), a Lilly Teaching Fellowship at the Georgia Institute of Technology (1991), and two Outstanding Professor awards. He has appeared in Who's Who in Science and Engineering, Who's Who in America, and Who's Who in the World.

Dr. Bullen brings to the Board special expertise in performance assessment modeling of radioactive waste disposal facilities, performance assessment of engineered barrier systems, radiolysis effects in spent-fuel dry casks in storage environments, radiation effects on materials, and materials degradation in severe service environments.

Dr. Bullen is a member of the American Nuclear Society; ASM International; the American Society of Mechanical Engineers; the National Society of Professional Engineers; and the Minerals, Metals & Materials Society.

In 1978, Dr. Bullen earned a bachelor of science degree in engineering science from Iowa State University. He was a research assistant at the University of Wisconsin-Madison while earning master of science degrees in nuclear engineering in 1979 and materials science in 1981 and a Ph.D. in nuclear engineering in 1984. He then worked for Lawrence Livermore National Laboratory as an engineer until 1986, when he became senior engineer for Science & Engineering Associates, Inc., in Pleasanton, California. In 1988, he became president of DG Engineering Associates, providing technical consulting services to Lawrence Livermore National Laboratory. Dr. Bullen moved to North Carolina State University in 1989 as an assistant professor of nuclear engineering and to the Georgia Institute of Technology in 1990 as an assistant professor of mechanical engineering. He moved to Iowa State University in 1992 as an associate professor of nuclear engineering.

Dr. Bullen resides in Ames, Iowa.

Norman L. Christensen, Jr., Ph.D.

On January 17, 1997, President Bill Clinton appointed Norman Christensen to the Nuclear Waste Technical Review Board.

Dr. Norman L. Christensen, Jr., is professor of ecology and dean of the Nicholas School of the Environment at Duke University in Durham, North Carolina. He has been teaching for more than 27 years and has more than 80 scientific articles and books to his credit. Dr. Christensen is the recipient of the 1977 Duke Endowment Award for Teaching Excellence, the 1991 Distinguished Teaching Award for Trinity College of Arts and Sciences at Duke, and the 1994 Distinguished Scholar-Alumni Award from California State University-Fresno. He was the E.V. Komarek Lecturer at the 1989 Tall Timbers Fire Ecology Conference, a Fellow of the American Association for the Advancement of Science in 1993, and a recipient of the National Park Service's A. Starker Leopold Award for distinguished service. Dr. Christensen has served on more than 25 national and regional panels and commissions and on the editorial boards of American Midland Naturalist, Journal of Vegetation Science, and Journal of Wildland Fire.

Dr. Christensen brings to the Board special expertise in biology and ecology. His research interests include the effects of disturbance on structure and function of populations and communities; comparative biogeochemical and community responses to varying fire regimes; use of remote sensing systems (such as synthetic aperture radar) to evaluate long-term changes in forest ecosystems; and pattern analysis of forest development following cropland abandonment as affected by environment, stand history, and plant demographic patterns. He has written widely on the importance of natural disturbance in the management of forests, shrublands, and wetlands, and he is interested in applying basic ecological theory and models to ecosystem management.

Dr. Christensen is a member of the American Association for the Advancement of Science, the British Ecological Society, the Ecological Society of America, Sigma Xi (Scientific Research Society), the Society of American Foresters, and the National Association of Environmental Professionals.

In 1968, Dr. Christensen earned a bachelor's degree in biology from Fresno State College. He earned a master's degree in biology from Fresno State College in 1970 and a Ph.D. in biology from the University of California-Santa Barbara in 1973. He began his teaching career as an assistant professor in the Department of Botany at Duke University in 1973. He became an associate professor in 1979 and was elevated to full professor in 1987. He became dean of the Nicholas School of the Environment in 1991.

Dr. Christensen resides in Chapel Hill, North Carolina.

Paul P. Craig, Ph.D.

On January 30, 1997, President Bill Clinton appointed Paul Craig to the Nuclear Waste Technical Review Board.

Dr. Paul P. Craig is Professor of Engineering Emeritus at the University of California, Davis, and is a member of the university's Graduate Group in Ecology. He has more than 21 years of teaching experience and more than 100 refereed publications to his credit. Dr. Craig is a member of the Sierra Club's Global Warming and Energy committees and of the American Association for the Advancement of Science and is a Fellow of the American Physical Society. His awards include a John Simon Guggenheim Memorial Foundation Fellowship and a National Science Foundation Meritorious Service Award. He is a member of Phi Beta Kappa.

Dr. Craig brings to the Board special expertise and research interest in

energy policy issues associated with energy system responses to global environmental change.

In 1954, Dr. Craig earned a bachelor's degree in mathematics and physics from Haverford College. He earned a Ph.D. in physics from the California Institute of Technology in 1959. He began his career as a staff scientist at Los Alamos National Laboratory in 1959 and moved to Brookhaven National Laboratory in 1962 as a physicist and a group leader. In 1971, he became deputy and acting director of the Office of Energy Research and Development Policy of the National Science Foundation, where he provided policy analysis support to the President's science advisor and to the Office of Management and Budget. Dr. Craig became director of the University of California Council on Energy and Resources in 1975 and professor of engineering at the University of California, Davis, in 1977. He received his emeritus standing in 1994.

Until his appointment to the Nuclear Waste Technical Review Board,

Dr. Craig was a Lawrence Berkeley National Laboratory Participating Guest Scientist (beginning in 1976) and a member of the National Academy of Sciences–National Research Council Board on Radioactive Waste Management.

Dr. Craig resides in Martinez, California.

Debra S. Knopman, Ph.D.

On January 17, 1997, President Bill Clinton appointed Debra Knopman to the Nuclear Waste Technical Review Board.

Dr. Debra S. Knopman is a senior engineer at RAND Corporation in Arlington, Virginia. She has more than 24 publications in scientific and technical journals to her credit. Dr. Knopman is a member of the National Research Council's Commission on Geosciences, Environment, and Resources. She served briefly on the Board on Radioactive Waste Management and the Panel for the Review of the DOE Environmental Restoration Priority System before accepting a position in the Clinton administration in 1993. She is a member of the American Geophysical Union. Dr. Knopman was a 1978-1979 Henry Luce Foundation Scholar.

Dr. Knopman brings to the Board special expertise in hydrology, environmental and natural resources policy, systems analysis, and public administration.

In 1975, Dr. Knopman earned a bachelor's degree in chemistry from Wellesley College. She earned a master of science degree in civil engineering from the Massachusetts Institute of Technology in 1978 and a Ph.D. from the Department of Geography and Environmental Engineering at Johns Hopkins University in 1986. Dr. Knopman began her career as a freelance science writer and editor in Israel and the United States in 1975. Following her Luce Scholar fellowship, which she served in Taiwan from 1978 to 1979, she served as legislative assistant for energy and environmental issues to Senator Daniel P. Moynihan in Washington, D.C., from 1979 to 1980. She served as a professional staff member of the U.S. Senate Committee on Environment and Public Works from 1980 to 1983. She moved to the U.S. Geological Survey in 1984, beginning as a student assistant and progressing through being a research hydrologist to becoming chief of the systems analysis branch. In 1993, Dr. Knopman was appointed Deputy Assistant Secretary for Water and Science, U.S. Department of the Interior. She served as director of the Progressive Policy Institute's Center for Innovation and the Environment from 1995 to 2000.

Dr. Knopman resides in Washington, D.C..

Priscilla P. Nelson, Ph.D.

On January 17, 1997, President Bill Clinton appointed Priscilla Nelson to the Nuclear Waste Technical Review Board.

Dr. Priscilla P. Nelson is Director, Division of Civil and Mechanical Systems, for the Directorate for Engineering at the National Science Foundation. She formerly was professor of civil engineering at The University of Texas at Austin. Dr. Nelson has more than 13 years of teaching experience and more than 100 technical and scientific publications to her credit. She has served as a member of the U.S. National Committee for Rock Mechanics, the U.S. National Committee for Tunneling Technology, and the Board on Radioactive Waste Management, all activities of the National Research Council. She is a member of the American Rock Mechanics Association (ARMA), the American Society of Civil Engineers (ASCE), the International Tunnelling Association, the American Underground Construction Association, the Association of Engineering Geologists, the British Tunnelling Society, and other professional organizations. She is past president of the Geo-Institute of ASCE and of ARMA. Her honors and awards include Exxon Teaching Fellowships at The University of Texas at Austin (1985-1987), the Case Studies Award from the U.S. National Committee for Rock Mechanics (1988), the Haliburton Education Foundation Award of Excellence (1991), the Basic Research Award from the U.S. National Committee for Rock Mechanics (1993), and election to The Moles, an association of the heavy construction industry (1995). At the National Science Foundation, she has received the Director's Award for Integrative Collaboration three times, and she received the Director's Award for Meritorious Service in 1997. In 1999, she was appointed to the Senior Executive Service. Also in 1999, she received the Director's Award for Superior Accomplishment from the NSF.

Dr. Nelson brings to the Board special expertise in rock engineering and underground construction. In 1970, Dr. Nelson earned a bachelor's degree in geological sciences from the University of Rochester. She earned master's degrees in geology from Indiana University in 1976 and in structural engineering from the University of Oklahoma in 1979. She was awarded a Ph.D. in geotechnical engineering by Cornell University in 1983. Dr. Nelson's career has included service as a Peace Corps volunteer and employment as a field engineer for the Alaskan Resource Sciences Corporation from 1975 to 1977. She joined the faculty of The University of Texas at Austin in 1983 and became full professor and holder of the John Focht Teaching Fellowship before joining the National Science Foundation in 1996. She has served as a consultant for major underground construction projects, including for the Superconducting Super Collider project from 1985 through 1992.

Dr. Nelson resides in Arlington, Virginia.

Richard R. Parizek, Ph.D.

On February 11, 1997, President Bill Clinton appointed Richard Parizek to the Nuclear Waste Technical Review Board.

Dr. Richard R. Parizek is a professor of geology and geoenvironmental engineering at The Pennsylvania State University; president of Richard R. Parizek and Associates, consulting hydrogeologists and environmental geologists; and a registered Professional Geologist. He has more than 37 years of teaching experience and numerous journal publications to his credit. His awards include a cooperative fellowship from the National Science Foundation (1960), a superior achievement award from the U.S. Environmental Protection Agency (1976), the Clearwater Conservancy Award (1985), the Matthew J. and Anne C. Wilson Teaching Award (1986), and the medal for distinguished service to environmental science and engineering of the Institute of Meteorology and Water Management, Warsaw, Poland (1991). Dr. Parizek was appointed an administrative law judge of the Atomic Safety and Licensing Board Panel of the U.S. Nuclear Regulatory Commission in 1990, a position he left upon appointment to the Nuclear Waste Technical Review Board.

Dr. Parizek brings to the Board special expertise in hydrogeology and environmental geology. His research interests include the hydrogeology of karst, fractured rock, and glaciated terranes; factors controlling groundwater occurrence and movement; and the relationship between land use and groundwater pollution resulting from disposal of nuclear waste and other hazardous substances.

Dr. Parizek is a member of the American Association for the Advancement of Science, the American Geophysical Union, the American Institute of Hydrology, the Geological Society of America, and Sigma Xi (Scientific Research Society).

In 1956, Dr. Parizek earned a bachelor's degree in geology from the University of Connecticut. He earned a master of science degree in geology in 1960 and a Ph.D. in geology in 1961, both from the University of Illinois. Dr. Parizek began his career as a research assistant with the Illinois State Geological Survey in 1956 and began teaching in 1961 as an assistant professor of geology and geophysics at The Pennsylvania State University. He became a full professor in 1971 and continues to teach in the Department of Geosciences. Dr. Parizek also has been a visiting scientist with the U.S. Geological Survey and a visiting scholar at Stanford University, the Desert Research Institute, Changchun College of Geology and the Institute of Karst Geology in the Peoples' Republic of China, and National Cheng Kuug University in Taiwan.

Dr. Parizek resides in State College, Pennsylvania.

Donald D. Runnells, Ph.D.

On June 23, 1998, President Bill Clinton appointed Donald Runnells to the Nuclear Waste Technical Review Board.

Dr. Donald D. Runnells is professor emeritus in the Department of Geological Sciences at the University of Colorado. He also is a technical consultant to Shepherd Miller, Inc., a firm providing environmental and engineering consultation primarily to the mining industry and to government agencies and other concerns. He has more than 27 years of teaching experience and numerous journal publications to his credit. Dr. Runnells is a Fellow of the Geological Society of America. His awards include selection as a National Science Foundation Graduate Fellow, election to Phi Kappa Phi Honorary Scholastic Fraternity, and election to the presidency of the Association of Exploration Geochemists. Dr. Runnells has been an editor or on the editorial board for Journal of Geochemical Exploration, Interface, Science of the Total Environment, Chemical Geology, and Journal of Applied Geochemistry. He has been a member of the Colorado Governor's Council on Science and Technology, the Review Board on Disposal and Permanent Storage of Inactive Uranium Tailings at Sandia National Laboratory, the Materials Review Board at Argonne National Laboratory, the Scientific Advisory Board on Toxics in Water for the Electric Power Research Institute, and several boards and panels of the National Research Council of the National Academy of Sciences.

Dr. Runnells brings to the Board special expertise in geochemistry, hydrochemistry, and mineral deposits.

He is a member of the Geochemical Society, the Association of Exploration Geochemists, and the American Chemical Society.

In 1958, Dr. Runnells earned a bachelor's degree in geology from the University of Utah. He earned a master of arts degree in geology in 1960 and a Ph.D. in geochemistry and geology in 1964, both from Harvard University. Dr. Runnells began his career as a teaching assistant at Harvard University in 1961. In 1963, he began working with Shell Development Company as a geochemist. He returned to teaching in 1967 as an assistant professor at the University of California. He moved to the University of Colorado in 1969. He was appointed full professor in 1975 and was elected chairman of the Department of Geological Sciences in 1990. He continued in that position until 1993, when he became president of Shepherd Miller, Inc. He now serves as a technical consultant to Shepherd Miller, Inc., specializing in water-rock interaction and water contamination.

Dr. Runnells resides in Fort Collins, Colorado.

Alberto A. Sagüés, Ph.D.

On June 11, 1999, President Bill Clinton reappointed Alberto Sagüés to serve on the Nuclear Waste Technical Review Board. Dr. Sagüés was first appointed to the Board in 1997.

Dr. Alberto A. Sagüés is Distinguished University Professor in the Department of Civil and Environmental Engineering at the University of South Florida and is a registered Professional Engineer. He has 20 years of teaching experience and more than 120 technical publications to his credit. From 1988 to 1992, Dr. Sagüés served as an expert task group member of the Strategic Highway Research Program of the National Research Council. He has made technical presentations to professional and scientific audiences across the United States and Canada and throughout Europe, Central America, and South America. He holds three patents related to corrosion control.

Dr. Sagüés brings to the Board special expertise in corrosion and materials engineering, physical metallurgy, and electrochemical measurements. His research interests are in corrosion of reinforcing steel in concrete and durability forecasting of civil infrastructure.

Dr. Sagüés is a member of NACE International (formerly the National Association of Corrosion Engineers), the Electrochemical Society, the American Society for Testing and Materials, the American Concrete Institute, and ASM International (formerly the American Society for Metals).

A native of Argentina, Dr. Sagüés earned his undergraduate degree in physics from the National University of Rosario, Argentina, in 1968. He earned a Ph.D. in metallurgy from Case Western Reserve University in Cleveland in 1972. A citizen of the United States since 1979, Dr. Sagüés began his career as a visiting assistant professor at Columbia University in 1972, performed postdoctoral research in 1973, and was a guest scientist at the Solid State Research Institute of the Jülich Nuclear Research Center in West Germany from 1974 to 1976. He served as a research associate at Argonne National Laboratory from 1976 to 1978 and as senior metallurgist, manager, and associate laboratory director of the Kentucky Center for Energy Research Laboratory from 1978 to 1985. At the same time, he continued his teaching career at the University of Kentucky. In 1985, he moved to the University of South Florida as an associate professor. Dr. Sagüés became professor of materials engineering in 1991 and Distinguished University Professor, Department of Civil and Environmental Engineering, in 1999.

Dr. Sagüés resides in Lutz, Florida.

Jeffrey Wong, Ph.D.

On June 11, 1999, President Bill Clinton reappointed Jeffrey Wong to serve on the Nuclear Waste Technical Review Board. Dr. Wong was first appointed to the Board in 1995.

Dr. Jeffrey Wong is Deputy Director for Science, Pollution Prevention and Technology; Department of Toxic Substances Control; California Environmental Protection Agency. Dr. Wong has nearly 20 years of experience in toxicology, including assessment of exposure risks at hazardous waste sites, at hazardous waste treatment, storage, and disposal facilities, and at hazardous material spills and accidents. He is an instructor in environmental toxicology at the University of California, Davis, and he has worked with the California Department of Justice in forensic toxicology. Dr. Wong was a National Institutes of Environmental Health Sciences Predoctoral Fellow in environmental toxicology and was the recipient of the American Academy of Forensic Sciences Regional Award in Toxicology in 1984.

Dr. Wong brings to the Board extensive experience in risk assessment and scientific team management. He served as the risk evaluation expert on the external expert review panel to the Consortium for Environmental Risk Evaluation, a program of Tulane and Xavier universities.

Dr. Wong also has served on National Academy of Sciences / National Research Council committees relating to remedial action for hazardous waste sites and the U.S. Department of Energy's environmental restoration program. He is a member of the editorial board of Journal of Contaminated Soils and is an advisory board member for the Association for the Environmental Health of Soils.

Dr. Wong earned a bachelor of arts degree in bacteriology in 1973, a master of science degree in food science and technology in 1976, and a Ph.D. in pharmacology and toxicology in 1981, all from the University of California, Davis. He worked for the California Department of Justice as a senior forensic toxicologist after his doctoral work. He moved to the California Department of Food and Agriculture as a staff toxicologist before beginning his career with the California Environmental Protection Agency in July 1985. Before assuming his current position, he was chief of the Human and Ecological Risk Division of the Department of Toxic Substances Control, California Environmental Protection Agency.

Dr. Wong resides in Sacramento, California.

Appendix B
Meeting List for 2000

January 25 –26
Winter Board Meeting
Las Vegas, Nevada
Topics:
- Addressing uncertainty; Repository safety strategy;
- Scientific program update

January 27
Board Business Meeting
Las Vegas, Nevada

April 30
Board Business Meeting
Pahrump, Nevada

May 1
Spring Board Meeting
Pahrump, Nevada
Topic:
- Repository design and geochemistry

May 2-3
Board Business Meeting
Las Vegas, Nevada

July 10
Meeting of the Panel on the Waste Management System
Idaho Falls, Idaho
Topic:
- Spent fuel transportation

August 1-2
Summer Board Meeting
Carson City, Nevada
Topic:
- Scientific and technical issues and Total system performance assessment

August 3
Board Business Meeting
Carson City, Nevada

December 4-6
Board Business Meeting
Durham, North Carolina

Appendix C
Panel Organization
Calendar Year 2000

1. Panel on Site Characterization

Chairman:	Dr. Debra S. Knopman	Staff:	Leon Reiter[1]
Members:	Dr. Priscilla P. Nelson		David M. Diodato
	Dr. Richard R. Parizek		Daniel J. Fehringer
	Dr. Donald D. Runnells		
	Dr. Alberto A. Sagüés		

2. Panel on the Repository

Chairman:	Dr. Daniel B. Bullen	Staff:	Carlos A. W. Di Bella[1]
Members:	Mr. John W. Arendt		Karyn D. Severson
	Dr. Priscilla P. Nelson		
	Dr. Donald D. Runnells		
	Dr. Alberto A. Sagüés		

3. Panel on the Waste Management System

Chairman:	Mr. John W. Arendt	Staff:	Michael G. Carroll[2]
Members:	Dr. Daniel B. Bullen		Carlos A. W. Di Bella[1]
	Dr. Norman L. Christensen, Jr.		Daniel S. Metlay
	Dr. Paul P. Craig		Karyn D. Severson
	Dr. Debra S. Knopman		

4. Panel on the Environment, Regulations, and Quality Assurance

Chairman:	Dr. Jeffrey Wong	Staff:	Daniel J. Fehringer[1]
Members:	Mr. John W. Arendt		Daniel S. Metlay
	Dr. Norman L. Christensen, Jr.		
	Dr. Paul P. Craig		
	Dr. Debra S. Knopman		

5. Panel on Performance Assessment

Chairman:	Dr. Daniel B. Bullen	Staff:	Leon Reiter[1]
Members:	Dr. Paul P. Craig		Carlos A. W. Di Bella
	Dr. Richard R. Parizek		Daniel S. Metlay
	Dr. Alberto A. Sagüés		
	Dr. Jeffrey Wong		

[1]Staff coordinator
[2]Staff coordinator until May 2000

Appendix D
U.S. Nuclear Waste Technical Review Board Publications

The following publications are available by mail from the Nuclear Waste Technical Review Board or electronically from the Board's web site at **www.nwtrb.gov**.

Report by letter to the Secretary of Energy and Congress. December 2000

This report, in the form of a letter, presents a brief update of the Board's views on the status of the DOE program.

Report to the U.S. Congress and the Secretary of Energy. April 2000.

In this report, the Board summarizes its major activities in calendar year 1999. Among the activities discussed in the report is the Board's 1999 review of the DOE's viability assessment (VA) of the Yucca Mountain site. The Board's evaluation of the VA concludes that Yucca Mountain continues to warrant study as the candidate site for a permanent geologic repository and that work should proceed to support a decision on whether to recommend the site for repository development. The Board suggests that the 2001 date for a decision is very ambitious, and focused study should continue on natural and engineered barriers. The Board states that a credible technical basis does not currently exist for the above-boiling repository design included in the VA. The Board recommends evaluation of alternative repository designs, including lower-temperature designs, as a potential way to help reduce the significance of uncertainties related to predictions of repository performance.

Report to the U.S. Congress and The Secretary of Energy. April 1999.

In this report, the Board summarizes its major activities during calendar year 1998. The report discusses the research needs identified in the DOE's recently issued *Viability Assessment* of the Yucca Mountain site, including plans to gather information on the amount of water that will eventually seep into repository drifts, whether formations under the repository will retard the migration of radionuclides, the flow-and-transport properties of the groundwater that lies approximately 200 meters beneath the repository horizon, and long-term corrosion rates of materials that may be used for the waste packages. The report describes other activities undertaken by the Board in 1998, including a review of the hypothesis that there were hydrothermal upwellings at Yucca Mountain, a workshop held to increase understanding of the range of expert opinion on waste package materials, and a review of the DOE's draft environmental impact statement for the Yucca Mountain site.

Report to the U.S. Congress and the Secretary of Energy: Moving Beyond the Viability Assessment. April 1999.

In its report, the Board offers its views on the DOE's December 1998 *Viability Assessment* of the Yucca Mountain site in Nevada. The Yucca Mountain site is

being characterized to determine its suitability as the location of a permanent repository for disposing of spent nuclear fuel and high-level radioactive waste. The Board discusses the need to address key uncertainties that remain about the site, including the performance of the engineered and natural barriers. The Board addresses the DOE's plans for reducing those uncertainties and suggests that consideration be given to alternative repository designs, including ventilated low-temperature designs that have the potential to reduce uncertainties and simplify the analytical bases for determining site suitably and for licensing. The Board also comments on the DOE's total system performance assessment, the analytical tool that pulls together information on the performance of the repository system.

Report to the U.S. Congress and The Secretary of Energy. November 1998.

In its report, the Board offers its views on the direction of future scientific and technical research under way and planned by the DOE as part of its program for characterizing a site at Yucca Mountain, Nevada, as a potential repository for spent fuel and high-level radioactive waste. The Board discusses some of the remaining key scientific and technical uncertainties related to performance of a potential repository. The Board's report addresses some of these uncertainties by examining information about the proposed repository system presented to it in meetings and other technical exchanges. The Board considers and comments on some of the important connections between the site's natural properties and the current designs for the waste package and other engineered features of the repository.

Review of Material on Hydrothermal Activity. July 24, 1998.

This series of documents concerns the Board's review of material related to Mr. Jerry Szymanski's hypothesis of ongoing, intermittent hydrothermal activity at Yucca Mountain and large earthquake-induced changes in the water table there. The series includes a cover letter, the Board's review, and the reports of the four consultants the Board contracted with to assist in the review.

1997 Findings and Recommendations. April 1998.

This report details the Board's activities in 1997 and covers, among other things, the DOE's viability assessment, due later this year; underground exploration of the candidate repository site at Yucca Mountain, Nevada; thermal testing underway at the site; what happens when radioactive waste reaches the water table beneath Yucca Mountain; transportation of spent fuel; and the use of expert judgment. The Board makes four recommendations in the report concerning (1) the need for the DOE to begin now to develop alternative design concepts for a repository, (2) the need for the DOE to include estimates of the likely variation in doses for alternative candidate critical groups in its interim performance measure for Yucca Mountain, (3) the need for the DOE to evaluate whether site-specific biosphere data is needed for license application, and (4) the need for the DOE to make full and effective use of formally elicited expert judgment.

Report by letter to the Secretary of Energy and the Congress. December 23, 1997.

This report, in the form of a letter, addresses several key issues, including the DOE's viability assessment of the Yucca Mountain site, design of the potential repository and waste package, the total system performance assessment, and the enhanced characterization of the repository block (east-west crossing).

Report to the U.S. Congress and the Secretary of Energy: January to December 1996. March 1997.

This report summarizes Board activities during 1996. Chapter 1 provides an overview of the Department of Energy's high-level nuclear waste management program from the Board's perspective, including the viability assessment, program status, and progress in exploration and testing. The chapter ends with conclusions and recommendations. Chapter 2 examines the three technical issues–hydrology, radionuclide transport, and performance assessment–and provides conclusions and recommendations. Chapter 3 deals with design , including the concept for underground operations, repository layout and design alternatives, construction planning, thermal loading, and engineered barriers. The

Board also makes conclusions and recommendations. Chapter 4 provides an overview of recent Board activities, including the international exchange of information, the Board's visit to the River Mountains tunnel, and a presentation to the NRC. Appendices include information on Board members, the organization of the Board's panels, meetings held in 1996 and scheduled for 1997, the DOE's responses to previous Board recommendations, a list of Board publications, references for the report, and a glossary of technical terms.

Nuclear Waste Management in the United States – The Board's Perspective. June 1996.

This publication was developed from remarks made by Dr. John Cantlon, Chairman of the Nuclear Waste Technical Review Board, at Topseal '96, an international conference on nuclear waste management and disposal. The meeting was sponsored by the Swedish Nuclear Fuel and Waste Management Company and the European Nuclear Society. The publication highlights the Board's views on the status of the U.S. program for management and disposal of commercial spent nuclear fuel and provides a brief overview of the program's organization. It summarizes the DOE's efforts to characterize the Yucca Mountain site and to develop a waste isolation strategy for the site. The publication also outlines legislative and regulatory changes under consideration at that time and the Board's views on the technical implications of those possible changes.

Report to the U.S. Congress and the Secretary of Energy: 1995 Findings and Recommendations. April 1996.

This report summarizes Board activities during 1995. Chapter 1 provides an overview of the DOE's high-level waste management program, including highlights, current status, legislative issues, milestones, and recommendations. Chapter 2 reports on Board Panel activities and Chapter 3 provides information on new Board members, meetings attended, interactions with Congress and congressional staff, Board presentations to other organizations, interactions with foreign programs, and a review of the Board's report on interim storage of spent nuclear fuel. Appendices include Board testimony and statements before Congress, Board correspondence of note, and the Department of Energy's responses to recommendations in previous Board reports.

Disposal and Storage of Spent Nuclear Fuel – Finding the Right Balance. March 1996.

This special report caps more than two years of study and analysis by the Board into the issues surrounding the need for interim storage of commercial spent nuclear fuel and the advisability and timing of the development of a federal centralized storage facility. The Board concludes in the report that the DOE's efforts should remain focused on permanent geologic disposal and the site investigations at Yucca Mountain, Nevada; that planning for a federal centralized spent fuel storage facility and the required transportation infrastructure be begun now, but actual construction delayed until after a site-suitability decision is made about the Yucca Mountain site; that storage should be developed incrementally; that limited, emergency backup storage capacity be authorized at an existing nuclear facility; and that, if the Yucca Mountain site proves unacceptable for repository development, other potential sites for both centralized storage and disposal be considered.

Report by letter to the Secretary of Energy and the Congress. December 13, 1995.

This report, in the form of a letter, addresses the DOE's progress in underground exploration with the tunnel boring machine, advances in the development of a waste isolation strategy, new work on engineered barriers, and progress being made in performance assessment.

Report to the U.S. Congress and the Secretary of Energy: 1994 Findings and Recommendations. March 1995.

This report summarizes Board activities during 1994. It covers aspects of the DOE's Program Approach, their emerging waste isolation strategy, and their transportation program. It also explores the Board's views on minimum exploratory requirements and thermal-loading issues. The report focuses a chapter on the lessons that have been

learned in site assessment from projects around the world. Another chapter deals with volcanism and resolution of difficult issues. The Board also details its observations from its visit to Japan and the Japanese nuclear waste disposal program. Findings and recommendations in the report centered around structural geology and geoengineering, hydrogeology and geochemistry, the engineered barrier system, and risk and performance analysis.

Report to The U.S. Congress and The Secretary of Energy: January to December 1993. May 1994.

This report summarizes Board activities primarily during 1993. It reviews the nuclear waste disposal programs of Belgium, France, and the United Kingdom; elaborates on the Board's understanding of the radiation protection standards being reviewed by the National Academy of Sciences; and, using "future climates" as an example, examines the DOE's approach to "resolving difficult issues." Recommendations center on the use of a systems approach in all of OCRWM's programs, prioritization of site-suitability activities, appropriate use of total system performance assessment and expert judgment, and the dynamics of the Yucca Mountain ecosystem.

Letter Report to Congress and the Secretary of Energy. February 1994.

This report is issued in letter format due to impending legislative hearings on the DOE's fiscal year 1995 budget and new funding mechanisms sought by the Secretary of Energy. The 8-page report (ninth in the NWTRB series) restates a recommendation made in the Board's Special Report, that an independent review of the OCRWM's management and organizational structure be initiated as soon as possible. Also, it adds two additional recommendations: ensure sufficient and reliable funding for site characterization and performance assessment, whether the program budget remains level or is increased, and build on the Secretary of Energy's new public involvement initiative by expanding current efforts to integrate the views of the various stakeholders during the decision-making process—not afterward.

Underground Exploration and Testing at Yucca Mountain A Report to Congress and the Secretary of Energy. October 1993.

This report (eighth in the NWTRB series) focuses on the ESF at Yucca Mountain, Nevada: the conceptual design, planned exploration and testing, and excavation plans and schedules. In addition to a number of detailed recommendations, the Board makes three general recommendations. First, the DOE should develop a comprehensive strategy that integrates exploration and testing priorities with the design and excavation approach for the exploratory facility. Second, underground thermal testing should be resumed as soon as possible. Third, the DOE should establish a geoengineering board with expertise in the engineering, construction, and management of large underground projects.

Special Report to Congress and the Secretary of Energy. March 1993.

The Board's seventh report provides a nontechnical approach for those not familiar with the details of the DOE's high-level nuclear waste management program. It highlights three important policy issues: the program is driven by unrealistic deadlines, there is no integrated waste management plan, and program management needs improvement. The Board makes three specific recommendations: amend the current schedule to include realistic intermediate milestones; develop a comprehensive, well-integrated plan for the overall management of all spent nuclear fuel and high-level defense waste from generation to disposal; and implement an independent evaluation of the Office of Civilian Radioactive Waste Management's (OCRWM) organization and management. These recommendations should be implemented without slowing the progress of site-characterization activities at Yucca Mountain.

Sixth Report to the U.S. Congress and the U.S. Secretary of Energy. December 1992.

The sixth report begins by summarizing recent Board activities, congressional testimony, changes in Board makeup, and the Little Skull Mountain earthquake. Chapter 2 details panel activities and offers seven technical recommendations on the dan-

gers of a schedule-driven program; the need for top-level systems studies; the impact of defense high-level waste; the use of high capacity, self-shielded waste package designs; and the need for prioritization among the numerous studies included in the site-characterization plans. In Chapter 3, the Board offers candid insights to the high-level waste management program in five countries, specifically those areas that might be applicable to the U.S. program, including program size and cost, utility responsibilities, repository construction schedules, and alternative approaches to licensing. Appendix F provides background on the Finnish and Swiss programs.

Fifth Report to the U.S. Congress and the U.S. Secretary of Energy. June 1992.

The Board's fifth report focuses on the cross-cutting issue of thermal loading. It explores thermal-loading strategies (U.S. and others) and the technical issues and uncertainties related to thermal loading. It also details the Board's position on the implications of thermal loading for the U.S. radioactive waste management system. Also included are updates on Board and panel activities during the reporting period. The report offers fifteen recommendations to the DOE on the following subjects: ESF and repository design enhancements, repository sealing, seismic vulnerabilities (vibratory ground motion and fault displacement), the DOE approach to the engineered barrier system, and transportation and systems program status.

Fourth Report to the U.S. Congress and the U.S. Secretary of Energy. December 1991.

The fourth report provides update on the Board's activities and explores in depth the following areas: exploratory studies facility (ESF) construction; test prioritization; rock mechanics; tectonic features and processes; volcanism; hydrogeology and geochemistry in the unsaturated zone; the engineered barrier system; regulations promulgated by the Environmental Protection Agency, the Nuclear Regulatory Commission (NRC), and the DOE; the DOE performance assessment program; and quality assurance in the Yucca Mountain project. Ten recommendations are made across these diverse subject areas. Chapter 3 offers insights from the Board's visit with officials from the Canadian nuclear power and spent fuel disposal programs. Background on the Canadian program is in Appendix D.

Third Report to the U.S. Congress and the U.S. Secretary of Energy. May 1991.

The third report briefly describes recent Board activities and congressional testimony. Substantive chapters cover exploratory shaft facility alternatives, repository design, risk-benefit analysis, waste package plans and funding, spent fuel corrosion performance, transportation and systems, environmental program concerns, more on the DOE task force studies on risk and performance assessment, federal quality assurance requirements for the repository program, and the measurement, modeling, and application of radionuclide sorption data. Fifteen specific recommendations are made to the DOE. Background information on the German and Swedish nuclear waste disposal programs is included in Appendix D.

Second Report to the U.S. Congress and the U.S. Secretary of Energy. November 1990.

The Board's second report begins with the background and framework for repository development and then opens areas of inquiry, making 20 specific recommendations concerning tectonic features and processes, geoengineering considerations, the engineered barrier system, transportation and systems, environmental and public health issues, and risk and performance analysis. The report also offers concluding perspectives on DOE progress, the state of Nevada's role, the project's regulatory framework, the nuclear waste negotiator, other oversight agencies, and the Board's future plans.

First Report to the U.S. Congress and the U.S. Secretary of Energy. March 1990.

The first report sets the stage for the Board's evaluation of the Department of Energy's (DOE) program to manage the disposal of the nation's spent fuel and high-level waste. The report outlines briefly the legislative history of the nation's spent fuel and

high-level waste management program including its legal and regulatory requirements. The Board's evolution is described, along with its protocol, panel breakdown, and reporting requirements. The report identifies major issues based on the Board's panel breakdown, and highlights five cross-cutting issues.

Appendix E
Communications Between the Board and the OCRWM

In addition to published reports, the Board periodically writes letters to the Director of the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM). The letters typically provide the OCRWM with the Board's views on specific technical areas earlier than do Board reports. The letters are posted on the Board's Web site after they have been sent to the OCRWM. For archival purposes, the four letters written during calendar year 2000 are reproduced here

The OCRWM typically responds to the Board's reports and letters, indicating its plans to respond to the Board's recommendations. Included here are the OCRWM's responses received by the Board during calendar year 2000. Inclusion of these responses does not imply the Board's concurrence.

Letter from Chairman Jared L. Cohon to Lake H. Barrett, Acting Director, OCRWM; November 10, 1999.
Subject: Board's reactions to presentations at September 1999 Board meeting.

Letter from Ivan Itkin, Director, OCRWM, to Chairman Jared L. Cohon; January 14, 2000.
Subject: The DOE's response to November 10, 1999, Board letter.

Letter from Chairman Jared L. Cohon to Wendy R. Dixon, EIS Project Manager, Yucca Mountain Site Characterization Office; February 7, 2000.
Subject: The DOE's proposed environmental impact statement for a geologic repository at Yucca Mountain, Nevada.

Letter from Chairman Jared L. Cohon to Ivan Itkin, Director, OCRWM; March 20, 2000.
Subject: Quantification of uncertainties in performance characterization.

Letter from Chairman Jared L. Cohon to Ivan Itkin, Director, OCRWM; March 20, 2000.
Subject: Board's reactions to presentations at January 2000 Board meeting.

Letter from Ivan Itkin, Director, OCRWM, to Chairman Jared L. Cohon; June 6, 2000.
Subject: The DOE's response to March 20, 2000, Board letter about January 2000 Board meeting.

Letter from Chairman Jared L. Cohon to Ivan Itkin, Director, OCRWM; June 16, 2000.
Subject: Board's reactions to presentations at May 2000 Board meeting.

Letter from Chairman Jared L. Cohon to Ivan Itkin, Director, OCRWM; September 20, 2000.
Subject: Board's reactions to presentations at August 2000 Board meeting.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

November 10, 1999

Mr. Lake H. Barrett
Acting Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Ave.
RW-2/5A-085
Washington, DC 20585

Dear Mr. Barrett:

As has become customary, I am writing to give you the Board's reactions to information presented by the DOE at the Board's latest meeting, which was held in Alexandria, Virginia, on September 14-15, 1999.

Board members uniformly feel that the meeting was very productive. This outcome was due, in large part, to the participation by the DOE and its contractors. The Board was pleased with the efforts of your team to develop presentations that addressed specific Board issues and concerns. The presentations were of high quality, well-integrated, and tightly focused. DOE and contractor staff responded to the Board's questions in an open and informative fashion.

The Board encourages the DOE to continue important work in three areas. First, the DOE should complete its latest revision of the repository safety strategy. This document can establish a critical foundation for explaining to both policy-makers and members of the general public how a repository at Yucca Mountain might function, for prioritizing investigations, and for developing a licensing safety case. Second, the DOE should continue pursuing experiments in the east-west cross drift aggressively. These studies can produce important data about seepage into the drifts and flow in the unsaturated zone, variables that strongly influence repository performance. Finally, the Board realizes that the DOE is making progress in evaluating new designs for the waste package and the engineered barrier system. For example, corrosion testing has produced important information about the degradation rates of Alloy 22. This work needs to be sustained into the future because it supports a central premise of the repository safety case.

The Board would like to communicate to the DOE the following specific thoughts about some of the topics that were addressed at the meeting.

Telephone: 703-235-4473 Fax: 703-235-4495

Repository Safety Strategy

Previously the Board stated that an appropriate repository safety strategy consists of an assessment of projected repository performance, design margin and defense-in-depth, consideration of disruptive processes and events, insights from natural or man-made analogs, and a performance confirmation plan. The Board is pleased, therefore, that the DOE is revising its repository safety strategy along these lines in light of new information collected and changes in repository design adopted since the viability assessment was completed. In particular, the Board is encouraged by the importance attached to demonstrating defense-in-depth. Barrier importance analysis seems to be a promising vehicle for describing how much defense-in-depth is available within a repository system. The Board, however, believes that this methodology needs to be refined further before valid conclusions can be drawn about defense-in-depth.

According to the presentations at the meeting, the DOE plans to focus on seven "principal factors." These factors apparently will strongly influence what investigations will be conducted during the next two years. Moreover, these factors apparently will be the key variables for upcoming performance assessments; other, less important, influences on repository performance may be only bounded. Given the importance assigned by the DOE to these factors, it is essential that their selection be based on rigorous technical analyses that are clearly presented and supported with as much empirical data as possible. The DOE also will need to consider carefully whether bounding other, less important, variables is appropriate. Unless the DOE can support its choice of principal factors and its use of bounding analysis, making the repository safety strategy technically persuasive will be difficult.

Model Validation

As DOE's presentations and our subsequent roundtable discussion revealed, the technical defensibility of a mathematical model of complex and only partially observed physical processes can sometimes be a matter of degree. In some situations, however, particularly under conditions beyond those for which calibration data are available, the model's inadequacies may clearly and unequivocally render it invalid. The use to which the model will be put may affect the standard by which technical defensibility is judged. For example, a model like TSPA that is used to guide decision-makers carries a higher burden of defensibility than a model that is used by field investigators to gain detailed process-level understanding and to guide a discrete and limited field sampling program.

On the basis of the DOE presentations, the Board is concerned that significant issues associated with model validation may not be examined adequately by the time the final site recommendation report is currently scheduled to be sent to the President. Among the questions the Board believes that the DOE needs to address in a technically defensible way are the following.

- Have sufficient data been collected to test and to evaluate adequately alternative process-level models?

- To what extent will multiple and independent lines of evidence, including natural analogs, be marshaled to test a model's validity?
- What will be the basis for judging a model's validity over long periods of time when the model was calibrated using short-term data?
- How will external peer review be used in the validation process?
- How will the validity of the overall performance assessment be judged in relation to the validity of the individual process models?

Answering these questions is admittedly challenging. Nonetheless, the Board feels that providing policy-makers, the technical community, and the general public with well-developed responses to the questions is essential for developing a credible site recommendation report.

Treatment of Uncertainty

As you know, the Board has a long-standing interest in how the DOE analyzes and presents the inherent uncertainty that will surround its performance assessments. The Board realizes that the DOE will have to follow applicable regulations and regulatory guidance when it presents its performance assessment findings in the context of a license application. The DOE has significantly more discretion, however, in how it treats uncertainty in the site recommendation report. In particular, the Board believes that the DOE has an important obligation to present its technical analyses in a way that gives policy-makers in the executive and legislative branches as well as interested members of the general public a clear understanding of the uncertainties involved in projecting the performance of a repository at Yucca Mountain.

The Board will be devoting a significant part of its upcoming meeting in January to how uncertainty can be analyzed and presented. Among the topics that will be considered are the following.

- The different kinds of uncertainty and how they can be treated
- Displaying uncertainty in a manner that best communicates its nature and extent
- Alternative ways of incorporating and considering uncertainty in decision-making.

After the January meeting, the Board will provide you with additional views on the evaluation and description of uncertainty.

Modeling Results and Technical Investigations

The Board wants to comment on two presentations. The presentation dealing with the model of seepage flux into a repository drift concluded tentatively that seepage in drifts constructed in the middle nonlithophysal zone would not occur unless the percolation flux exceeds 1000 mm/year. This conclusion is an extremely important one, but as acknowledged in the technical analysis, it is highly dependent on assumptions about the shape of the drift and

about its long-term structural integrity. The Board will be looking closely at this model and will comment in greater detail about its appropriateness for inclusion in forthcoming performance assessments.

The presentation on waste package degradation indicated that valuable information is being collected on Alloy 22 at a rapid pace. However, concern still exists about the effects on corrosion of radiolytic species, including species formed in the vapor phase. Resolving that concern may necessitate additional experimental and theoretical work. In addition, in the last year or two, the project has done a significant amount of work to determine, or at least to bracket, the entire range of chemical compositions and temperatures that could exist in water films on waste package surfaces. It is important that the DOE's suite of corrosion tests continues to be performed in environments that approximate that range. Finally, the information needed to evaluate the adequacy of the new drip shield design is still fragmentary. The DOE has not established the technical foundation for the performance claims it is making for this element of the engineered subsystem.

In closing, I would like to repeat the Board's view that the DOE team's efforts made the Board's September meeting highly productive.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

Department of Energy
Washington, DC 20585

January 14, 2000

JAN 24 2000

Dr. Jared L. Cohon
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, Virginia 22201-3367

Dear Dr. Cohon ~~Jerry~~

Thank you for your letter of November 10, 1999, providing the Board's perspective on the information presented by the Department at the September 14-15, 1999, Board meeting. We appreciate your compliments on the integration and quality of the presentations.

Your letter encourages the Department to continue important work in three areas: completing the latest revision of the repository safety strategy, testing in the cross drift related to seepage into drifts and flow in the unsaturated zone, and evaluating the new designs for the waste package and the engineered barrier system. We agree with the Board and are pursuing high priority work in these three areas. Revision 3 of our repository safety strategy was completed earlier this month. The next revision of the strategy will define the safety case for site recommendation. This revision will be traceable to the total system performance assessment and process model reports that support the site recommendation consideration report. In addition, we continue to test in the east-west cross drift and to evaluate and test new design concepts for the waste package and the engineered barrier system.

Your letter also raises two important issues related to analyzing repository performance: how to analyze and clearly present the uncertainties involved in our projections of repository performance and how to ensure the defensibility of the models we use to assess the overall performance of the repository system. We agree that both issues will be important in developing a credible basis for site recommendation and look forward to further interaction with the Board as we continue developing the appropriate methods to address them.

The Department appreciates the timely feedback from the Board as we proceed towards a decision on a site recommendation. Our responses to the Board's specific issues are provided in the enclosure. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

Ivan Itkin

Ivan Itkin, Director
Office of Civilian Radioactive
Waste Management

Enclosure

Department of Energy's Responses to the November 10, 1999, Letter from the Nuclear Waste Technical Review Board

Repository Safety Strategy

- *The Board ... believes that this methodology [for barrier importance analysis] needs to be refined before valid conclusions can be drawn about defense-in-depth.*

The Department believes the preliminary barriers importance analyses conducted for the enhanced system design have provided valuable insights into the way the system performs, and the roles and contributions of the various natural and engineered barriers. These analyses, which involved the neutralization of barriers and processes, were based on the models developed for the Viability Assessment, with appropriate adjustments to reflect revisions to the design. The results were considered in the process of identifying the principal factors for the postclosure safety case described in Revision 3 of the Repository Safety Strategy. The Department is aware of the limitations in these neutralization analyses and intends to refine the method before using it with the updated total system performance assessment models being developed to support site recommendation. The refined method for neutralization analyses, and possibly other methods, will be employed to examine system performance and draw conclusions about the contributions of the various barriers and the degree of defense-in-depth provided by the updated design. The refined evaluations of the performance of key barriers will be documented in the next revision of the Repository Safety Strategy and will be fully traceable to the total system performance assessment documentation for site recommendation.

- *Unless the DOE can support its choice of principal factors and its use of bounding analyses, making the repository safety strategy technically persuasive will be difficult.*

As the Department noted in the September Board meeting, the selection of principal factors is a work in progress. The proposed principal factors discussed in Revision 3 of the Repository Safety Strategy were selected using professional judgment of the principal investigators, existing sensitivity studies, and insights from preliminary barrier importance analyses. This revision of the Repository Safety Strategy provides the rationale for the selection of the seven principal factors for the postclosure safety case. The next revision of the Safety Strategy will be based on the documented results from the total system performance assessment that is being conducted to support site recommendation, including information from the supporting Analysis and Model Reports and Process Model Reports. These results will provide the technical basis to confirm or revise the set of principal factors for the postclosure safety case for site recommendation, and for the work to be done to enhance the safety case for licensing.

The Department agrees that if bounding analyses are used in the evaluation of system performance, they must be technically sound and defensible. The Department plans to develop models and conduct analyses that are as realistic as possible, given the data that are available. In some instances, use of conservative or bounding analyses may be the only credible approach. In other instances, sensitivity studies conducted for site recommendation may indicate that performance is relatively insensitive to certain models or processes. In such cases, it may be appropriate to use a conservative or bounding approach in licensing to facilitate a focus on those aspects of system performance that are the most important to the findings that need to be made. Revision 3 of the Repository Safety Strategy identifies possible candidates for such simplification. Sensitivity studies conducted for site recommendation will be used to confirm or revise this list of candidates.

Model Validation

- *Significant issues associated with model validation may not be examined adequately by the time the final site recommendation report is scheduled to be sent to the President.*

The Department's goal is to establish adequate confidence in the relevant models by the time the site recommendation report is completed to support a decision by the Secretary. Validation is a process used to provide confidence that a conceptual model, as represented in a corresponding mathematical model, software, or analysis, adequately represents the phenomenon, process, or system being modeled. As the Department noted in the September meeting, the goal of model validation as defined by our quality assurance program is to establish the adequacy of the scientific basis for a model and to demonstrate that this basis is sufficiently representative for its intended purpose. The level of confidence required for a specific model is tied to the importance of that model to the safety case for the decision at hand. One goal of the Repository Safety Strategy has been to identify the elements of the repository system that are most important to system performance. This allows ongoing investigations to be focused on these elements and the validation of the models used to represent the performance of these elements.

The Department is validating models by comparison of modeling results to independent lines of evidence from laboratory observations, field observations, analog studies, and alternative models. Peer review panels may be convened to review the model, the underlying assumptions, and the results. Validation is an ongoing process that will continue after site recommendation, if the site is found suitable. The Department plans for additional monitoring and data collection to test our models and enhance confidence in their validity, including testing of phenomena that are calibrated with short-term data.

Treatment of Uncertainty

- *The DOE has an important obligation to present its technical analyses in a way that gives policy-makers ... as well as interested members of the general public a clear understanding of the uncertainties involved in projecting the performance of a repository.*

The Department agrees that it is important to present technical analyses in a way that provides the policy-makers and members of the interested public a clear understanding of the uncertainties in projecting the long-term performance of the potential repository at Yucca Mountain. The Department will discuss its approach to addressing uncertainty in the total system performance assessment for site recommendation during the Full Board Meeting in January 2000. The Department is looking forward to receiving additional feedback from the Board following this meeting regarding its views on how uncertainty can be evaluated and presented.

Modeling Results and Technical Investigations

- *[The tentative] conclusion [regarding the existence of a seepage threshold] is an extremely important one but ... it is highly dependent on assumptions about shape of the drift and ... structural integrity.*

The Department agrees that the concept of a seepage threshold presented in the discussion of the seepage flux model at the September Board meeting is an important one. Recent analysis reported in the Seepage Calibration Analysis and Modeling Report (AMR) has lowered the calculated seepage threshold for the Middle Non-lithophysal unit from 1000 to 200 mm/yr. The Department also agrees that it is important to evaluate the effects of the shape of the drift on seepage, and this work has started and is reported in another AMR entitled, "Seepage Model for PA". Furthermore, the Department will soon start testing the seepage characteristics of the main repository unit, the Lower Lithophysal unit. We are looking forward to receiving feedback from the Board regarding its views on the appropriateness of the model of seepage flux and the concept of a seepage threshold for inclusion in our performance assessment for site recommendation.

- *Concern still exists about the effects on corrosion of radiolytic species, including species formed in the vapor phase.*

With adoption of the new thinner-walled waste package design, the radiation levels at the surface of the waste packages are expected to be higher than for the thicker-walled viability assessment design. To assess potential radiolysis effects, the Department has conducted calculations of radiation levels at various locations within the drift for the new design. These calculations show that the waste package surface radiation dose levels for the bounding case (21-PWR, 75,000 MWD/MTU, 5-year cooled fuel) are less than 3000 rad/hr at emplacement

and decrease to about 260 rad/hr after 50 years. The radiation levels will continue to decrease if the repository is kept open for a longer period. Since the radiation levels required to cause significant enhancement of corrosion for the nickel and titanium alloys that are planned for used in the waste package and drip shield range from 10,000 to 100,000 rad/hr, the potential impact of radiolysis on the corrosion behavior of the new design is expected to be negligible.

Current plans call for forced ventilation of emplacement drifts for at least 50 years after emplacement. With ventilation during preclosure, the relative humidity will be about 20% or lower, which is well below that required for surface films to be generated. During this time, there is little likelihood of forming a water film on the near-field components within the emplacement drifts (e.g., ground support, waste package support structures, and invert materials). Further, any species formed in the vapor phase are not likely to cause a concern if the products cannot condense on the metal surface. The calculated radiation levels on the near-field components are expected to be about 2000 rad/hr or less at emplacement and decrease to less than 200 rad/hr after 50 years. Doses at the rock bolts would be substantially lower. This suggests that the potential for radiolysis enhanced corrosion of near-field structural components or rock bolts is also negligible.

- *The DOE has not established the technical foundation for the performance claims it is making for the drip shield.*

The Department agrees with the Board's view, and has enhanced its ongoing investigations of titanium drip shield performance and the effects of the drip shield on other elements of the engineered system to strengthen the technical basis for the performance of the drip shield. The Department is conducting a broad-based, comprehensive testing program that considers known corrosion mechanisms, as well as examining engineered and natural analogs. The tests focus on the corrosion mechanisms considered to be relevant to expected repository conditions. Accordingly, the work includes testing under service conditions and aggressive conditions in order to develop models for prediction of the long-term performance of the drip shield. Specifics of the testing program were recently provided to the Board (Barrett 1999).

Reference:

Barrett, L.H. 1999. Letter from L.H. Barrett (DOE/HQ) to J.L. Cohon, November 23, 1999.

UNITED STATES
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February 7, 2000

Wendy R. Dixon, EIS Project Manager
Yucca Mountain Site Characterization Office
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
P.O. Box 30307, Mail Stop 010
North Las Vegas, Nevada 89036-0307

Dear Ms. Dixon:

The Nuclear Waste Technical Review Board appreciates the opportunity to comment on the Department of Energy's (DOE's) proposed environmental impact statement (EIS) for a geologic repository at Yucca Mountain, Nevada. The Board submits these comments as part of its responsibility under the Nuclear Waste Policy Act, as amended, to evaluate the scientific and technical validity of the activities carried out by the Secretary of Energy and the DOE Office of Civilian Radioactive Waste Management. The Board focuses its comments on the technical quality of the analyses that support the draft EIS. The Board believes that resolution of its comments will improve the estimates of environmental impacts in the final EIS and improve the technical basis for deciding whether to pursue the proposed action described in the document.

The Board's comments on the draft EIS are attached to this letter. Some key comments are:

- The final EIS should be based on an updated repository design and should include the updated performance assessment results that the DOE plans to produce to support a possible recommendation that the site be developed as a geologic repository.

- It is clear that the nature of environmental risks posed by both alternatives, and the uncertainty about those risks, change over time. Tables S-1 and 2-7, which categorize all impacts as either short-term or long-term, should be supplemented by a discussion that explains how the environmental risks of both alternatives progress over time, including the period beyond 10,000 years.

- The specific transportation routes assumed for the analyses of transportation impacts should be identified in the EIS.

- The analyses of the impacts of transportation accidents should include estimates of the environmental impacts associated with cleaning up after any accidents that release radioactive materials to the environment.

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- Population data used in the EIS should be updated from the 1990 census figures and should be extrapolated to estimate continued population growth for a reasonable time in the future.

- The EIS should acknowledge the potential for stigma effects near a Yucca Mountain repository or associated transportation routes and should explain why it is not appropriate to include estimates of those possible effects.

The estimates of long-term repository performance for the proposed action of the draft EIS are essentially the same as those used by the DOE to prepare its 1998 Viability Assessment of a Yucca Mountain repository. After reviewing the Viability Assessment, the Board stated its belief that identifying important sources of uncertainty, estimating the magnitude of those uncertainties, reducing critical uncertainties, and evaluating the effects of residual uncertainties on expected repository performance are essential for supporting a technically defensible site-suitability determination. The Board concluded that a significant amount of additional scientific and engineering work will be needed to increase confidence in a site-suitability determination. The Board recommended that the DOE evaluate alternative repository designs that have the potential to reduce uncertainties in projected repository performance, thereby reducing the scope of additional necessary scientific study. Because the draft EIS relies on essentially the same performance assessment capabilities as those used to prepare the Viability Assessment, the Board believes that these conclusions and recommendations are equally applicable to the draft EIS.

The Board believes that neither of the no-action scenarios evaluated in the draft EIS is likely to occur, but the two scenarios do appear to represent the extremes of a spectrum of possible futures. Because the no-action alternative is hypothetical, there may be little merit in attempting analyses of this alternative more sophisticated than those presented in the draft EIS.

Again, the Board appreciates the opportunity to comment on the draft EIS for a Yucca Mountain repository.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

Attachment:
Comments on draft EIS

U.S. Nuclear Waste Technical Review Board

Comments on the Draft Environmental Impact Statement for a Geologic Repository at Yucca Mountain, Nevada

1. The performance assessment models and data used to project the long-term performance of a Yucca Mountain repository are very similar to those used by the U.S. Department of Energy (DOE) to prepare its 1998 Viability Assessment of a Yucca Mountain repository. The Board has previously commented on the Viability Assessment[1] and those comments would also apply to the draft Yucca Mountain EIS. The DOE intends to refine its models and collect additional data before the final Yucca Mountain EIS is prepared. The Board recommends that the final EIS include the updated performance assessment results that the DOE plans to produce to support a possible recommendation that the site be developed as a geologic repository.

2. It is clear that the nature of environmental risks posed by both alternatives, and the uncertainty about those risks, change over time. Tables S-1 and 2-7, which categorize all impacts as either short-term or long-term, should be supplemented by a discussion that explains how the environmental risks of both alternatives progress over time, including the period beyond 10,000 years.

3. The repository design that was assumed when preparing the draft EIS already has evolved and may change further before the final EIS is prepared. The Board recommends that the final EIS be based on the most advanced design concepts available at the time the final EIS is prepared.

4. The description of the proposed action indicates that active institutional controls (e.g., monitored and enforced limitations on site access) would be applied to the Yucca Mountain site only until permanent closure of the repository has been completed. This seems contrary to the provision of the Energy Policy Act of 1992 that directs the Secretary of Energy to "continue to oversee the Yucca Mountain site to prevent any activity at the site that poses an unreasonable risk . . . ." The oversight mandated by the Energy Policy Act appears to require some degree of active institutional control of the site, which would cause environmental impacts not evaluated in the draft EIS. The Board recommends that the final EIS clarify the extent to which active institutional control of the Yucca Mountain site may be required by the Energy Policy Act, and estimate the environmental impacts that would be associated with a scenario that incorporates such control.

5. Appendix J of the draft EIS describes the use of the HIGHWAY and INTERLINE computer codes to project the specific transportation routes to be used for analysis of transportation

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[1] U.S. Nuclear Waste Technical Review Board, *Moving Beyond the Yucca Mountain Viability Assessment*, Washington, D.C., April, 1999.

impacts when moving radioactive wastes to a Yucca Mountain repository. However, the draft EIS does not report what those transportation routes are. The Board recommends that the final EIS identify the specific transportation routes that are used for analysis of transportation impacts. If the DOE has identified preferred transportation routes, those also should be identified in the final EIS. If preferred transportation routes have not been identified, the final EIS should discuss when and how such identification will occur.

6. The analyses of transportation accidents that result in releases of radioactive materials to the environment assume that the released materials are not cleaned up. While this assumption may provide a bounding estimate of the radiation doses that nearby residents could receive, it is unrealistic because it fails to estimate the environmental impacts of clean-up (e.g., worker radiation exposure; condemnation of roads, land, or water supplies; disposal of contaminated soil and building materials). A methodology for making such estimates was presented in *Transportation of Radionuclides in Urban Environs: Draft Environmental Assessment,* NUREG/CR-0743; SAND 79-0369, July 1980. While somewhat dated, the cost estimates and perhaps the methodology could be updated for today's use. The Board recommends that the final EIS include estimates of the environmental impacts of clean-up after transportation accidents.

7. The draft EIS uses 1990 census data for those analyses that require estimates of population sizes. Because of rapid growth in the Las Vegas Valley area, the 1990 census data are out of date. More recent population estimates and twenty-year projections of future growth are available from the Nevada State Demographer's Office at the University of Nevada, Reno. The Board recommends that the State Demographer's population projections be used when preparing impact estimates for the final EIS.

8. Comments at public meetings on the draft EIS have indicated a significant public concern about possible stigma effects (reduced land values, decreased tourism) in areas near a Yucca Mountain repository or associated transportation routes. The Board recognizes that assessing the impact of stigma effects would be difficult because such effects depend not on the actual physical effects of the proposed action, but on the negative perception of those effects by some members of the public. The extent to which stigma effects might occur is extremely speculative and therefore might be inappropriate for analysis in a Yucca Mountain EIS. The Board recommends that the final EIS acknowledge the possibility that stigma effects might occur and explain the basis for deciding whether to include an analysis of such effects in the final EIS.

9. The draft EIS uses the "Modal Study" (discussed on page 6/29 of the draft EIS) in its analyses of transportation accidents. It is our understanding that this study will be updated by the U.S. Nuclear Regulatory Commission, but not in time for inclusion in the final Yucca Mountain EIS. The Board recommends that the final EIS note any efforts to update the study and discuss the DOE's plans for reviewing the results of any update to determine whether a supplement to the final EIS may be needed.

10. The draft EIS identifies the Caliente/Chalk Mountain route (possible rail or heavy-haul route) as a *non-preferred alternative.* However, the draft EIS presents no *environmental* logic for

this designation. Instead, the draft EIS states that the designation is based on opposition from the U.S. Air Force, which is concerned about potential interference with Nellis Air Force Range testing and training activities. Since this route is about half the overall distance of the more circuitous Caliente route and therefore should be less harmful to the environment, and since this route avoids the population centers surrounding Las Vegas, it would seem to be a candidate for designation as a *preferred alternative* from an environmental perspective. The Board recommends that the final EIS provide a more thorough explanation of the basis for deciding whether to exclude the Caliente/Chalk Mountain route from consideration..

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

March 20, 2000

Dr. Ivan Itkin
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Itkin:

The Nuclear Waste Technical Review Board was established by Congress in 1987 to evaluate the technical and scientific validity of the activities undertaken by the Secretary of Energy to implement the Nuclear Waste Policy Act, as amended.

As the Department of Energy (DOE) approaches the critical milestone of determining the suitability of the Yucca Mountain site, the Board believes that clarity in how the DOE will characterize the performance of a potential Yucca Mountain repository is imperative. The Board believes that meaningful quantification of the uncertainties associated with performance, clearly and understandably presented, is an essential element of performance characterization. The complexity of the repository system and the length of time over which performance must be estimated make uncertainty both large and unavoidable (although perhaps reducible). Especially important in such a situation is that policy-makers and other interested parties understand the uncertainty associated with key decisions.

Over the years, the Board has endorsed the use of performance assessment (PA) as one means of estimating the long-term behavior of a repository for spent nuclear fuel and high-level radioactive waste. In this letter, the Board comments further on the DOE's current and proposed use of PA in the context of the site-suitability decision. In the Board's view, the DOE has not yet developed a consistent and transparent approach to representing the uncertainty in its estimates of long-term repository performance. Moreover, because the uncertainties in PA may be substantial, the Board believes that the DOE should supplement its performance estimates with additional lines of argument and evidence. Because these comments have a direct bearing on the DOE's recently proposed site-suitability guidelines, I am sending a copy of this letter to be included in the rule-making on 10 CFR 963.

Analysis and Display of Uncertainty in Performance Estimates

The DOE has conducted four major PA's since 1991. Although each iteration has become more sophisticated and more comprehensive, the results are still associated with a wide range of uncertainties. The uncertainties arise for many reasons, including the following:

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- Incomplete information for characterizing the site and its important heterogeneities and for constructing and calibrating process models
- Lack of information on the conceptual validity of the mathematical process models
- Possible errors in extrapolating short-term information on repository subsystems to long-term projections of repository performance
- Effects on repository performance of phenomena and events that are presently not anticipated.

Some of these uncertainties, such as those associated with site heterogeneity, often have been included in past PA's; others, such as those associated with model uncertainty, often have been left out. Of course, the uncertainties associated with unanticipated phenomena cannot be included.

For the PA being prepared for its site recommendation, the DOE is using a methodology in which uncertainties are addressed differently for different input assumptions and parameters. According to presentations made to the Board at its January 2000 meeting, some of these assumptions and parameters will be single-valued conservative estimates, and others will be represented probabilistically. The Board understands the value of using conservative estimates, but it strongly urges the DOE to work with statisticians and other experts to develop coherent and consistent probability statements about projected repository performance based on those conservative estimates.

The Board is concerned that the PA approach now envisioned by the DOE could deprive policy-makers of critical information on possible trade-offs between projected performance and the uncertainty in those projections. For example, one policy-maker might be willing to accept development of a repository that would release half of the permitted dose, with only a 1 in 1,000 chance of exceeding that permitted dose. However, that same policy-maker might decline to develop a repository that is expected to release only a tenth of the permitted dose, but has a 1 in 4 chance of exceeding that permitted dose. Another policy-maker's preferences might be the opposite. Because the uncertainties about repository system performance may be substantial, estimates of uncertainty about doses are at least as important as estimates of performance.

Importance of Multiple Lines of Argument and Evidence

As explained in the Board's April 1997 letter commenting on an earlier DOE proposal to revise the site-suitability guidelines, the Board endorsed the use of PA in support of a site-suitability determination. But the Board stated that the DOE should supplement PA with other meaningful approaches, such as a demonstration of defense-in-depth—including multiple and independent barriers—and compliance with a margin of safety. Similarly, in its 1999 report on the DOE's *Viability Assessment*, the Board concluded that PA could be used as the "core analytical tool" for making the safety case for a repository. However, the Board also noted the limits of PA and expressed doubt that relying "solely on [PA] to demonstrate repository safety will ever be possible." Therefore, the Board recommended that additional lines of evidence, such as natural analogs, be used to overcome these limitations.

The DOE has acknowledged the limits of PA in its *Repository Safety Strategy*. The DOE has indicated that it would demonstrate waste isolation by a number of approaches, including

PA, safety margins and defense-in-depth, performance confirmation, consideration of disruptive processes and events, and insights from natural and man-made analogs. These approaches add confidence to the evaluation of the repository system. They help address concerns about uncertainties that are not explicitly incorporated in PA. Given past experiences at Yucca Mountain and the long operating life of the repository, those concerns may be well-founded. Nonetheless, the DOE's draft site-suitability guidelines propose using only PA to determine the suitability of the Yucca Mountain site, leaving unclear how these additional approaches will in fact be used in the context of site suitability.

Conclusions

The Board continues to endorse the use of PA, along with other supporting lines of evidence and reasoning, for making a site-suitability determination. At the same time, the Board believes that addressing PA's uncertainties and the sources of these uncertainties as clearly as possible is essential for technical credibility and sound decision-making. Therefore, the Board recommends that the DOE include in its representation of performance uncertainty a description of critical assumptions, an explanation of why particular parameter ranges were chosen, a discussion of possible data limitations, an explanation of the basis and justification for using expert judgments (whether or not they are elicited formally), and an assessment of confidence in the conceptual models used. In addition, the Board recommends that the uncertainties associated with the performance estimates be identified and quantified well enough so that their implications for the performance estimates can be understood. This analysis also would help the DOE demonstrate the safety-margin component of the postclosure safety case described in the latest revision of *Repository Safety Strategy*.

The Board believes that PA should not be used as the sole source of guidance about the features, events, and processes that might affect long-term repository system performance. Multiple lines of argument and evidence—combined with a clear and complete description of uncertainty—will present a much more technically defensible demonstration of repository safety than will any individual component of the safety case. The Board urges the DOE to keep this perspective in mind as the program moves forward.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

cc:
W. Boyle

jlc074f

UNITED STATES
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March 20, 2000

Dr. Ivan Itkin
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW, RW-2/5A-085
Washington, DC 20585

Dear Dr. Itkin:

On behalf of the Nuclear Waste Technical Review Board, please let me thank you and your staff and contractors for participating in the Board's January 2000 meeting, which all members felt was productive and stimulating. We were particularly pleased that you were able to attend and participate in the meeting.

In your remarks to the Board, we noted your intention to maintain the DOE's current schedule for evaluating the suitability of the Yucca Mountain site. According to that schedule, the Secretary of Energy will decide in less than 18 months whether to recommend the site to the President. The DOE's scientific program has amassed a considerable body of knowledge to date, and additional efforts in the scientific program during the next year and a half will augment that body of knowledge. Despite the large amount of work, however, significant technical uncertainties will still be present at the time of the Secretary's decision. A central theme of the January meeting was the challenge of describing uncertainties in ways that will be meaningful in the decision-making process. This letter gives the Board's views on four aspects of uncertainty relating to: repository safety strategy, repository design, scientific studies, and communication.

Repository Safety Strategy. The repository safety strategy presented to the Board recognizes the importance of describing uncertainties as part of the postclosure safety case. The strategy proposes five ways of addressing uncertainty:

1. Quantification of repository performance in a performance assessment (PA).
2. Mitigation of uncertainties through safety margin and defense-in-depth.
3. Consideration of potentially disruptive processes and events.
4. Insights from studying natural analogues.
5. Long-term reduction of uncertainties through a continuing program of testing and performance confirmation until permanent closure.

In a separate letter on the DOE's Part 963 rulemaking (dated March 20, 2000), we note that the Board continues to endorse the use of PA, along with other supporting lines of evidence and reasoning, for making a site-suitability determination. At the same time, the Board believes

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that addressing PA's uncertainties and the sources of these uncertainties as clearly as possible is essential for technical credibility and sound decision-making. Therefore, the Board recommends that the DOE include in its representation of performance uncertainty a description of critical assumptions, an explanation of why particular parameter ranges were chosen, a discussion of possible data limitations, an explanation of the basis and justification for using expert judgments (whether or not they are elicited formally), and an assessment of confidence in the conceptual models used. In addition, the Board recommends that the uncertainties associated with the performance estimates be identified and quantified well enough so that their implications for the performance estimates can be understood. This analysis also would help the DOE demonstrate the safety-margin component of the postclosure safety case described in the latest revision of *Repository Safety Strategy.*

The Board believes that PA should not be used as the sole source of guidance about the features, events, and processes that might affect long-term repository system performance. Multiple lines of argument and evidence—combined with a clear and complete description of uncertainty—will present a much more technically defensible demonstration of repository safety than will any individual component of the safety case. The Board urges the DOE to keep this perspective in mind as the program moves forward.

In developing the repository safety strategy, sensitivity analyses were among the considerations used by the DOE to identify the seven "principal factors" that most strongly affect the postclosure safety case. As indicated above, performance assessment is only one element of the safety case. We urge the DOE to ensure consideration of all elements of the safety case, including defense-in-depth, in defining principal factors.

The principal factors apparently will be the focus of much of the DOE's scientific studies in the future. The Board's understanding is that current performance assessment models may not adequately describe the interactions of heat, water flow, chemical reactions, and mechanical disturbances within the rocks near heated emplacement drifts. If this is the case, then sensitivity analyses could fail to identify coupled processes as principal factors. The Board recommends that the DOE reexamine its evaluation of the importance of coupled processes in its identification of principal factors.

The Board urges the DOE to pursue studies of natural analogues. The Board is concerned that there continues to be little evident progress in this area. Presentations at the January Board meeting described modest plans for studying analogues, but there seems to be no serious commitment to funding such studies. In addition to those analogues discussed at the meeting (e.g., Peña Blanca, Rainier Mesa), the Board urges the DOE to consider studies of josephinite, a naturally occurring alloy of nickel and iron that may provide insights into the long-term corrosion resistance of waste packages in a Yucca Mountain repository.

To maintain its site recommendation and licensing schedules, the program may choose to rely more heavily on performance confirmation rather than on site characterization for the information needed to determine whether the Yucca Mountain site can safely isolate wastes. If this is the case, the Board believes that the DOE should develop and communicate a carefully

thought-out plan for its performance confirmation and site monitoring program as an integral part of its site recommendation.

Repository Design. One way to address uncertainties is to reduce them through modifications of repository design, although uncertainties can never be entirely eliminated. In a recent letter,[1] the Board stated that it ". . . does not believe that a strong-enough technical basis exists at this time to support adequately any above-boiling repository design." (In that letter, "above-boiling" referred to the temperatures of the drift walls after closure.) The Board suggested that many of the above-boiling designs studied by the management and operating (M&O) contractor could be modified to achieve below-boiling conditions by aging the spent fuel or by increasing the rate or the duration of ventilation before repository closure.

In its response to the Board's letter,[2] the DOE committed to examining uncertainties associated with coupled thermally driven processes, to refine models that are the basis for evaluating thermal conditions, and to evaluate design options for increasing the efficiency of heat removal prior to repository closure. We look forward to reviewing the results of these very important efforts and discussing them with you as soon as they become available.

We noted above the possibility that existing models may not have captured adequately the effects of coupled processes when identifying principal factors. Similarly, the evaluation of repository design alternatives (including above-boiling and below-boiling design options) using performance assessment models may cause above-boiling designs to appear to have greater certainty about performance than they really have. Adoption of a below-boiling design could substantially reduce most concerns about coupled processes.

Scientific Studies. Another way to address uncertainties is to attempt to reduce them through additional scientific and engineering studies. Presentations on scientific studies at the January Board meeting indicated that significant new information continues to be generated and plans for important future work are being developed. Expert judgment and careful interpretation of data will be needed to accurately characterize and quantify the uncertainties associated with data and their use in predicting repository performance.

The Board heard at the meeting that moisture conditions within the bulkheaded part of the cross-drift appear to be approaching equilibrium conditions and active dripping does not appear evident. We look forward to additional observations from within that part of the cross-drift, including evaluation of the apparent condensation of moisture in some locations. Regarding seepage modeling efforts, there is a need either to incorporate U.S. Geological Survey calcite deposition data and concepts into seepage models or to explain why it would be inappropriate to do so.

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[1] July 9, 1999, letter from Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board, to Lake H. Barrett, Acting Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy.

[2] September 10, 1999, letter from Lake H. Barrett, Acting Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, to Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board.

We were impressed with the careful planning and attention to detail for the fluid inclusion studies. We look forward to completion of that work and hope that it will help resolve remaining questions about the hydrothermal history of the Yucca Mountain site. The Board also looks forward to reviewing plans and schedules for other new tests to be carried out in support of site characterization and, potentially, repository licensing. We noted that coordination of Yucca Mountain participants with the Nye County Early Warning Drilling Program appears to be productive. However, we were disappointed in continuing delays in the chlorine-36 validation studies. At this, and previous, Board meetings, presentations on this important topic were canceled due to insufficient progress. We look forward to hearing about the results of these studies at our next meeting.

Communication. Accurately portraying the nature of uncertainties about the performance of a complex system like a Yucca Mountain repository is a formidable challenge. As you are aware, the DOE will need to communicate effectively to a wide variety of audiences as the project moves forward. The DOE's initiative to develop a simplified performance-assessment capability is a commendable effort to make the "black box" of performance assessment more transparent to nonspecialists. While it remains to be seen how successful this will be, we urge the DOE to make this tool available to the public well in advance of the release of the site recommendation consideration report. We also urge the DOE to seek other innovative ways of improving communication with all stakeholders.

Again, the Board thanks you for your efforts in supporting the Board's January meeting. We that hope you find these comments timely and helpful.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

Department of Energy
Washington, DC 20585

June 6, 2000

JUN 12 2000

Dr. Jared Cohon
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, Virginia 22201-3367

Dear Dr. Jared:

Thank you for your letter of March 20, 2000, providing the Board's perspective on the information presented by the Department of Energy at the January 25-26, 2000, Board meeting in Las Vegas, Nevada. The Department appreciates your comment that the meeting was productive and stimulating. We, too, found the exchange to be valuable.

In your letter you stressed that technical uncertainties about repository performance will still be present at the time of an anticipated site recommendation decision and noted the challenge of communicating those uncertainties in a meaningful way for the purposes of decision-making. The Department recognizes that the treatment of uncertainty has always been an important factor in the decision-making process on a repository recommendation. The Department's goal is to ensure that the technical basis for any site recommendation fully describes the performance assessment results and the associated uncertainties in data and models. The technical basis will also indicate the scope of uncertainty related to the estimates of repository performance. This information will be evaluated by the Department to provide a sound scientific basis for decision-making.

The Board stated that repository operation at below-boiling temperatures would reduce uncertainties in assessing performance, in particular those associated with the complexity of thermally coupled processes. The Board has also suggested that these reduced uncertainties would increase the confidence in any site suitability determination by the Department by improving confidence in the scientific basis for the determination.

In response to the Board's recommendations, the Department is developing a flexible repository design concept that can balance technical and programmatic considerations. The Program's ongoing evaluation is focused on combinations of operational parameters that would allow a future choice from a wide range of possible thermal behaviors, including below-boiling temperatures.

The Department appreciates feedback on the meeting from the Board as we proceed toward a decision on a possible site recommendation. The Department's responses to the Board's specific issues are provided in the enclosure. If you have any questions, please contact me at (202) 586-6850.

Sincerely,

Ivan Itkin, Director
Office of Civilian Radioactive
Waste Management

Enclosure

Department of Energy's Responses to the March 20, 2000, Letter from the Nuclear Waste Technical Review Board

Repository Safety Strategy

... the Board recommends that the DOE include in its representation of performance uncertainty a description of critical assumptions, an explanation of why particular parameter ranges were chosen, a discussion of possible data limitations, an explanation of the basis and justification for using expert judgments (whether or not they are elicited formally), and an assessment of confidence in the conceptual models used. In addition, the Board recommends that the uncertainties associated with the performance estimates be identified and quantified well enough so that their implications for the performance estimates can be understood. (page 2)

The Department recognizes that it must clearly identify uncertainties, explain the sources of these uncertainties, and characterize the potential implications of these uncertainties for system performance. This work is necessary to support the technical credibility of the total system performance assessment (TSPA). The Department intends to build on its experience in preparing the TSPA report for the Viability Assessment (VA) and the supporting Technical Basis Document as it completes the TSPA document for any site recommendation (TSPA-SR) and its technical basis.

Ongoing work in developing the Analysis and Model Reports (AMRs) and Process Model Reports (PMRs) that support the TSPA-SR is documenting the basis for and treatment of uncertainty at multiple levels: from the basic data, through the conceptual models, to the abstractions that are the building blocks for the TSPA. The TSPA-SR document will provide a synopsis of those uncertainties associated with each component model. The TSPA-SR will also include detailed discussions on the treatment of uncertainty, uncertainty versus variability, and the use of alternative conceptual models. It will include presentation and analysis techniques for dealing with uncertainty. The Department's evaluation of the implications of the uncertainties on estimates of repository performance will be a major component of the TSPA-SR. The results of these evaluations will be discussed explicitly for the nominal scenario and for the disruptive scenarios.

The Board believes that PA should not be used as the sole source of guidance about the features, events, and processes that might affect long-term repository system performance. Multiple lines of argument and evidence—combined with a clear and complete description of uncertainty—will present a much more technically defensible demonstration of repository safety than will any individual component of the safety case. The Board urges the DOE to keep this perspective in mind as the program moves forward.....We urge the DOE to ensure consideration of all elements of the safety case, including defense-in-depth, in defining principal factors. (page 2)

The Department agrees that multiple lines of evidence and reasoning will be important to support any site recommendation. We are identifying and evaluating multiple and independent barriers to waste isolation to provide information on defense-in-depth. Insights from natural and man-made analogues are being analyzed and included in the TSPA. The underlying documentation of the TSPA calculation will include the margin by which the expected performance of the repository meets the applicable radiation protection standards.

The Department shares the Board's view that elements of the safety case beyond performance assessment should be considered in defining the principal factors. One foundation for development of a technically credible TSPA-SR is identification of the full set of features, events, and processes (FEPs) that must be considered in evaluating long-term repository performance. These FEPs are being identified through a screening process that begins with a comprehensive list of potentially relevant FEPs. The bases for identifying the initial list of FEPs for consideration and for selecting those FEPs that are actually considered in evaluating performance have been documented. Support for inclusion or exclusion of any FEP involves consideration of probability and consequences. Potentially disruptive processes and events are included to the extent that they meet the screening criteria, and natural analogue information is considered in the screening process. For each of the process models supporting TSPA-SR, an AMR is being developed to document the screening of FEPs and the bases for identifying the set of FEPs that will be considered in developing the representation of system behavior. Sensitivity studies will be used to narrow the focus to those factors (and related FEPs) that have the greatest influence on performance. Barrier importance analyses will be used to help identify factors that would provide defense-in-depth, if particular barriers did not perform as expected. The results of these various analyses will be presented in the TSPA-SR document. The Department is committed to considering all elements of the postclosure safety case in defining the principal factors to carry forward to a site recommendation decision.

The Board recommends that the DOE reexamine its evaluation of the importance of coupled processes in its identification of principal factors. (page 2)

The Department agrees with the Board's position. Because of the iterative nature of TSPA and development of the postclosure safety case, the Repository Safety Strategy (RSS) is periodically updated. Revision 3 of the RSS was based on the information then available. That information included the TSPA models used for the VA with modifications to reflect subsequent design enhancements, such as the use of backfill. The evaluations performed for Revision 3 resulted in the preliminary identification of seven principal factors. Workshops are currently underway to support the development of Revision 4 of the RSS. These workshops are being conducted in parallel with development of the technical basis for TSPA-SR and are considering the available TSPA results. These workshops are designed to provide a forum for consideration of the technical information being developed for a site recommendation decision and to continue development of the principal factors of the postclosure safety case. The importance of thermally coupled processes in the identification of principal factors is

being reexamined during the course of these workshops. Revision 4 of the RSS will include the results from performance analyses, sensitivity studies, and barrier importance analyses in establishing principal factors, which may be modified from those in Revision 3.

The Board urges the DOE to pursue studies of natural analogues. The Board is concerned that there continues to be little evident progress in this area.....there seems to be no serious commitment to funding such studies. .....the Board urges the DOE to consider studies of josephinite, a naturally occurring alloy of nickel and iron that may provide insights into the long-term corrosion resistance of waste packages in a Yucca Mountain repository. (page 2)

The Department agrees that natural analogues have the potential to increase understanding of certain processes that are principal factors in the postclosure safety case. Natural analogues can thus play an important role in supporting any recommendation and as a means of reducing uncertainty. For these reasons, funding for analogue studies has been continued in Fiscal Year 2000 despite budget constraints. These studies include continuation of work at Peña Blanca, modeling unsaturated zone flow and radionuclide transport in fractured rocks at the Idaho National Engineering and Environmental Laboratory, modeling of processes at selected active geothermal sites, a field and modeling study of Paiute Ridge intrusive bodies, and, potentially, process modeling with Krasnoyarsk (K-26) data. It is anticipated that in future years, consideration will be given to funding confirmatory studies of additional natural analogues that address Yucca Mountain processes and models.

The Department agrees that studies of metallic natural analogues may prove useful. Although josephinite is not Alloy 22, the material selected for the waste package outer barrier, josephinite and selected meteorites are metallic analogues that could provide useful information on long-term performance. Studies of these materials will continue with an emphasis on understanding the development and stability of the passive film. To date, only preliminary microstructural analysis of samples of josephinite has been performed.

To maintain its site recommendation and licensing schedules, the program may choose to rely more heavily on performance confirmation rather than on site characterization for the information needed to determine whether the Yucca Mountain site can safely isolate wastes. If this is the case, the Board believes that the DOE should develop and communicate a carefully thought-out plan for its performance confirmation and site monitoring program as an integral part of its site recommendation. (pages 2-3)

The Department has always viewed performance confirmation as essential to the assurance of acceptable repository performance in support of an eventual decision on whether and when to close the repository. The role of performance confirmation in the Yucca Mountain Project has not changed in light of the Project's current site recommendation and licensing schedules.

The Department expects that preliminary analysis of repository performance conducted for site recommendation, together with the safety margin and defense-in-depth provided by the multiple natural and engineered barriers in the current repository design, will provide a sufficient technical basis to judge whether the Yucca Mountain site is suitable and should be recommended for development as a repository.

As the Board, the Department, the Environmental Protection Agency, and the Nuclear Regulatory Commission (NRC) all have recognized, uncertainty about long-term repository performance cannot be totally eliminated. As one means of enhancing confidence in the understanding of repository behavior in support of the NRC decision to permit repository closure, the NRC requires that a performance confirmation program be put in place, starting during site characterization and continuing until repository closure. Such a program requires continued involvement in evaluating new information obtained during licensing, construction, operation, and monitoring of the potential repository to determine whether the essential assumptions and bases for the postclosure compliance evaluation are confirmed. The length of the post-emplacement performance confirmation period will exceed by several times the length of the site characterization period, and the actual performance of repository systems will be monitored. Therefore, the Department expects performance confirmation to lead to a significant increase in understanding and confidence before any decision to close the repository is made.

Repository Design

... the DOE committed to examining uncertainties associated with coupled thermally driven processes, to refine models that are the basis for evaluating thermal conditions, and to evaluate design options for increasing the efficiency of heat removal prior to repository closure. (page 3)

The Department has recently initiated an effort to better quantify the uncertainties in the current thermal-hydrologic model; we will keep the Board apprised of this effort. The current design has adequate flexibility to be operated in above-boiling or below-boiling modes, and we recognize the need to further address the uncertainties associated with a choice of operating mode. Even with an above-boiling operating mode, for which boiling would be restricted to less than half of the thickness of the pillar between emplacement drifts and water could drain within the pillars, uncertainties associated with thermally driven processes would be considerably reduced compared with the design concept in the VA.

Some additional design features for increasing the efficiency of heat removal have undergone preliminary consideration; however, to date, they have not been determined to be cost-effective. The current expectation is that approximately 70 percent of generated heat will be removed through the ventilation system. Other additional design features, which have not been explored during the preliminary work done to date, may be able to remove more of the remaining heat and will be evaluated.

Scientific Studies

Regarding seepage modeling efforts, there is a need either to incorporate U.S. Geological Survey calcite deposition data and concepts into seepage models or to explain why it would be inappropriate to do so. (page 3)

The calcite deposition data collected by the U.S. Geological Survey provides important information on seepage into lithophysal cavities. The seepage models developed by the Project will incorporate, as appropriate, these data sets, as well as the niche seepage data. The results from these models will provide additional insight about seepage into emplacement drifts over long time periods.

Communication

The DOE's initiative to develop a simplified performance-assessment capability is a commendable effort to make the "black box" of performance assessment more transparent to nonspecialists.....we urge the DOE to make this tool available to the public well in advance of the release of the site recommendation consideration report. (page 4)

The Department intends to make a version of the simplified TSPA available to the public via the Internet and in a CD-ROM version that can be run on a personal computer. Timing of this initiative is constrained by availability of resources. We anticipate making the simplified TSPA available about the time the site recommendation consideration report is released, allowing the public to use it during the public comment and hearing process on a possible site recommendation.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

June 16, 2000

Dr. Ivan Itkin
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Itkin:

On behalf of the Board, I would like to extend our appreciation for the presentations made by your staff and contractors at the Board's meeting held last month in Pahrump, Nevada. We were especially pleased that you were able to attend and participate in the gathering.

Although the meeting covered a wide range of topics, the presentations raised among Board members an interrelated set of impressions and observations. In particular, the Board notes that the Department of Energy (DOE) is still in the process of addressing key uncertainties and that new uncertainties continue to arise. The existence of these uncertainties, coupled with some of your own comments, suggests that the DOE is beginning to explore ways of systematically tying important milestones to the acquisition of critical information. For such an approach to be credible and effective, preserving flexibility and ensuring that the bases for decision-making are transparent will be important.

Addressing Old and New Uncertainties. We appreciated Jean Younker's presentation on thermally driven uncertainties. The presentation demonstrated that DOE scientists have a good grasp of the types of uncertainties that currently are present. The next step, important for the fast-approaching site recommendation by the Secretary of Energy, is to analyze and explain quantitatively the size and significance of those uncertainties for performance and how they vary with repository temperature. For example, the variations with temperature of uncertainties in generalized and localized aqueous corrosion rates of waste-package and drip-shield materials must be determined over the temperature range from ambient to at least the boiling point of water that contains highly concentrated dissolved salts. Similarly, quantifying uncertainties in variables and processes that pertain to fluid flow and transport in the repository rock over the temperature range from ambient to the maximum predicted temperature in the rock is very important.

Other uncertainties that had not been discussed previously with the Board also became evident during the meeting. One involves potential interactions between repository materials. An employee of the management and operating contractor (M&O), commenting from the floor, indicated that closely placed steel sets (ring beams) would be used throughout the emplacement drifts for rock support. We are concerned about the adequacy of the corrosion database on the interaction of steel and its corrosion products with Alloy 22. We realize that steel sets rather

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than concrete drift liners were chosen for rock support because concrete might have deleterious effects on waste package performance. However, we have not seen the analysis indicating that steel would be less deleterious than concrete. Additional corrosion studies may be needed to determine whether current waste package designs are compatible with the environmental conditions that might result from the use of steel for rock support.

The Board also appreciated the information in the presentations by Bill Boyle of the DOE and Marc Caffee of Lawrence Livermore National Laboratory (LLNL). We were pleased as well by the candor of the subsequent discussions among the two presenters, June Fabryka-Martin of Los Alamos National Laboratory (LANL), and Board members. The Board realizes that much of the data discussed were obtained very recently and that the analysis of the data is just beginning. LLNL and LANL investigators appear to disagree about the presence of bomb-pulse chlorine-36 in a faulted and fractured area of the Exploratory Studies Facility and about the background ratio of the chlorine-36 to chlorine in that area. Because the presence of bomb-pulse chlorine-36 at specified locations within the ESF has been interpreted as evidence of fast paths for the infiltration of water to the repository level and the background ratio of chlorine-36 to chlorine has been used to estimate the age of the water in the rock, validating the chlorine-36 measurements is important. Perhaps of even greater importance is how this dispute could affect the credibility of the scientific program. Although differences in interpretation are quite normal and expected in science in general and in geology in particular, the standing of the program is not enhanced if these differences appear, as is presently the case, to be due to differences in sampling and processing techniques. In the Board's view, resolving the apparent disagreement should be a very high priority.

Predictions of performance that will be developed to support the Secretary's site recommendation will depend on the assumptions that the waste packages and drip shields can be manufactured with high reliability and will function as intended. Showing that these assumptions are true may take many years of research, development, and demonstration. Although complex designs may be justified under some circumstances, they often are the source of increased uncertainty. For example, the designs of the final closure end of the waste package and the connections between drip shields have become very complex over the last year or so. As a result, current performance assessment models do not capture well how water might elude the drip shields and cause stress corrosion cracking. Thus, the Board urges DOE to explore the possibility of simplifying the current designs for the repository, the waste package, and the drip shield.

Another significant area of uncertainty is the saturated zone flow-and-transport model. It may be possible to improve this model using geochemical information being collected by Nye County. In fact, Don Shettel's presentation included a substantial amount of geochemical data. The Board is looking forward to the interpretation of those data in the larger context of the geochemical and hydrological investigations of the regional groundwater system.

Of course, there are many other sources of uncertainty that will affect estimates of repository performance. As the Board has communicated to you before, meaningful quantification of the uncertainties associated with performance, clearly and understandably presented, is an essential element of performance characterization.

Interpreting New Data Acquired Over Time. In your prepared remarks to the Board and in the discussion that followed, you made reference to the reality that the Yucca Mountain project is unique in its long duration, its high degree of complexity, and the persistence of significant technical and institutional uncertainties. You alluded to the possibility of using a modular approach to design and proceeding in stages to develop a repository at Yucca Mountain. Although you did not specifically use the term, the process you seemed to outline appears to be an "evolutionary" one as opposed to one that tries to foresee and address in advance all potential contingencies.

The Board can appreciate why the DOE may think that this kind of evolutionary process may offer important advantages, especially given many of the singular characteristics of the Yucca Mountain project. The Board observes, however, that for such an approach to be technically credible and effective, the DOE would likely want to consider several prerequisites. For example, broad agreement would have to be reached on how to quantify and rank uncertainties that significantly affect performance, a program would have to be created to gather data designed to address key uncertainties, clearly stated benchmarks and criteria would have to be developed to evaluate uncertainty reduction, and a clear protocol for technical decision-making, including a bona fide exit strategy from the site if a fatal flaw were found, would have to be established.

Ric Craun's presentation suggested that the current repository design contains sufficient flexibility to allow for changes in repository design as new data are acquired. The chart he presented, which related ventilation time, "staging" time, and distance between waste packages to repository temperature, was very helpful. We agree that there is a great deal of operational latitude in the current design. In particular, the chart clearly shows that broad flexibility exists to implement the design as either a below-boiling or an above-boiling repository. The Board notes, however, that even more flexibility might be available if certain factors now held constant (e.g., spacing between drifts, age of fuel when received at the repository, ventilation efficiency) were allowed to vary.

On several occasions, the Board has commented to the DOE on the importance of carrying out technical analyses and making critical decisions in a manner that is highly transparent to the broad range of interested and affected parties involved in developing a potential repository at Yucca Mountain. The remarks made at the Board meeting by the representatives from the municipality of Oskarshamn, Sweden, suggest that the complicated development process can be carried out in a transparent fashion. Although it is unclear which, if any, lessons from Sweden might be applied in this country, it is clear that transparency has been and will continue to be an important requirement for this program.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

September 20, 2000

Dr. Ivan Itkin
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Itkin:

On behalf of the Nuclear Waste Technical Review Board, I extend our appreciation for the presentations made by your staff and contractors at the Board's meeting last month in Carson City, Nevada. We were especially pleased that you were again able to attend the meeting and address the Board. The main focus of the meeting was total system performance assessment for site recommendation (TSPA/SR), and we appreciate your staff's willingness to present and discuss the preliminary results of the calculations that are the bases for estimates of repository performance in models being developed for the TSPA/SR. The presenters were very responsive to the Board's requests for information and helped make this one of the most informative meetings the Board has held over the last few years. We would like to single out Claudia Newbury of your staff for her contributions to this meeting and other DOE-Board interactions.

The comments enclosed with this letter provide the DOE with the Board's views on the status of the program at a time when changes can be made that will strengthen the technical and scientific bases for a DOE decision, scheduled for July 2001, on whether to recommend the Yucca Mountain site. The Board notes that most of the key issues discussed in the letter (extrapolation of corrosion rates, modeling coupled processes, analyzing alternative repository designs, developing multiple lines of evidence, quantifying uncertainty) have been raised by the Board in previous letters and reports to the DOE. The Board also notes that in several areas the DOE has made significant progress since the 1998 viability assessment—e.g., substantial improvements have been made in performance assessment capability, integration has increased significantly, new and better models have been developed, and new and important data are being collected.

There remain many areas where improvements are needed, however. The Board is not convinced that the range of experiments and analyses carried out by the DOE is broad enough to describe, or even bound, all relevant coupled processes in the near-field environment affecting the engineered barrier system. Furthermore, because the understanding of fundamental corrosion processes is limited, extrapolation of corrosion rates determined from short-term (several years)

experiments to predict waste package performance over tens of thousands of years is a subject of concern. Extrapolations based on assumptions about the fundamental long-term mechanisms that affect the passive layer critical to the corrosion resistance of Alloy 22 may be suspect. Although the Nye County Early Warning Drilling Program has yielded improved hydrogeological information, substantial uncertainties persist. Furthermore, it is not clear to the Board how the program plans to incorporate or reflect new data and analyses that are obtained in the next year or so in its site recommendation.

In its March, 20, 2000, letter to you, the Board discussed the importance of proper treatment and estimation of uncertainties. Several suggestions were made to assist the DOE in this task. We are encouraged by the efforts made thus far and presented at the meeting, but we also offer the caution that additional efforts are needed before a case can be made that uncertainties are estimated in a technically credible manner. The Board believes that the quantification, analysis, integration, and communication of uncertainty need to be addressed in a more rigorous manner than shown in the presentations at the Board meeting. Any projection of repository performance will be incomplete unless the DOE also provides a description and a meaningful quantification of the level of uncertainty associated with its predictions.

The Board has strongly endorsed the DOE's efforts in developing multiple lines of evidence to construct a "safety case" for the proposed repository. However, the Board believes that the evolving *Repository Safety Strategy (RSS)* does not yet substantially increase confidence that a repository at Yucca Mountain will perform as anticipated, because a majority of the components of the *RSS* are all dependent on performance assessment. In the Board's view, multiple lines of evidence that are not subject to the same limitations of performance assessment are needed to increase confidence in performance projections.

Recently, the Board answered questions from Representative Joe Barton following the Board's June 23, 2000, testimony before Mr. Barton's Subcommittee on Energy and Power. In its answers, which also are enclosed, the Board noted that, on the basis of information it has reviewed to date, the Board believes that the technical basis for current long-term projections of repository performance has critical weaknesses. These projections and their associated weaknesses reflect in part the DOE's "base case" (above-boiling) repository design. Although the site may merit a positive recommendation, the DOE has not yet demonstrated—for the base-case design—a firm technical basis for such a conclusion. As the Board pointed out in its July 1999 letter to Lake Barrett, who was at that time Acting Director of the program, some of the current large uncertainties about waste package and repository performance are directly or indirectly related to the high (i.e., above-boiling) repository temperatures associated with the current base-case design. Other uncertainties are related to a lack of fundamental understanding about physical processes that will occur over thousands of years; realistic predictions are therefore very difficult to make.

The Board reiterates its observation that there have been substantial improvements in performance assessment since the viability assessment. We particularly appreciate the DOE's willingness to discuss its preliminary calculations in an open and thoughtful manner. Addressing

the concerns we have discussed in this letter will help to make the TSPA/SR and the proposed *Repository Safety Strategy* more useful and understandable to the scientific community and to the decision-makers involved in deciding whether to recommend development of a repository at Yucca Mountain.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

Attachments:
"Comments of Nuclear Waste Technical Review Board
on Meeting of August 1 and 2, 2000, in Carson City, Nevada"
"Nuclear Waste Technical Review Board Responses to
Questions for the Record from Mr. Barton, August 31, 2000"

Comments of Nuclear Waste Technical Review Board on Meeting of August 1 and 2, 2000, in Carson City, Nevada

Total System Performance Assessment

The Board notes with satisfaction the substantial improvements made in performance assessment capabilities since the last iteration in 1998 for the viability assessment (TSPA/VA). Integration has increased substantially, and new and better models have been developed, including the site-scale saturated zone flow-and-transport model and the model relating the presence or absence of water on the surface of the waste package to relative humidity at high temperatures. New and important field data are being collected, for example, in the Exploratory Studies Facility (ESF), the east-west cross drift, the Nye County Early Warning Drilling Program, and the Busted Butte facility. Laboratory data also are being collected, for example, in the long-term-corrosion testing facility at Lawrence Livermore National Laboratory (LLNL).

In the following paragraphs, we provide detailed comments on TSPA and its specific components. Carrying out a performance assessment for the proposed exceedingly long-lived repository at Yucca Mountain, including taking into account highly complex interactions between the natural and engineered systems, is an extremely difficult undertaking. As might be expected for such a challenging project, our comments tend to highlight areas where improvement is needed. They should not be interpreted as diminishing the significant progress made in the last few years.

TSPA: General Comments

Efforts were made in the TSPA/VA and in the most recent performance assessment to increase transparency, but additional work is needed. For example, the most recent performance assessment and the latest version of *Repository Safety Strategy* contain sensitivity studies that show the effect of "neutralized" and "degraded" barriers. The differences between neutralized and degraded barriers should be stated clearly and justified. In addition, a clear explanation is needed to justify why some neutralization analyses assume the complete removal of a barrier while others, such as waste package neutralization, assume only partial removal of a barrier. Differences between the "nominal" and the "igneous activity" scenarios also need to be clarified, and the rationale for separating these scenarios should be clearly stated and justified. "Nominal" may be a poor name for what usually has been referred to as the "base case." In addition, presenting only the probability-weighted igneous scenario is confusing. It would be much clearer if the conditional results of the igneous scenario were presented and discussed both with and without probability weighting.

The Board is concerned about the lack of formal peer review for the TSPA/SR. The peer review panel convened for the TSPA/VA provided very useful comments and insights on that analysis. Several of their suggestions were implemented in the TSPA/VA and in the current version of the TSPA/SR. Areas where peer review would be particularly useful for site recommendation are statistics and uncertainty estimation. Evaluation of the statistical techniques used to estimate parameter ranges and the overall treatment of uncertainty could increase the

credibility of the conclusions drawn. At the meeting, the Board was told that a peer review (by an international body) would be completed for license application. Unfortunately, important national decisions, whose technical components will rest in large part on the TSPA/SR, must be made for site recommendation.

TSPA: Comments on Specific Components

Program integration has improved, but problems still exist. Several models were presented that address coupled processes, including the mountain-scale thermal-hydrological (TH) model, the thermal-hydrological-chemical (THC) model, and the thermal-hydrological multiscale model. Determining how these coupled-process models interact with each other and with other TSPA models is difficult. For example, the input to the isothermal seepage model is somewhat arbitrarily taken to be the fluxes predicted by the TH multiscale model 5 meters above the drifts. Because a large amount of thermally mobilized water is predicted to be present at this location at the time of peak waste package and drift-wall temperatures, seepage into the drifts is predicted. This is contrary to the conceptual model that to a large degree provides major justification for an above-boiling repository design showing that heat would move water away from the emplacement drifts when drift-wall and waste package temperatures are high. The credibility of these analyses would be improved by a coherent narrative description of the interrelationships of the various process models and their abstraction for TSPA.

The THC model predicts that coupled THC processes will have no significant effect on flow in the unsaturated zone. The TSPA/VA peer review panel, on the other hand, observed that a precipitate cap could be formed by thermally induced mineral deposits above the repository. Formation of such a cap would be important in determining how the repository environment would change with time and how that would affect the distribution and quantity of water flowing through the repository. At the Board meeting, Yucca Mountain scientists stated that the assumption of minimal THC effects on flow may be optimisitic—that is, nonconservative. The validity of the assumption that there are no THC effects on flow in the unsaturated zone should be demonstrated in a scientifically sound and defensible manner.

The DOE stated that radionuclide transport in the unsaturated zone is not affected significantly by large changes in fracture aperture. The Board is puzzled by this statement, given the known sensitivity of permeability to fracture aperture and the known sensitivity of radionuclide transport to permeability. The DOE should examine the justification for this assumption more closely. In addition, some assumed rock properties are supported by little or no data. Examples are the dearth of information at the appropriate measurement scale on intrinsic permeability, variability of permeability (including anisotropy), and input parameters needed for the models of active fractures and saturated zone diffusion.

According to DOE sensitivity studies, an important assumption affecting repository performance is the value assigned to the coefficient for diffusion of radionuclides through the invert to the rock immediately below the waste package. The DOE should evaluate whether the currently assigned diffusion coefficient may be too high (conservative). If so, justification for a different diffusion coefficient not only would improve predicted repository performance but also would allow a more robust estimation of barrier performance.

The environment affecting the engineered barrier system (EBS) is critical to determining the interactions between the natural and engineered components of the repository. Of particular importance to the corrosion of the drip shield and the waste packages is the chemistry of water and gases in the drifts. The Board is not convinced that the range of experiments and analyses carried out by the DOE is broad enough to describe, or even bound, all relevant coupled processes in the near-field environment affecting the EBS. For example, the work done at LLNL in the last few years to determine the changes in composition and boiling point of synthetic J-13 water as it becomes more concentrated via evaporation represents a major advancement in knowledge. However, the Board is unaware of any work—theoretical or experimental—for determining whether there are plausible fractionation mechanisms that could result in brines that are disproportionately enriched in trace elements or that show significant composition differences other than those anticipated to result from simple evaporation. Given the importance of the EBS environment, the DOE should examine and evaluate all pertinent and important chemical interactions.

Because sensitivity and neutralization studies indicate that the waste package may be the most important barrier for containing and isolating radioactive waste, the data, models, and assumptions pertaining to the waste package deserve special scrutiny. There have been significant improvements in waste package data and models since the TSPA/VA. For example, a major advancement is the model relating the presence or absence of water on the outer surface of the waste package to relative humidity at temperatures above the boiling point. Similarly, LLNL's long-term-corrosion testing facility (LTCTF) has improved the data set from which corrosion rates are estimated.

Still, there are important gaps in understanding waste package performance. For instance, the current TSPA model for generalized corrosion of Alloy 22 is based almost entirely on corrosion data from the LTCTF. These data were developed using Alloy 22 samples in comparatively dilute J-13-derived brines at temperatures no higher than 90°C. However, recent experimental and theoretical work carried out principally at LLNL shows that concentrated brines could be present on waste packages at temperatures up to 120°C. The DOE must establish that the water that will contact waste packages is similar to (or bounded by) J-13-derived water and ensure that the basis for predicting generalized corrosion rates at 90°-120°C is adequate.

The work for determining the temperatures and compositions at which water (with dissolved components) could exist on waste package surfaces has been under way for only a few years. Although progress has been made, the work should continue and broaden. For example, work comparing J-13 water and pore water from the repository horizon raises the issue of whether they are sufficiently similar so that J-13-derived water can be used as a reasonable surrogate for water that will contact waste packages. This issue needs to be resolved.

Extrapolation of corrosion rates determined from short-term (several years) experiments to predict waste package performance over tens of thousand of years is a subject of great concern to the Board. Long-term extrapolations may be suspect if they are made with little or no understanding of the fundamental mechanisms that either preserve or dissolve the passive layer critical to the corrosion resistance of Alloy 22. Such understanding should be accompanied by examples of long-term (archeological-geological) protection by passive layers in aggressive environments. Currently "unknown" processes that could affect the long-term viability of the passive layer include the following:

- passive layer defect accumulation—that is, the passive layer encounters microscopic defects as it sweeps into metal
- passive layer debris accumulation—that is, the long-term effects of corrosion products on the passive layer
- (quasi)transpassive dissolution—that is, if the open-circuit potential creeps up over time, transpassive regimes may be approached, promoted by the high molybdenum content of Alloy 22.

Several groups, including those at VTT (Finland), the Center for Nuclear Waste Regulatory Analyses, and The Pennsylvania State University, are investigating mechanisms that could affect the long-term behavior of passive layers. The DOE should familiarize itself with this work to improve the credibility of the extrapolation of long-term performance from short-term data.

The waste form consists of the radioactive waste itself, cladding, and any encapsulating or stabilizing matrix. Models of waste form degradation take into account several important considerations, including the radionuclide inventory, degradation of spent nuclear fuel and high-level defense waste, cladding, radionuclide solubilities, and formation of colloids. Waste form degradation determines the availability of radionuclides for transport out of the EBS and into the natural system after a waste package is breached. As in other areas, there have been substantial improvements since the TSPA/VA. Such improvements include better models for the perforation and unzipping of Zircaloy cladding, radionuclide solubilities, and in-package chemistry. In-package chemistry (for example, pH, carbonate content, ionic strength, and fluoride concentration) is particularly important because it will have a large effect on waste form degradation. Low pH in the first thousand years after waste package breach would result in a relatively high solubility for neptunium, which is the prime contributor to long-term dose.

The model that simulates colloid-facilitated transport of radionuclides seems reasonable but lacks sufficient data. Colloids are microscopic particles and other solids that can, and do, move rapidly through groundwater systems. Colloids can be man-made, resulting from corrosion of the waste package or the waste form itself, or they can be naturally occurring. Examples of natural colloids include organic humic substances, microbes, and inorganic materials, such as clays, iron and manganese oxides, and some silicates. Colloids are important in unsaturated and saturated zone transport because several important radionuclides, including plutonium and americium, can attach (sorb) themselves onto these microscopic solids. Recent studies, such as those at the Nevada Test Site, have shown that colloids are present in larger amounts than previously assumed. Data presented thus far are not adequate to form a technical basis for simulating colloidal transport. Recent performance assessments apparently assumed that colloid concentrations leaving the waste form are determined by the availability and stability of iron oxide. However, other studies have shown that sorbed plutonium is associated with manganese oxide and smectite (a form of clay) rather than iron oxide. Basing colloidal-transport coefficients on site-specific studies that consider the appropriate colloidal forms is needed for a technically defensible prediction of radionuclide transport.

Flow and transport in the saturated zone determine the timing and rate at which radionuclides reaching the water table beneath Yucca Mountain travel to the accessible environment, currently defined as 20 km from the repository. This is an area where there have

been particularly important changes since the TSPA/VA. For example, in TSPA/VA, the DOE relied on an extremely simple flow-tube model to characterize flow and transport in the saturated zone. The current approach makes use of a three-dimensional site-scale flow-and-transport model for most radionuclides. Other changes include simulation of matrix diffusion and sorption in the alluvium.

The Nye County Early Warning Drilling Program has yielded improved hydrogeological information; continuation of that program will produce very valuable data in the future. Unfortunately, substantial hydrogeological uncertainties persist at present. Rock and fault permeabilities (including anisotropy) remain to be measured at the appropriate scale for numerical model predictions. The vertical distance between zones of fracture concentration that conduct fluid flow is a critical parameter for fracture-matrix diffusion calculations. This parameter has been quantified only in the 3 C-Well boreholes, located outside of the likely flow paths from the repository footprint to the proposed compliance points downgradient. The extent of the alluvial zone, a potentially important contributor to repository performance because of its ability to retard radionuclides, still has not been defined adequately by field investigations. The areal extent and magnitude of the upward gradient from the deep regional carbonate aquifer remain defined by only a single data point. The use of the same dispersivity values for all rock formations is better suited to homogeneous rocks than to the rocks near Yucca Mountain. The Board anticipates that the Nye County program can help to fill in many of these data gaps.

Biosphere models in the TSPA determine how the plant and animal communities take up radionuclides that reach the accessible environment. A major change has occurred at the interface between the saturated zone and the biosphere. In the TSPA/VA, radionuclide concentrations in water were determined by calculating the concentration in water wells penetrating specific locations in the saturated zone. The current approach simply assumes that all the radionuclides crossing a boundary 20 km from the repository are diluted by the amount of water used by a hypothetical agricultural community. This approach lessens the need to determine specific flow paths unless they change the time it takes for transported radionuclides to reach the 20-km boundary. The Board notes, however, that this approach may be inconsistent with the "representative volume" concept used by the U.S. Environmental Protection Agency (EPA) in its proposed standards for a Yucca Mountain repository, 10 CFR Part 197. Consistent with the EPA's proposal, the current approach assumes that future populations will be similar to present populations. This eliminates the need to predict changes in the communities surrounding Yucca Mountain thousand of years into the future, predictions that are impossible to make reliably.

One of the most interesting results from the current performance assessment is the conclusion that igneous activity is the only contributor to estimated dose during the 10,000-year regulatory period. This is due to increased efforts in modeling the consequences of igneous activity and to the assumption that, absent igneous activity, waste packages will not be breached during the first 10,000 years. Modeling the consequences of igneous activity includes two igneous release scenarios: (1) eruption through the repository and (2) disruption of the waste packages in the emplacement drifts, allowing greatly increased exposure of waste to water seeping into the drifts. These scenarios involve many assumptions about the nature of igneous activity, the extent of waste package disruption, the transport of radionuclides through the atmosphere, and dose-conversion factors for atmospherically transported radionuclides. Future technical interactions between the DOE and the Nuclear Regulatory Commission on igneous

activity will, in large part, be devoted to examining the assumptions made by the DOE in its consequence models. The Board will be examining the basis for the assumptions.

TSPA: Treatment of Uncertainty

In its March 20, 2000, letter to you, the Board discussed the importance of proper treatment and estimation of uncertainties. Several suggestions were made to assist the DOE in this task. We are encouraged by the efforts made thus far and presented at the meeting, but we also offer the caution that additional efforts are needed before a case can be made that uncertainties were estimated in a technically credible manner. The Board believes that the quantification, analysis, integration, and communication of uncertainty need to be addressed in a more rigorous manner than shown in the presentations at the Board meeting. Any projection of repository performance will be incomplete unless the DOE also provides a description and a meaningful quantification of the level of uncertainty associated with its predictions.

The Board believes that meaningful quantification of the uncertainties associated with performance, clearly and understandably presented, is essential to provide policy-makers who are deciding on a site recommendation with critical information on trade-offs between projected performance and uncertainty in those projections. The Board realizes that projecting long-term performance of a potential repository at Yucca Mountain, or anywhere else for that matter, is inherently associated with uncertainty. Eliminating all the uncertainties will never be possible (although they can be reduced). In fact, the Board has noted that a decision on whether to recommend the site can be made at any time, depending in part on how much uncertainty policy-makers are prepared to accept. The timing of the site recommendation, of course, is clearly beyond the Board's charge.

At the Board meeting, we noted several issues that need further attention. For example, the ranges of chosen parameters need further justification. The use of performance assessment to set these ranges by determining what "really counts" may be of limited value because of the dependence of this method on the specific models used. Sound evidence is needed to justify the parameter range chosen. The number of "realizations" to be used for uncertainty analyses appears to have been determined somewhat arbitrarily. A more rigorous determination of the optimal number of realizations would make the uncertainty analyses more defensible. We heard at our meeting the preliminary results of sensitivity studies aimed at defining the effect of changes in assumptions about models and input parameters. In some cases, it was difficult to determine whether results were insensitive to some parameters because of the underlying physics and chemistry in the process models or because of simplifying assumptions used in the abstractions. We realize that many of these studies were so new that the presenters did not have sufficient time to evaluate them. Analysts and project scientists need to make the effort to do so and, as appropriate, modify them accordingly. Otherwise, they will be of limited use to reviewers.

Analysis and integration of uncertainties are other topics of Board interest. The Board is puzzled by the sharp decrease in uncertainty, as defined by the bandwidth of the Monte Carlo simulations after 100,000 years. Uncertainty typically increases over time, but in the performance assessment analyses, this measure of uncertainty decreases. If, as some maintain, the decrease is due to the assumed failure of most of the waste packages by that time, an effort should be made to demonstrate convincingly that this is so. As indicated previously, a clear analysis of the contribution of uncertainty to the overall results is needed.

Another issue requiring further thought is the adoption of a mix of conservative, realistic, and optimistic assumptions in models and parameters: for example, the "conservative" estimates of diffusion through the invert and the "optimistic" estimate of the extent of THC coupling. Determining the overall level of conservatism for a mix of conservative, realistic, and optimistic assumptions will be very difficult. If the DOE wants to argue that the TSPA is conservative, an effort must be made to provide a defensible estimate of the overall level of conservatism.

Finally, even if a technically credible performance assessment is carried out, poor communication can hurt the perception of credibility. An example of this is the potential confusion generated by the differences between the nominal scenario and the igneous scenario, as discussed above. In contrast to the nominal scenario, the igneous scenario is heavily influenced by the very low probability of the occurrence of igneous activity affecting the proposed repository. This probability is about one chance in 100,000,000 per year. Much of this confusion can be prevented if the differences between the two scenarios and the rationale behind probability weighting are clearly explained along with a presentation and discussion of igneous activity scenarios without probability weighting.

Ongoing Scientific Studies

Results of ongoing scientific investigations at Yucca Mountain were presented at the August Board meeting. Much significance was attached to certain observations in the lower lithophysal rock in the cross drift. These observations appear to show greater capillary suction and fracture permeability and therefore lower seepage in the lower lithophysal unit than in the middle nonlithophysal unit in the ESF. According to present plans, the lower lithophysal units will house more than 70 percent of the waste packages. Based on other observations, a new mechanism explaining the mineral deposits found in lithophysal cavities also was proposed. Both these observations and the related hypotheses are important in determining the ability of water to seep into the drift. They need to be evaluated carefully.

Access to the lower lithophysal unit is providing very useful information to the project. We understand that some tests, including the thermal test in the cross drift, are being deferred. The Board urges the DOE to continue and complete ongoing studies, such as the crossover-drift test, and start deferred tests in a timely manner. To finalize a repository design and conduct a convincing performance assessment, the DOE needs to know as much as reasonably possible about the actual rocks within which the waste will be placed.

Finally, at the May 1, 2000, meeting in Pahrump, Nevada, an independent study was presented that apparently contradicted results from the original study of chlorine-36 in the ESF and the cross drift. The differences may be due in large part to differences in sample processing. No new results were presented at the August meeting. We understand that an effort is under way to address the processing differences, and we look forward to resolution of the issue.

Repository Safety Strategy

At its August meeting, the Board heard a presentation on the latest version of *Repository Safety Strategy (RSS)*. Although demonstrating, in the conventional sense, how a repository will behave thousands of years into the future may not be possible, steps can be taken to increase confidence in estimates of future performance. The Board has strongly endorsed the DOE's

efforts in developing multiple lines of evidence to construct a "safety case" for the proposed repository. The DOE develops such a case in the *RSS*, now being revised. The DOE's safety case rests on six elements, or "pillars": performance-assessment calculations, safety margins, defense-in-depth, explicit consideration of potentially disruptive events, insights from natural analogs, and performance confirmation.

In the Board's view, the pillars of the *RSS* do not yet satisfy the goal of providing multiple lines of evidence and do not substantially increase confidence that a repository at Yucca Mountain will perform as anticipated. Four of the pillars—performance-assessment calculations, safety margins, defense-in-depth, and analyses of disruptive events—as currently presented are not independent of each other. They are all dependent on performance assessment. Thus, if one lacks confidence in the DOE's performance assessment, one is not likely to have much confidence in any of the four pillars. The last two pillars of the repository safety case—natural analogs and performance confirmation—*are* independent of performance-assessment calculations. However, the DOE's evaluation of natural analogs so far has been minimal, and performance confirmation is simply a plan of activities that will be subject to future budget and time constraints.

The Board has endorsed the DOE's use of performance assessment-calculations, but it has noted the limits of those calculations and has expressed doubt that relying solely on them to demonstrate repository safety will ever be possible. Multiple lines of evidence that are not subject to the same limitations of performance assessment can increase confidence in performance projections. The DOE's safety case has not yet accomplished those important ends.

Finally, as part of its approach to demonstrating defense-in-depth, the DOE conducted neutralization analyses. The analyses show the effect on the calculated dose of neutralizing or removing different barriers. We point out above the need to clarify this effort. We also note that a useful supplement to this approach would be to see the incremental effect on dose of adding individual barriers. In other words, the analysis would start off by estimating the dose, assuming that the radioactive waste was lying exposed at the surface. Individual elements of the geologic and engineered system then would be added, and resulting dose estimates would be calculated until the repository system reached its proposed form. Such an analysis could give interested parties a clearer picture of how much each individual element adds to repository performance.

Appendix F
Other Board Communications

Letter from Chairman Jared L. Cohon to Jim Wells; Director; Energy, Resources, and Science Issues; United States General Accounting Office; July 21, 2000.
Subject: Repository Design.

Letter from Rep. Joe Barton, Chairman, Subcommittee on Energy and Power, Committee on Commerce, United States House of Representatives, to Debra S. Knopman, Board member; July 20, 2000.
Subject: Appearance before Subcommittee on Energy and Power on June 23, 2000. Questions for NWTRB enclosed as attachment.

Letter from Chairman Jared L. Cohon to Rep. Joe Barton, Chairman, Subcommittee on Energy and Power, Committee on Commerce, United States House of Representatives; August 31, 2000.
Subject: Response to questions for NWTRB attached to July, 2000, letter from Rep. Barton to Debra S. Knopman.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

July 21, 2000

Mr. Jim Wells
Director
Energy, Resources, and Science Issues
United States General Accounting Office
Washington, D.C. 20548-0001

Dear Mr. Wells:

In your recent report for Senator Pete Domenici, *Radiation Standards: Scientific Basis Inconclusive, and EPA and NRC Disagreement Continues*, you referred to the views of the Nuclear Waste Technical Review Board (Board) about the design for the proposed Yucca Mountain high-level waste repository. I believe that your report is misleading in two respects. First, by stating that the Board "favors" a below-boiling repository design, your report creates a mistaken perception that the Board has recommended a particular design to the Department of Energy (DOE). Second, your report creates a mistaken perception of the cost of alternative repository designs.

Consistent with its mandate from Congress, the Board has followed closely the evolution of the DOE's repository design. The Board has stated that the choice of design could reduce the uncertainties in projecting repository performance for thousands of years. It also has stated that there is not yet a strong technical basis for selecting an above-boiling repository design. Thus, the Board has recommended that the DOE evaluate (among other things) the magnitude of uncertainty associated with alternative designs having different thermal characteristics. However, contrary to the impression created by your report, the Board has never recommended that the DOE select either an above-boiling or a below-boiling design. In fact, in its June 2000 testimony before the House Commerce Subcommittee on Energy and Power, the Board explicitly stated that "more thorough analysis is needed before any judgment is made about the optimal thermal conditions for repository operation."

Your report also stated that a below-boiling design "could add about $2 billion to the costs" of developing a repository at Yucca Mountain. At the Board's meeting in May 2000, the DOE presented some preliminary results and cost estimates related to its evaluation of alternative thermal designs. That analysis suggests that the incremental discounted cost of implementing a below-boiling (as opposed to an above-boiling) design might be as low as $600 million. If, for example, different assumptions are adopted about the distance between repository tunnels, the incremental cost might be reduced even further. This type of evaluation, stimulated by a Board recommendation, will likely help the DOE to understand better the technical and economic trade-offs associated with alternative repository designs. Such an understanding is essential for a sound decision, regardless of what regulatory standard is ultimately established.

Telephone: 703-235-4473 Fax: 703-235-4495

Regrettably, the Board was not given the opportunity to comment on a draft during your report's preparation. We strongly encourage your office to contact the Board to ensure that possibly misleading impressions of Board positions are not created.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

cc:
The Honorable Pete V. Domenici
Dr. Ivan Itkin

jlc085v2

U.S. House of Representatives
Committee on Commerce
Room 2125, Rayburn House Office Building
Washington, DC 20515–6115

July 20, 2000

JUL 26 2000

Dr. Debra S. Knopman
Board Member
U.S. Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Suite 1300
Arlington, VA 22201

Dear Dr. Knopman:

I am writing to thank you for appearing before the Subcommittee on Energy and Power on June 23, 2000, to present testimony on the status of the Department of energy (DOE) program to develop a permanent geologic repository at Yucca Mountain, Nevada for spent nuclear fuel and high-level radioactive waste. Your testimony allowed the Subcommittee Members to gain a better understanding of this extremely important issue.

Pursuant to the Chair's order of June 23, 2000, the record of the Subcommittee's hearing remains open to permit Members to submit questions to witnesses in writing. Attached you will find questions submitted by Members of the Subcommittee. I would appreciate it if you could respond to these questions in writing no later than the close of business on August 18, 2000 in order to facilitate the printing of the hearing record.

Thank you again for your time and effort in preparing and delivering testimony before the Subcommittee.

Sincerely,

Joe Barton

Joe Barton
Chairman
Subcommittee on Energy and Power

Attachment

QUESTIONS FOR THE RECORD FROM MR. BARTON FOR NWTRB

1. Is the Technical Review Board concerned that funding constraints are causing DOE to postpone or skip critical technical analyses necessary to support the site recommendation and licensing decisions? If so, please identify the specific areas that are not being addressed adequately by DOE.

2. Is it correct that the Technical Review Board is concerned that DOE is not paying enough attention to the uncertainties inherent in the repository's long-term performance, especially with respect to the "hot" repository design?

3. How would the Board suggest that DOE should take these uncertainties into account -- is this a matter of DOE actually changing its repository design, or merely a matter of presenting this uncertainty information to the decision-makers?

4. When does the decision on hot versus cool repository design have to made? Can DOE leave this decision open into the licensing phase?

5. A recent GAO report on radiation standards suggested that the cooler repository design favored by the Board could add $ 2 billion to the cost of the repository. What is the basis for that statement by GAO, and is that estimate correct?

6. Please identify any other outstanding technical issues with the repository design that, in the Board's view, are not being addressed adequately by DOE. Explain these concerns fully, and make recommendations on actions that DOE and the Congress should take to resolve these issues.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

August 31, 2000

Honorable Joe Barton
Chairman
Subcommittee on Energy and Power
Committee on Commerce
U.S. House of Representatives
Room 2125, Rayburn House Office Building
Washington, DC 20515-6115

Dear Mr. Barton:

Enclosed are responses to the questions posed in your letter of July 20, 2000, to Dr. Debra Knopman following her appearance before the Subcommittee on Energy and Power on June 23, 2000. The Board provides independent advice on the technical issues associated with the management of the country's commercial spent nuclear fuel and defense high-level radioactive waste. The Board offers its technical views to help inform the larger consideration of issues that faces the Department of Energy and the Congress in their evaluation of the suitability of the Yucca Mountain candidate repository site.

The Board is keenly aware that many of the issues that must be considered in making decisions in this policy area are technical ones, but others are not. Regarding site suitability, we believe that Congress and the Secretary will find it useful to have our views on the adequacy of current information to technically support a possible site recommendation. As noted in our responses, a site recommendation can be made at any time, depending in part on how much uncertainty policy-makers are prepared to accept.

Please let me or the Board's staff know if we can provide you or your staff with any additional information on the enclosed responses.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

Enclosure

Telephone: 703-235-4473 Fax: 703-235-4495

NUCLEAR WASTE TECHNICAL REVIEW BOARD RESPONSES TO QUESTIONS FOR THE RECORD FROM MR. BARTON AUGUST 31, 2000

1. Is the Technical Review Board concerned that funding constraints are causing DOE to postpone or skip critical technical analyses necessary to support the site recommendation and licensing decisions? If so, please identify the specific areas that are not being addressed adequately by DOE.

The Board's congressional mandate is statutorily limited to reviewing the technical and scientific validity of Department of Energy (DOE) activities. Therefore, the Board has not examined the details of DOE's budget for Yucca Mountain research or its funding allocations for program operation, management, procurement, and contracting. Consequently, the Board cannot judge the extent to which the Yucca Mountain site characterization and repository design activities have been or will be constrained by budget limitations. What is clear, however, is that the Board's present understanding of a potential repository located at Yucca Mountain is affected by many policy-related factors, including congressional appropriations, DOE's research and program priorities, and statutory and administrative deadlines, as well as the significant challenge of undertaking a first-of-a-kind activity.

Because less than a year remains before the scheduled site-recommendation decision in July 2001, the amount of additional scientific and technical work that can be completed by that date is very limited. Thus, the information available in July 2001 for a site recommendation will in all likelihood not be appreciably affected by whatever budget Congress passes for FY 2001. However, funding constraints in DOE's budget for FY 2001 and beyond could limit ongoing and new work that might support a DOE license application for repository construction.

The Board reviews the scientific and technical program as it is and makes its technical judgments accordingly. On the basis of information it has reviewed to date, the Board believes that the technical basis for DOE's current long-term projections of repository performance has critical weaknesses. These projections and their associated weaknesses reflect in part the DOE's "base-case" (above-boiling) repository design. Although the site may, in fact, merit a positive site recommendation, DOE has not yet demonstrated—for the base-case design—a firm technical basis for that conclusion.

Some of the current large uncertainties about waste package and repository performance are directly or indirectly related to the high (i.e., above-boiling) repository temperatures associated with DOE's current base-case design. High temperatures increase the level, extent, and significance of the combined, or "coupled," effects of thermal, hydrologic, mechanical, and chemical processes. Furthermore, the waste packages may be more vulnerable to corrosion at higher temperatures if water is present. The Board believes that it will be very difficult for the DOE to improve substantially its current understanding of these high-temperature effects during the next year or two. However, it may be possible over the next several months to reduce some uncertainties, for example, by developing a defensible technical basis for a lower-temperature repository design.

In addition to the effects of high temperatures, some uncertainties are related to a lack of fundamental understanding about physical processes that will extend over thousands of years; realistic predictions are therefore very difficult to make. For example, the performance of the waste packages over thousands of years has been extrapolated from a few years of corrosion data and too limited an understanding of fundamental corrosion processes. Finally, the characterization of the hydrogeology below the repository horizon, although supported by some data, continues to rest largely on inadequately supported hypotheses. As a result, for example, the flow and transport of radionuclides in the unsaturated and saturated zones from the repository to the accessible environment are poorly understood.

The Board believes that significantly improving the fundamental understanding of these natural features and engineered barriers during the next year or two will be very difficult. However, the Board believes that work in these areas is important and should continue. Because of the complexity of the Yucca Mountain site and the challenges involved in extrapolating data over long time periods, gaining such an understanding of these basic processes will take time. Continued adequate funding of these long-term studies will be important.

2. Is it correct that the Technical Review Board is concerned that DOE is not paying enough attention to the uncertainties inherent in the repository's long-term performance, especially with respect to the "hot" repository design?

The persistence of substantial uncertainties has led the Board over the last few years to recommend strongly that DOE develop a more technically defensible basis for making design, site-recommendation, and licensing decisions. In particular, the Board has recommended initiation of fundamental studies on long-term corrosion, evaluation of alternative repository designs, improved characterization of rock formations in the vicinity of Yucca Mountain, examination of radionuclide retardation in the unsaturated and saturated zones below the repository horizon, evaluation of colloidal transport, and investigation of the effect of structures and heterogeneities on water movement above and below the water table. DOE has responded to many of the Board's suggestions, but it has not yet completed all of those studies. Although the Board is encouraged by the level of attention DOE is now giving to the quantification and characterization of uncertainty in estimating repository system performance, the Board also continues to have concerns in this area.

The Board realizes that projecting long-term performance of a potential repository at Yucca Mountain, or anywhere else for that matter, is inherently associated with uncertainty. Eliminating all the uncertainties will never be possible (although they can be reduced). In fact, the Board has noted that a site recommendation can be made at any time, depending in part on how much uncertainty policy-makers are prepared to accept. The timing of the site recommendation, of course, is clearly beyond the Board's charge.

As noted in the answer to question #1, on the basis of information reviewed to date, the Board believes that the technical basis for DOE's current long-term projections of repository performance has critical weaknesses. These projections and their associated weaknesses reflect in part the DOE's base-case (above-boiling) repository design. The Board explicitly raised this concern about above-boiling repository designs in a July 9, 1999, letter to DOE's Office of Civilian Radioactive Waste Management. Although the site may, in fact, merit a positive site

recommendation, DOE has not yet demonstrated—for the base-case design—a firm technical basis for that conclusion.

Adopting a lower-temperature repository design for commercial spent fuel might mitigate some of the weaknesses associated with projections of long-term repository performance, such as problems associated with coupled processes. A lower-temperature repository design could make projections of performance less dependent on areas where scientific understanding is incomplete. Therefore, DOE should augment its current design evaluations with a rigorous and persuasive evaluation of the performance of, and trade-offs associated with, alternative repository designs, including assessing the effects of the following factors on performance and uncertainty: age of waste at emplacement, spacing between waste packages, ventilation rates and efficiencies, and time before repository closure. It is possible, but not certain, that a cooler, drier, and simpler design than the current base-case design would lower the technical hurdles that DOE now faces in projecting long-term waste package and repository performance.

DOE, however, has not yet carried out a sufficiently thorough evaluation of low-temperature repository designs. By carrying out such an evaluation, DOE would develop a much better understanding of how the thermal characteristics of different designs may affect critical uncertainties (e.g., those associated with coupled processes, the stability of the passive layer of Alloy 22, and the waste package environment). But the magnitude of other uncertainties, such as those associated with the saturated zone under the repository, are very likely to be independent of the facility's design.

3. How would the Board suggest that DOE should take these uncertainties into account—is this a matter of DOE actually changing its repository design, or merely a matter of presenting this uncertainty information to the decision-makers?

DOE intends to base its site-recommendation decision primarily on the results of a total system performance assessment (TSPA), a complex computer model that estimates repository performance many thousands of years into the future. The technical soundness of DOE's site-recommendation decision will therefore depend to a large extent on the technical validity of its TSPA. Put another way, policy-makers' confidence in performance assessment reflects in many ways the level of uncertainty associated with estimates of performance: the greater the uncertainty, the lower the confidence in repository performance may be.

There are several internationally recognized strategies for managing or reducing uncertainties. One strategy involves using "conservative" assumptions and parameters throughout the performance assessment. Thus, if the assessment is in error, the long-term performance of the repository is underestimated, not overestimated. A second strategy involves using multiple lines of evidence independent of performance assessment in developing a "repository safety case." A third strategy involves making repository design choices that minimize uncertainties.

DOE has made progress in implementing each of these three strategies, but it can—and should—do more. For example, it is difficult to know whether the assumptions and parameters used in DOE's performance assessments are truly conservative or how the combination of conservative, optimistic, and realistic estimates affects overall dose calculations and the uncertainties associated with those calculations. As noted in the response to question #6, DOE has not yet

completed the evaluation of independent lines of evidence—an evaluation that is needed to increase confidence in the conclusions of its safety case derived from performance assessment. Finally, as noted in the answer to question #2, DOE has not yet performed a rigorous and persuasive analysis of how uncertainty in repository performance varies with repository design.

Regardless of what strategies are used to manage or reduce uncertainty, the Board believes that DOE's projections of repository performance will be incomplete unless DOE also provides a description and a meaningful quantification of the level of uncertainty associated with its predictions. DOE then will be in a better position to make important decisions, including choosing waste package and repository designs having acceptable predictions of performance, and decision-makers will be able to make technically informed choices related to the DOE's work at Yucca Mountain.

4. When does the decision on hot versus cool repository design have to be made? Can DOE leave this decision open into the licensing phase?

For DOE to make a positive site recommendation, the Board believes that DOE would need to make a technically defensible argument that at least one repository design concept, including firm operational assumptions, will perform satisfactorily for thousands of years. Such an argument would presumably consider the associated levels of uncertainty in repository performance. Therefore, the Board assumes that DOE would describe for the site recommendation at least one design concept and a set of operational assumptions with sufficient specificity so that sound and complete assessments of performance can be developed.

The Nuclear Regulatory Commission, of course, will determine whether the particular detailed design or designs used in DOE's license application will, in fact, provide reasonable assurance of satisfactory performance to warrant constructing a facility.

5. A recent GAO report on radiation standards suggested that the cooler repository design favored by the Board could add $2 billion to the cost of the repository. What is the basis for that statement by GAO, and is that estimate correct?

The statements in the GAO report are misleading in two respects. First, although the Board noted in July 1999 that the technical basis supporting any above-boiling repository design was, in its opinion, not strong enough, the Board is not in a position to *recommend* a specific design alternative. In fact, in its June 23, 2000, testimony before the Subcommittee, the Board explicitly stated, "... more thorough analysis is needed before any judgment is made about the optimal thermal conditions for repository operation."

Second, at the Board's meeting in May 2000, DOE presented some preliminary results and cost estimates related to alternative thermal designs. That analysis suggested that the incremental discounted cost of implementing a below-boiling (as opposed to an above-boiling) design may be as low as $600 million. If, for example, different assumptions were adopted about the distance between repository tunnels, the incremental cost might be reduced even more. This type of result, stimulated by a Board recommendation, is likely to help DOE understand better the technical and economic trade-offs associated with alternative repository designs. Such an

understanding is essential for making a sound decision, regardless of what regulatory standard is ultimately established.

6. Please identify any other outstanding technical issues with the repository design that, in the Board's view, are not being addressed adequately by DOE. Explain these concerns fully, and make recommendations on actions that DOE and the Congress should take to resolve these issues.

Unfortunately, DOE's models are not well enough developed or supported by sufficient data to differentiate between the performance of below-boiling and above-boiling repository designs over the next several thousand years. To develop the tools necessary for evaluating these differences, DOE would have to increase substantially its understanding of the coupled thermal, hydrologic, mechanical, and geochemical processes taking place within the repository; the mechanisms and paths by which radionuclides could be transported from the repository tunnels into the unsaturated and saturated zones below; and the data and fundamental knowledge used to project the long-term corrosion susceptibility of waste packages.

Although the Board has endorsed the use of TSPA, in an April 1999 report the Board noted the limits of TSPA calculations and expressed doubt that relying "solely on [performance assessment] to demonstrate repository safety" will ever be possible. Therefore, the Board recommended in this report that DOE develop multiple lines of evidence that can supplement performance assessment.

DOE is working on a repository safety case that is designed to increase confidence that a repository at Yucca Mountain is likely to perform as predicted. The strategy currently rests on six "pillars": performance-assessment calculations, safety margins, analysis of disruptive events, defense-in-depth, natural analogs, and performance confirmation during and after waste emplacement. On the surface, these pillars may appear to satisfy the Board's recommendation that DOE develop multiple lines of evidence that can supplement performance assessment. A closer look suggests otherwise.

To begin with, four of the pillars—performance-assessment calculations, safety margins, defense-in-depth, and analysis of disruptive events—as currently presented are not independent of each other. They are all dependent on performance assessment. Thus, if one lacks confidence in DOE's performance assessment, one is not likely to have much confidence in any of the four pillars. The last two pillars of the repository safety case—natural analogs and performance confirmation—*are* independent of performance-assessment calculations. However, DOE's evaluation of natural analogs so far has been minimal, and performance confirmation is simply a plan of activities that will be subject to future budget and time constraints.

Appendix G
Nuclear Waste Technical Review Board Strategic Plan for FY 2001-2006 (Revised March 2001)

Statement of the Chairman

The U.S. Nuclear Waste Technical Review Board was established as an independent agency of the United States Government on December 22, 1987, in the Nuclear Waste Policy Amendments Act. Congress charged the Board with evaluating the technical and scientific validity of activities undertaken by the Secretary of Energy, including characterizing a site at Yucca Mountain, Nevada, for its suitability as the location of a permanent repository for civilian spent nuclear fuel and high-level radioactive waste. The Board also reviews activities related to packaging and transporting such waste. In creating the Board, Congress realized that an unbiased technical and scientific evaluation of the credibility of site evaluation and other high-level radioactive waste management activities would be crucial to public acceptance of any approach for disposing of the waste.

The Board takes its peer review role very seriously. The Board strives to provide Congress and the Secretary of Energy with completely independent, credible, and timely technical and scientific program evaluations and recommendations achieved through peer review of the highest quality. The Board's technical and scientific findings and recommendations are included in reports that are submitted at least twice each year to the Secretary of Energy and the Congress. The Board can make recommendations but cannot compel the Department of Energy to comply.

The attached strategic plan includes the Board's goals and objectives for 2001 through 2006. *If* the site is recommended for repository development, much important technical and scientific work will continue on repository design, and transportation and packaging of the waste will gain in prominence. Because many critical decisions will be made throughout this period, we believe that the Board's ongoing review of these efforts will continue to be critically important.

On behalf of the Board,
Jared L. Cohon, Chairman

Mission

The Board's mission, established in the Nuclear Waste Policy Amendments Act (NWPAA) of 1987 (Public Law 100-203), is to "…evaluate the technical and scientific validity of [high-level radioactive waste management] activities undertaken by the Secretary of Energy, including site-characterization activities; and activities related to the packaging or transportation of high-level radioactive waste and spent nuclear fuel." By law, the Board shall cease to exist not later than one year after the date on which the Secretary begins disposal of high-level radioactive waste or spent nuclear fuel in a repository.

Vision

By performing ongoing technical and scientific review and evaluation of the highest quality, the Board makes a unique and essential contribution to enhancing the technical and scientific credibility of the Secretary of Energy's efforts to characterize the Yucca Mountain site for its suitability as the location of a permanent repository for the safe disposal of spent nuclear fuel and high-level radioactive waste. If the Secretary and the President recommend the site and if the site is accepted, the Board will continue to perform critical technical and scientific peer review of performance-confirmation work. If construction of a repository proceeds at the site, the Board also will provide technical and scientific oversight of activities related to packaging and transporting the waste to the repository.

Values

To achieve its goals, the Board conducts itself according to the following values.

The Board strives to ensure that its members and staff have no conflicts of interest—real or perceived—related to the Secretary's efforts to characterize the Yucca Mountain site or to package and transport spent nuclear fuel and high-level radioactive waste.

The Board members arrive at their conclusions on the basis of objective evaluations of the technical and scientific validity of the Secretary's activities.

The Board's practices and procedures are open and conducted so that the Board's integrity and objectivity are above reproach.

The Board's findings and recommendations are technically and scientifically sound and are based on the best available technical analysis and information.

The Board's findings and recommendations are communicated clearly and in time for them to be most useful to Congress, the Secretary, and the public. The Board encourages public discussion of its findings and recommendations at its meetings.

NWTRB General Goals and Objectives

The national goal for radioactive waste management established by Congress in the Nuclear Waste Policy Act of 1982 and the Nuclear Waste Policy Amendments Act of 1987 is safe disposal of civilian spent nuclear fuel and high-level radioactive waste in a permanent geologic repository at a suitable site or sites. In the acts, Congress directed the U.S. Department of Energy (DOE) to characterize a site at Yucca Mountain, Nevada, to determine its suitability as the potential location of a permanent repository for high-level radioactive waste. Congress charged the Nuclear Waste Technical Review Board with reviewing the technical and scientific validity of the Secretary of Energy's activities associated with achieving this goal, including characterizing the site and packaging and transporting the waste. The Board's general goals have been established in accordance with its congressional mandate.

General Goals

To accomplish its congressional mandate, the Board has established four general goals.

1. Ensure that technical and scientific activities undertaken by the DOE related to determining the suitability of the Yucca Mountain site as the possible

location of a permanent repository and predicting the performance of a potential repository establish a sound technical basis for a decision on whether to recommend the site for repository development.

2. Ensure that technical and scientific activities undertaken by the DOE related to designing a repository and waste packages are well integrated and establish a sound technical basis for designing the repository system, including the engineered barrier system (EBS).

3. Ensure that technical and scientific activities undertaken by the DOE related to packaging, handling, and transporting spent nuclear fuel and high-level radioactive waste to a permanent repository are well integrated and establish a sound technical basis for designing and operating a waste management system.

4. Ensure that long-term technical and scientific activities undertaken by the DOE, including performance confirmation and design modifications, establish a sound technical basis for reducing uncertainties related to repository performance, operating a repository, and revising repository and waste package designs. (Will apply only if the site is found suitable and a site recommendation is approved.)

Strategic Objectives

To achieve its general goals, the Board has established the following long-term objectives.

1. Objectives Related to Site Suitability and Predicting Repository Performance

1.1 Evaluate the technical and scientific validity of DOE studies, testing, and analyses supporting a decision on whether to recommend the Yucca Mountain site.

1.2 Evaluate the hydrologic, geologic, chemical, and other natural processes at the Yucca Mountain site that establish the foundation for predicting repository performance.

1.3 Review the technical and scientific validity of models used to predict repository performance.

1.4 Evaluate the DOE's progress in developing a safety strategy for the Yucca Mountain site.

1.5 Review the *Record of Decision* for the final environmental impact statement (EIS) for a potential Yucca Mountain site.

2. Objectives Related to the Engineered Repository System

2.1 Evaluate repository and waste package designs, including the technical bases for the designs.

2.2 Review the progress and results of materials testing being conducted to address uncertainties about waste package performance.

2.3 Assess the integration of science and engineering in the DOE program, paying particular attention to the effects of site-characterization studies (e.g., modeling, testing, and analyses of thermal, mechanical, and chemical effects) on repository and waste package designs.

3. Objectives Related to the Waste Management System

3.1. Evaluate the accuracy and reasonableness of analyses, methods, and major assumptions used by the DOE in estimating health and safety risks associated with transporting spent nuclear fuel and high-level radioactive waste.

3.2. Review the adequacy of requirements for developing the transportation infrastructure necessary to move significant amounts of spent nuclear fuel from individual reactor sites to a DOE storage or disposal site. Compare these requirements with current transportation capabilities, and determine the effort needed to develop a large-scale transportation capability.

3.3 Review the adequacy of the DOE's plans for safely handling and packaging spent nuclear fuel and high-level radioactive waste for transport to a permanent repository.

3.3. Evaluate the effectiveness of the DOE's efforts to integrate the various components of the waste management system (packaging, handling, transport, storage, and disposal of the waste).

3.4. Review the DOE's plans for addressing public safety concerns and for enhancing safety capabilities along transportation corridors. This includes activities related to development of plans (e.g., route selection), coordination, accident prevention (e.g., improved inspections and enforcement), and emergency response.

4. Objectives Related to Long-Term Activities
(Will apply only if the site is found suitable and a site recommendation is ratified)

4.1 Monitor performance-confirmation activities undertaken by the DOE that are designed to reduce uncertainties related to repository performance, including corrosion testing.

4.2 Monitor performance-confirmation activities undertaken by the DOE, and evaluate the need to revise repository or waste package designs on the basis of the results of such activities.

Achieving the Goals and Objectives

Congress granted significant investigatory powers to the Board in the NWPAA. In accordance with the NWPAA, the Board may hold such hearings, sit and act at such times and places, take such testimony, and receive such evidence as it considers appropriate. By law, no nominee to the Board is employed by the DOE or its contractors. The Board has adopted strong anti-conflict-of-interest procedures that go even further to ensure that the Board avoids even the appearance of a conflict.

Subject to existing law, the DOE is directed to provide all records, files, papers, data, and information requested by the Board, including drafts of work products and documentation of work in progress. According to the legislative history, in providing this access, Congress expected that the Board would review and comment on DOE decisions, plans, and actions as they occurred, not after the fact. The Board believes that it has adequate powers under current law to achieve its goals and objectives.

Much of the Board's information gathering is done at open public meetings where the DOE, its contractors, and other program participants present technical information. The Board's five panels meet as needed and are organized around specific issue areas. The full Board meets three or four times each year. The Board also gathers information through field trips to the Yucca Mountain site, visits to contractor laboratories and facilities, and informal meetings with individuals working on the project. Although the Board's information-gathering activities are carried out primarily to further the Board's review, they have the collateral benefit of promoting communication and integration of technical information within the DOE program and facilitating the dissemination of information among interested parties outside the program. Analyses of the information gathered by the Board are performed by its members, the Board's professional staff, and consultants hired to supplement the expertise of the Board and the staff.

The DOE is scheduled to decide in 2001 whether to recommend the Yucca Mountain site for repository development. If the decision is positive and the President and Congress approve the recommendation, the DOE will apply to the Nuclear Regulatory Commission (NRC) for a license to construct and operate a repository at the site. If the license is approved, the expectation is that testing will continue at the site to increase confidence in predictions of repository performance. The Board expects to review the analytical processes as well as the base of technical information used by the DOE in making decisions about site recommendation. The Board also will review the technical and scientific validity of activities related to confirmatory testing and to transportation and packaging of spent nuclear fuel and high-level radioactive waste. The Board reports the results of its reviews at least twice each year to Congress and the Secretary of Energy. Additional communication occurs as needed. Such communications are available to the public either by request or on the Board's Web site at www.nwtrb.gov.

Crosscutting Functions

Several entities and agencies share responsibility for the ultimate national goal established by Congress of packaging, transporting, and disposing of spent nuclear fuel and high-level radioactive waste in a geologic repository at a suitable site. Although there may be crosscutting areas of interest, the Board's role is unique among those involved in managing high-level radioactive waste. For example:

Congress and the Administration, including the Secretary of Energy, make policy decisions on what the national goals will be and how they will be implemented. The Board's role in this process is to help ensure that policy-makers are given unbiased and credible technical and scientific analyses and information.

State and local governments comment on and oversee DOE activities. The Board's oversight activities are different in that they are (1) unconstrained by any stake in the outcome of the endeavor besides the credibility of the scientific and technical activities, (2) confined to scientific and technical evaluations, and (3) conducted by individuals nominated by the National Academy of Sciences and expressly chosen by the President for their expertise in the various disciplines represented in the DOE program.

Federal agencies that have roles in achieving a safe waste management program include the DOE, the NRC, the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the United States Geological Survey (USGS). The DOE and its contractors are responsible for developing and implementing the waste management system and for planning and conducting research activities related to disposal, packaging, and transportation of spent nuclear fuel and high-level radioactive waste. The NRC is the regulatory body authorized to license the construction and operation of the repository to ensure protection of public health and safety and the environment. The EPA is the agency given the responsibility to issue health-based safety standards. The DOT is responsible for regulating the transportation of the waste. The USGS participates in site-characterization activities at the Yucca Mountain site. The Board's role is unique among these federal agencies: perform ongoing, independent review and oversight of the technical and scientific validity of the Secretary of Energy's activities relating to civilian radioactive waste management, including site characterization and packaging and transportation of spent nuclear fuel and high-level radioactive waste, and communicate its findings and recommendations to Congress, the Secretary of Energy, and the public. The Board's evaluation of the technical and scientific validity of the Secretary's activities related to civilian radioactive waste management complements and enhances the work of other agencies involved in achieving the national goal.

Key External Factors

Some factors that are beyond the Board's control could affect its ability to achieve its goals and objectives. Among them are the following:

The Board has no implementing authority. The Board is by definition and mandate a review body that can only make recommendations to the DOE. Congress expected that the DOE would accept the Board's recommendations or indicate why the recommendations should not be followed. However, the DOE is not legally obligated to accept any of the Board's recommendations.

To increase its effectiveness, the Board has developed procedures for increasing the relevance of its findings and recommendations for Congress, the Secretary, DOE program managers, and the public. The Board's recommendations and the DOE's responses are included in Board reports to Congress and the Secretary. If the DOE does not accept a Board recommendation, the Board's recourse is to advise Congress or reiterate its recommendation to the DOE, or both.

Legislation could affect nuclear waste policy. Congress has considered nuclear waste legislation several times in the last few years, and the current Congress may vote on legislation in the next two years. The effects of such legislation, if enacted, on

the program or the Board's activities are not currently known.

The Board will evaluate the status of these external factors, identify any new factors, and, if warranted, modify the "external factors" section of the strategic plan as part of the annual program evaluation described below.

Evaluating Board Performance

The Board will conduct an annual review of its actions in achieving its performance goals from the previous year. The Board believes that measuring its effectiveness by directly correlating improvements in the DOE program with Board actions and recommendations would be ideal. However, the Board has no implementing authority, so it cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome for the DOE program is, in most cases, (1) subjective and (2) an imprecise indicator of Board performance because implementation of Board recommendations by the DOE is outside the Board's direct control. Therefore, to measure its performance in a given year, the Board has developed the following performance measures.

In evaluating its performance, the Board will consider (1) whether the reviews, evaluations, and other activities included in its performance goals have been completed; and (2) whether the results of reviews, evaluations, and other activities undertaken under the auspices of program goals have been communicated in a timely, understandable, and appropriate way to the Secretary of Energy and Congress. The results of this evaluation will constitute the Board's assessment of its performance for the year. The Board will regard its performance as minimally effective if the activities, reviews, evaluations, and other activities included in its annual performance goals were completed. The Board will regard its performance as effective if those activities were completed and the results were communicated in a timely way to the Secretary of Energy and Congress

The Board will use its evaluation of its own performance from the current year, together with its assessment of current or potential key issues of concern related to the civilian radioactive waste program, to establish its annual performance goals and to develop its budget request for subsequent years. The results of the Board's performance evaluation are included in the Board's annual summary report to Congress and the Secretary.

Congressional and Stakeholder Consultations

In developing its original strategic plan, the Board consulted with the Office of Management and Budget, the DOE, congressional staff, and members of the public and provided a copy of the plan to the NRC and to representatives of state and local governments. The Board solicited public comment and presented its strategic plan at a session held expressly for this purpose during a meeting in Amargosa Valley, Nevada, on January 20, 1998. A copy of the plan is available on the Board's Web site: www.nwtrb.gov.

Appendix H
Nuclear Waste Technical Review Board FY 2000 Performance Plan and Evaluation (Revised March 2001)

NWTRB General Goals and Objectives

The national goal for radioactive waste management established by Congress in the Nuclear Waste Policy Act of 1982 and the Nuclear Waste Policy Amendments Act of 1987 is safe disposal of civilian spent nuclear fuel and high-level radioactive waste in a permanent geologic repository at a suitable site or sites. In the acts, Congress directed the U.S. Department of Energy (DOE) to characterize a site at Yucca Mountain, Nevada, to determine its suitability as the potential location of a permanent repository for civilian spent nuclear fuel and high-level radioactive waste. Congress charged the Nuclear Waste Technical Review Board with reviewing the technical and scientific validity of the Secretary of Energy's activities associated with achieving this goal, including characterizing the site and packaging and transporting the waste. The Board's general goals have been established in accordance with its congressional mandate.

General Goals

To accomplish its congressional mandate, the Board has established four general goals.

1. Ensure that technical and scientific activities undertaken by the DOE related to determining the suitability of the Yucca Mountain site as the possible location of a permanent repository and predicting the performance of a potential repository establish a sound technical basis for a decision on whether to recommend the site for repository development.

2. Ensure that technical and scientific activities undertaken by the DOE related to designing a repository and waste packages are well integrated and establish a sound technical basis for designing the repository system, including the engineered barrier system (EBS).

3. Ensure that technical and scientific activities undertaken by the DOE related to packaging, handling, and transporting spent nuclear fuel and high-level radioactive waste to a permanent repository are well integrated and establish a sound technical basis for designing and operating a waste management system.

4. Ensure that long-term technical and scientific activities undertaken by the DOE, including performance confirmation and design modifications, establish a sound technical basis for reducing uncertainties related to repository performance, operating a repository, and revising repository and waste package designs. (Will apply only if the site is found suitable and a site recommendation is approved.)

Strategic Objectives

To achieve its general goals, the Board has established the following long-term objectives.

1. Objectives Related to Site Suitability and Predicting Repository Performance

1.1 Evaluate the technical and scientific validity of DOE studies, testing, and analyses supporting a decision on whether to recommend the Yucca Mountain site.

1.2 Evaluate the hydrologic, geologic, chemical, and other natural processes at the Yucca Mountain site that establish the foundation for predicting repository performance.

1.3 Review the technical and scientific validity of models used to predict repository performance.

1.4 Evaluate the DOE's progress in developing a safety strategy for the Yucca Mountain site.

1.5 Review the *Record of Decision* for the final environmental impact statement (EIS) for a potential Yucca Mountain site.

2. Objectives Related to the Engineered Repository System

2.1 Evaluate repository and waste package designs, including the technical bases for the designs.

2.2 Review the progress and results of materials testing being conducted to address uncertainties about waste package performance.

2.3 Assess the integration of science and engineering in the DOE program, paying particular attention to the effects of site-characterization studies (e.g., modeling, testing, and analyses of thermal, mechanical, and chemical effects) on repository and waste package designs.

3. Objectives Related to the Waste Management System

3.1 Evaluate the accuracy and reasonableness of analyses, methods, and major assumptions used by the DOE in estimating health and safety risks associated with transporting spent nuclear fuel and high-level radioactive waste.

3.2 Review the adequacy of requirements for developing the transportation infrastructure necessary to move significant amounts of spent nuclear fuel from individual reactor sites to a DOE storage or disposal site. Compare these requirements with current transportation capabilities, and determine the effort needed to develop a large-scale transportation capability.

3.3 Review the adequacy of the DOE's plans for safely handling and packaging spent nuclear fuel and high-level radioactive waste for transport to a permanent repository.

3.4 Evaluate the effectiveness of the DOE's efforts to integrate the various components of the waste management system (packaging, handling, transport, storage, and disposal of the waste).

3.5 Review the DOE's plans for addressing public safety concerns and for enhancing safety capabilities along transportation corridors. This includes activities related to development of plans (e.g., route selection), coordination, accident prevention (e.g., improved inspections and enforcement), and emergency response.

4. Objectives Related to Long-Term Activities
(Will apply only if the site is found suitable and a site recommendation is ratified)

4.1 Monitor performance-confirmation activities undertaken by the DOE that are designed to reduce uncertainties related to repository performance, including corrosion testing.

4.2 Monitor performance-confirmation activities undertaken by the DOE, and evaluate the need to revise repository or waste package designs on the basis of the results of such activities.

Performance Goals for FY 2000

The Board's performance goals for FY 2000 have been developed to further the achievement of the Board's general goals and strategic objectives. Because some of the general goals and strategic objectives relate to work and activities that will be undertaken in the future, they may not have corresponding annual performance goals in any given year. For example, the following performance goals for FY 2000 relate primarily to DOE activities supporting a DOE decision on whether to recommend the Yucca Mountain site to the President, the design of a potential repository and waste package, and transportation planning.

1. Performance Goals Related to Site Suitability and Predicting Repository Performance and Strategy for Achieving Performance Goals

Performance Goals

1.1.1 Identify and evaluate uncertainties that need to be addressed for making a technically supportable site-suitability decision in preparation for a possible site recommendation.

1.1.2 On the basis of an evaluation of the natural processes at work at the Yucca Mountain site, recommend additional needed information, paying particular attention to estimates of the rate and distribution of water seepage into the proposed repository.

1.2.1 Evaluate geologic, hydrologic, and geochemical information obtained from the enhanced characterization of the repository block (ECRB) at Yucca Mountain.

1.2.2 Monitor the results of ongoing thermal tests, and evaluate DOE plans for using the test results to support models of the thermally disturbed region near the repository.

1.3.1 Monitor the results of flow-and-transport studies being conducted to obtain information on the potential performance of the saturated zone as a natural barrier in the repository system.

1.3.2 Determine the strengths and weaknesses of the total system performance assessment (TSPA).

1.3.3 Evaluate the DOE's use of risk assessment and quantification of uncertainty, and determine whether they are being used appropriately.

Strategy for Achieving Goals

The strategy for achieving performance goals for fiscal year 2000 is similar to that used and proven successful in previous years. The Board will accomplish its goals by doing the following.

Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, the TSPA for site recommendation, and the site recommendation.

Meeting with contractor principal investigators on technical issues, including those related to climate change, unsaturated and saturated zone flow and transport, seepage, and the biosphere.

Holding public meetings with the DOE and contractor personnel at least three times a year with the full Board and several meetings with individual Board panels.

Visiting and observing ongoing laboratory investigations, including the facilities at Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Sandia National Laboratory, and the engineered barrier test facility.

Observing field investigations, including the niche, alcove, and sealed cross drift (ECRB) studies and Busted Butte.

Meeting with other entities carrying out research on, or providing input to, scientific and technical issues related to waste disposal, including the NRC and its contractors the Southwest Research Institute, the Nye County Early Warning Drilling Program, the University of Nevada at Las Vegas project on fluid inclusions, the Environmental Protection Agency, and the State of Nevada Nuclear Waste Projects Office.

2. Performance Goals Related to the Engineered Barrier System and Strategy for Achieving Performance Goals

Performance Goals

2.1.1 Monitor and evaluate the DOE's progress in analyzing alternatives to the reference design for the waste package and the repository.

2.2.1 Evaluate the results of corrosion studies on materials being proposed for the EBS.

2.3.1 Assess the effects of site-characterization studies on the EBS design.

Strategy for Achieving Goals

The Board will accomplish its goals by doing the following.

Evaluating the technical bases for EBS design by reviewing technical documents and databases, particularly the technical bases for making and inspecting final closure welds of the waste package and the methods for making drip shield sections. Meetings will be held as necessary with project personnel to obtain clarification and confirmation.

Evaluating the technical bases for repository design by reviewing documents and databases, paying particular attention to design features developed to promote drainage, control ventilation, and protect workers in the exhaust end of the ventilation system.

Evaluating repository and waste package designs to identify which parts (if any) of the designs do not have a satisfactory technical basis.

Evaluating the DOE's technical bases for alternative design features.

After identifying the corrosion mechanisms most important to performance of the overall repository system, reviewing the common database (literature, laboratory, and field data) and judging the adequacy of the database for a site recommendation decision.

3. Performance Goals Related to the Waste Management System and Strategy for Achieving Performance Goals

Performance Goals

3.1.1 Determine the adequacy of the DOE's treatment of transportation in the draft environmental impact statement (DEIS).

3.5.1 Monitor progress by the railroad industry in implementing new technologies (e.g., electronic braking, wheel-bearing monitoring).

Strategy for Achieving Goals.

The Board will accomplish its goals by doing the following.

Attending DOE-sponsored public hearings to determine what, in the public's view, are the critical issues not currently addressed or adequately addressed in the DEIS. The Board also will contract with an independent contractor to conduct an analysis of the treatment of transportation in the DEIS. If the Board determines that there are weaknesses in the DEIS, it will provide feedback to the DOE.

Meeting with the American Association of Railroads (AAR) to review draft performance specification and evaluating the potential effect of the performance specification on the safety of the DOE's proposed shipping campaign. The Board will conduct a panel meeting with the AAR, the DOE, the DOT, and others to further evaluate the benefits of the ARR's performance specification. The Board will travel to the ARR's Technology Center in Pueblo, Colorado, to see demonstrations of the latest technologies related to train safety.

Measuring Board Performance

The Board will conduct an annual review of its actions in achieving its performance goals from the previous year. The Board believes that measuring its effectiveness by directly correlating improvements in the DOE program with Board actions and recommendations would be ideal. However, the Board has no implementing authority, so it cannot compel the

DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome for the DOE program is, in most cases, (1) subjective and (2) an imprecise indicator of Board performance because implementation of Board recommendations by the DOE is outside the Board's direct control. Therefore, to measure its performance in a given year, the Board has developed the following performance measures.

In evaluating its performance, the Board will consider (1) whether the reviews, evaluations, and other activities included in its performance goals have been completed; and (2) whether the results of reviews, evaluations, and other activities undertaken under the auspices of program goals have been communicated in a timely, understandable, and appropriate way to the Secretary of Energy and Congress. The results of this evaluation will constitute the Board's assessment of its performance for the year. The Board will regard its performance as minimally effective if the activities, reviews, evaluations, and other activities included in its annual performance goals were completed. The Board will regard its performance as effective if those activities were completed and the results were communicated in a timely way to the Secretary of Energy and Congress

The Board will use its evaluation of its own performance from the current year, together with its assessment of current or potential key issues of concern related to the civilian radioactive waste program, to establish its annual performance goals and to develop its budget request for subsequent years. The results of the Board's performance evaluation are included in the Board's annual summary report to Congress and the Secretary.

Performance Evaluation for Fiscal Year 2000

On the basis of the following evaluation and in accordance with the performance measures described above, the Board's overall performance in fiscal year 2000 was effective. However, primarily because DOE engaged in very little transportation-related activity in 2000, the Board's performance in meeting its two goals related to transportation of spent fuel and high-level radioactive waste was judged minimally effective.

1. Performance Goals Related to Site Suitability and Predicting Repository Performance

1.1.1 Identify and evaluate uncertainties that need to be addressed for making a technically supportable site-suitability decision in preparation for a possible site recommendation.

Evaluation of 1.1.1: The Board reviewed DOE efforts to identify uncertainties and recommended that the DOE quantify any remaining uncertainties to increase the transparency of technical evaluations supporting a decision on site suitability. The Board commented on the importance of this issue in testimony before the House Subcommittee on Energy and Power, Committee on Commerce, on June 23, 2000. A comprehensive discussion of program uncertainties was included in Board answers to questions posed by Representative Joe Barton, Chair of the House Subcommittee on Energy and Power, following the congressional hearing. The Board's answers were submitted to Congressman Barton on August 31, 2000. The Board also commented on this issue in letters to Office of Civilian Radioactive Waste Management (OCRWM) director Ivan Itkin on March 20, 2000, on June 16, 2000, and on September 20, 2000, and in its year-end letter report to the U.S. Congress and the Secretary of Energy (December 2000).

1.1.2 On the basis of an evaluation of the natural processes at work at the Yucca Mountain site, recommend additional needed information, paying particular attention to estimates of the rate and distribution of water seepage into the proposed repository.

Evaluation of 1.1.2: The Board commented on this issue in letters to OCRWM director, Ivan Itkin on March 20, 2000, and September 20, 2000. This subject was discussed at several Board meetings and was touched on in the answers to questions from Representative Joe Barton (August 31, 2000).

1.2.1 Evaluate geologic, hydrologic, and geochemical information obtained from the enhanced characterization of the repository block (ECRB) at Yucca Mountain.

Evaluation of 1.2.1: Members of the Board toured the ECRB in 2000. Studies in the ECRB were the subject of discussion during several Board meetings in 2000. The Board commented on studies in the ECRB in letters to OCRWM director Ivan Itkin on March 20, 2000, and September 20, 2000, and in congressional testimony in June 2000.

1.2.2 Monitor the results of ongoing thermal tests, and evaluate DOE plans for using the test results to support models of the thermally disturbed region near the repository.

Evaluation of 1.2.2: Results from thermal tests were not available in 2000. The Board will continue to monitor these tests and will evaluate the results when they become available.

1.3.1 Monitor the results of flow-and-transport studies being conducted to obtain information on the potential performance of the saturated zone as a natural barrier in the repository system.

Evaluation of 1.3.1: The Board monitored the progress of flow-and-transport studies conducted by the Nye County Early Warning Drilling program and commented on findings from the studies and on coordination with the DOE in letters to OCRWM director Ivan Itkin on March 20, 2000, and September 20, 2000.

1.3.2 Determine the strengths and weaknesses of the total system performance assessment (TSPA).

Evaluation of 1.3.2: The Board commented extensively on the TSPA during meetings with the DOE, in letters to OCRWM director Ivan Itkin on March 20, 2000, and September 20, 2000, in congressional testimony on June 23, 2000, in answers to questions from Representative Joe Barton (August 31, 2000), and in its year-end letter report to the U.S. Congress and the Secretary of Energy.

1.3.3 Evaluate the DOE's use of risk assessment and quantification of uncertainty, and determine whether they are being used appropriately.

Evaluation of 1.3.3: The Board commented extensively on the need for the DOE to quantify uncertainty in meetings with the DOE, in letters to OCRWM director Ivan Itkin on March 20, 2000, and September 20, 2000, in congressional testimony (June 23, 2000), in answers to questions from Representative Barton, and in its year-end report to the U.S. Congress and the Secretary of Energy (December 2000).

2. Performance Goals Related to the Engineered Barrier System

2.1.1 Monitor and evaluate the DOE's progress in analyzing alternatives to the reference design for the waste package and the repository.

Evaluation of 2.1.1: The Board monitored the DOE's efforts in this area and commented extensively on the importance of this issue in letters to Ivan Itkin on March 20, 2000, on June 16, 2000, and on September 20, 2000; in testimony before the House Energy and Power Subcommittee (June 23, 2000); in answers to questions from Representative Barton; and in its year-end report to Congress and the Secretary of Energy (December 2000).

2.2.1 Evaluate the results of corrosion studies on materials being proposed for the EBS.

Evaluation of 2.2.1: The Board monitored the progress of corrosion testing conducted by the DOE and its contractors in 2000 and commented on the importance of this issue in its letter to Ivan Itkin on September 20, 2000, and in congressional testimony (June 2000).

2.3.1 Assess the effects of site-characterization studies on the EBS design.

Evaluation of 2.3.1: The Board commented on the importance of the waste package environment in a letter to Ivan Itkin on September 20, 2000.

3. Performance Goals Related to the Waste Management System

3.1.1 Determine the adequacy of the DOE's treatment of transportation in the draft environmental impact statement (DEIS).

Evaluation of 3.1 1: DOE activities related to transportation of spent nuclear fuel and high-level radioactive waste were very limited. The Board's Panel on the Waste Management System held a meeting in July 2000 during which this topic was discussed.

3.1.2. Monitor progress by the railroad industry in implementing new technologies (e.g., electronic braking, wheel-bearing monitoring).

Evaluation of 3.1.2: There was very little activity in 2000 related to transportation of spent nuclear fuel and high-level radioactive waste. The Board's Panel on the Waste Management System held a meeting in July 2000 during which this topic was discussed briefly.

Board Operations

The Board is composed of 11 members appointed by the President who serve on a part-time basis; are eminent in a relevant field of science or engineering, including environmental sciences; and are appointed solely on the basis of distinguished service. Because of the comprehensive nature of the program and the part-time availability of the members, Congress authorized the Board to maintain a small professional staff of 10 full-time employees to support the Board's comprehensive review of the DOE program. In addition to the members and professional staff, the Board maintains a small administrative staff that supports its activities.

The full Board meets three or four times each year. The Board has organized itself into panels that meet as needed. The Board also gathers information from field trips to the Yucca Mountain site, visits to contractor laboratories and facilities, and informal meetings with individuals working on the project. On the basis of the information gathered throughout the year, the Board issues its findings in letters and reports.

Resource Allocation for Fiscal Year 2000

The Board's budget request for fiscal year 2000 was $3,150,000. Of that total, $2,150,000 was allocated to activities related to site characterization. The allocation included the salaries and benefits of the Board's members and professional staff. It also included the cost of conducting meetings, field trips, and other fact-finding activities and the production of reports related to the activities. Transportation and packaging activities, which include activities similar to those used to evaluate site-characterization efforts, was allocated $550,000. The balance of $450,000 was allocated to the management and administrative support of the Board's activities in fiscal year 2000.

The Board's appropriation for fiscal year 2000 was $2,600,000. As a result of reduction from the Board's budget request, the Board has had to adapt the performance plan to the reduced appropriation level. The revised allocations are as follows: $1,350,000 for activities related to site characterization; $500,000 for transportation and packaging activities,* which include activities similar to those used to evaluate site-characterization efforts; $200,000 for communications (Congress, public, etc.); and $550,000 for management support and for administrative and information technology support of the Board's activities in fiscal year 2000.

* Because of DOE inactivity in the area of packaging and transportation in fiscal year 2000, almost $400,000 of this amount was reallocated to activities related to site characterization. The remainder was spent on a meeting of the Board's panel on transportation and the waste management system and on reviewing work supporting the Board's FY 2001 transportation goals.

Appendix I
Nuclear Waste Technical Review Board Fiscal Year 2001 Performance Plan (Revised March 2001)

NWTRB General Goals And Strategic Objectives

The national goal for radioactive waste management established by Congress in the Nuclear Waste Policy Act of 1982 and the Nuclear Waste Policy Amendments Act of 1987 is safe disposal of civilian spent nuclear fuel and high-level radioactive waste in a permanent geologic repository at a suitable site or sites. In the acts, Congress directed the Department of Energy (DOE) to characterize a site at Yucca Mountain, Nevada, to determine its suitability as the potential location of a permanent repository for high-level radioactive waste. Congress charged the Nuclear Waste Technical Review board with reviewing the technical and scientific validity of the Secretary of Energy's activities associated with achieving this goal, including characterizing the site and packaging and transporting the waste. The Board's general goals have been established in accordance with its congressional mandate.

General Goals

To accomplish its congressional mandate, the Board has established four general goals.

1. Ensure that technical and scientific activities undertaken by the DOE related to determining the suitability of the Yucca Mountain site as the possible location of a permanent repository and predicting the performance of a potential repository establish a sound technical basis for a decision on whether to recommend the site for repository development.

2. Ensure that technical and scientific activities undertaken by the DOE related to designing the repository and waste packages are well integrated and establish a sound technical basis for designing the repository system, including the engineered barrier system (EBS).

3. Ensure that technical and scientific activities undertaken by the DOE related to packaging, handling, and transporting spent nuclear fuel and high-level waste to a permanent repository are well integrated and establish a sound technical basis for designing and operating a waste management system.

4. Ensure that long-term technical and scientific activities undertaken by the DOE, including performance confirmation and design modifications, establish a sound technical basis for reducing uncertainties related to repository performance, operating a repository, and revising repository and waste package designs. (Will apply only if the site is found suitable and a site recommendation is approved.)

Strategic Objectives

To achieve its general goals, the Board has established the following long-term objectives.

1. Objectives Related to Site Suitability and Predicting Repository Performance

1.1 Evaluate the technical and scientific validity of DOE studies, testing, and analyses supporting a decision on whether to recommend the Yucca Mountain site.

1.2 Evaluate the hydrologic, geologic, chemical, and other natural processes at the Yucca Mountain site that establish the foundation for predicting repository performance.

1.3 Review the technical and scientific validity of models used to predict repository performance.

1.4 Evaluate the DOE's progress in developing a safety strategy for the Yucca Mountain site.

1.5 Review the *Record of Decision* and maintain awareness of legal challenges to the final environmental impact statement (EIS) for a potential Yucca Mountain site.

2. Objectives Related to the Engineered Repository System

2.1 Evaluate repository and waste package designs, including the technical bases for the designs.

2.2 Review the progress or results of materials testing being conducted to address uncertainties about waste package performance.

2.3 Assess the integration of science and engineering in the DOE program, paying particular attention to the effects of site-characterization studies (e.g. modeling, testing, and analyses of thermal and mechanical effects) on repository and waste package designs.

3. Objectives Related to the Waste Management System

3.1 Evaluate the accuracy and reasonableness of analyses, methods, and major assumptions used by the DOE in estimating health and safety risks associated with transporting spent nuclear fuel and high-level radioactive waste.

3.2 Review the adequacy of plans and requirements for developing the transportation infrastructure necessary to move significant amounts of spent fuel from individual reactor sites to a DOE storage or disposal site. Compare these requirements with current transportation capabilities, and determine the effort needed to develop a large-scale transportation capability.

3.3 Review the adequacy of the DOE's plans for safely handling and packaging spent nuclear fuel and high-level radioactive waste for transport to a permanent repository.

3.4 Evaluate the effectiveness of the DOE's efforts to integrate the various components of the waste management system (packaging, handling, transport, storage, and disposal of the waste).

3.5 Review the DOE's plans for addressing public safety concerns and for enhancing safety capabilities along transportation corridors. This includes activities related to development of plans (e.g., route selection), coordination, accident prevention (e.g., improved inspections and enforcement), and emergency response.

4. Objectives Related to Long-Term Activities (Will apply only if the site is found suitable and a site recommendation is ratified)

4.1 Monitor performance-confirmation activities undertaken by the DOE that are designed to reduce uncertainties related to repository performance.

4.2 Monitor performance-confirmation activities undertaken by the DOE, and evaluate the need to revise repository or waste package designs on the basis of the results of such activities.

Performance Goals for FY 2001

The Board's performance goals for FY 2001 have been developed to further the achievement of the Board's general goals and strategic objectives. Because some of the general goals and strategic objectives relate to work and activities that will be

undertaken in the future, they may not have corresponding annual performance goals in any given year. For example, the following performance goals for FY 2001 relate primarily to DOE activities supporting a DOE decision on whether to recommend the Yucca Mountain site to the President, the design of a potential repository and waste package, and transportation planning.

1. Performance Goals Related to Site Suitability and Predicting Repository Performance and Strategy for Achieving Performance Goals

Performance Goals

1.1.1 Review for technical validity the technical and scientific components of the DOE site recommendation report.

1.1.2 Review for technical validity the technical and scientific components of the DOE site recommendation "notification document."

1.1.3 Review for technical validity the technical components of the DOE site recommendation "consideration document."

1.1.4 Evaluate the DOE's use of risk assessment and quantification of uncertainty, and determine whether they are being used appropriately.

1.2.1 Monitor the results of flow-and-transport studies being conducted to obtain information on the potential performance of the saturated zone as a natural barrier in the repository system.

1.2.2 Evaluate geologic, hydrologic, and geochemical information obtained from the enhanced characterization of the repository block at Yucca Mountain.

1.2.3 Evaluate results of the fluid inclusion study.

1.3.1 Set priorities among and evaluate for technical validity the DOE process model reports that will be used to support a decision on site recommendation.

1.3.2 Determine the strengths and weaknesses of the total system performance assessment (TSPA) and recommend additional measures to strengthen DOE's repository safety case.

1.4.1 Determine the appropriateness of the "principal factors" identified by the DOE in its safety strategy.

1.4.2 On the basis of an evaluation of the natural processes at work at the Yucca Mountain site, recommend additional work needed to address uncertainties, paying particular attention to estimates of the rate and distribution of water seepage into the proposed repository.

Strategy for Achieving Goals

The strategy for achieving performance goals for fiscal year 2001 is similar to that used and proven successful in previous years. The Board will accomplish its goals by doing the following.

Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, the TSPA, and the site recommendation.

Meeting with contractor's principal investigators on technical issues, including those related to climate change, unsaturated and saturated zone flow and transport, seepage, and the biosphere.

Holding public meetings with the DOE and contractor personnel at least three times a year involving the full Board and several meetings with individual Board panels.

Visiting and observing ongoing laboratory investigations, including the facilities at Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Sandia National Laboratory, and the engineered barrier test facility.

Observing field investigations, including the niche, alcove, and sealed cross drift (ECRB) studies and Busted Butte.

Meeting with other entities carrying out research on, or providing input to, scientific and technical issues related to waste disposal, including the NRC and its contractors, the Southwest Research Institute, The Nye County Early Warning Drilling Program, the University of Nevada at Las Vegas project on fluid inclusions, the Environmental Protection Agency, and the State of Nevada Nuclear Waste Projects Office.

1. Performance Goals Related to the Engineered Repository System and Strategy for Achieving Performance Goals

Performance Goals

2.1.1 Evaluate the accuracy and completeness of the technical bases for repository and waste package designs.

2.1.2 Evaluate the extent to which the DOE is using the technical bases for developing repository and waste package designs.

2.1.3 Monitor and evaluate the DOE's progress in developing a technical basis for modified or novel design features.

2.1.4 Evaluate the adequacy for a site recommendation decision of corrosion studies on materials being proposed for the EBS.

2.1.5 Assess the integration of scientific studies with engineering designs for the repository and waste package. In particular, monitor the results of ongoing thermal tests and evaluate DOE plans for using the test results to support models of the thermally disturbed region near the repository and to decide on spacing between emplacement drifts, degree of preclosure ventilation, and closure date.

Strategy for Achieving Goals

The Board will accomplish its goals by doing the following.

Evaluating the technical bases for the EBS design by reviewing technical documents and databases (e.g., the controlled design assumption document and the technical database), paying particular attention to the technical bases for making and inspecting final closure welds of the waste package and methods for making drip shield sections. Meetings will be held as necessary with project personnel to obtain clarification and confirmation.

Evaluating the technical bases for repository design by reviewing federal documents and databases, paying particular attention to design features designed to promote drainage, control ventilation, and protect workers in the exhaust end of the ventilation system.

Evaluating repository and waste package designs to identify which parts (if any) of the designs do not have a technical basis.

Evaluating the DOE's technical program to fill in the gaps. In addition, where the DOE is working on alternative design features, the Board will evaluate the technical basis for these features.

After identifying the corrosion mechanisms most important to performance of the overall repository system, reviewing the common database (literature, laboratory, and field data) and judging the adequacy of the database for a site recommendation decision.

3. Performance Goals Related to the Waste Management System and Strategy for Achieving Performance Goals

Performance Goals

3.1.1 Evaluate storage cask and container designs to ascertain whether there is a sufficient technical basis for predicting potential problems that could develop during storage and that could affect the performance of the spent nuclear fuel during subsequent repository disposal.

3.2.1 Evaluate the effects of "off-normal" events at the surface facility and how the events could affect the ability of the facility to receive waste shipments.

3.2.2 Evaluate the effects of reduced receiving capacity at the repository surface facility on the nationwide transportation system.

3.3.1 Examine the ability of storage casks and containers, including multipurpose canisters, to serve as disposal casks and containers in a repository.

3.4.1 Monitor progress by the railroad industry in implementing new technologies that would enhance the safety of spent-fuel transportation (e.g., electronic braking, wheel-bearing monitoring). Evaluate how well the DOE works with the railroad industry to design an integrated transportation cask-rail and car-train system that would ensure maximum safety and efficiency.

3.4.2 Review criteria for waste acceptance for storage to ensure that accepted material has been suitably characterized for subsequent disposal.

3.4.3 Evaluate the DOE's plans for enhancing safety capabilities along transportation corridors and review the DOE's planning and coordination activities (e.g., route selection), accident prevention activities (e.g., improved inspections and enforcement), and emergency response activities.

Strategy for Achieving Goals

The Board will accomplish its goals by doing the following:

Meeting with the American Association of Railroads (AAR), individual railroad companies, and railroad infrastructure manufacturers to determine the current state of rail infrastructure and noting the effects of a sustained transportation campaign on the railroad industry. The Board will monitor the construction of a short-line rail line currently under construction in Minnesota as an analog to a possible rail line in Nevada from a main line to a repository at Yucca Mountain.

Continuing to meet with the AAR to keep up to date on the work they are doing related to their performance specification for shipping radioactive waste. Meeting with AAR personnel at the AAR Technology Center in Pueblo, Colorado.

Attending the semiannual DOE-sponsored Transportation External Working Group meetings to meet with first responders along the proposed transportation corridors to determine how well the DOE is working to implement Section 180(c) of the Nuclear Waste Policy Act.

Holding a meeting of the Board's Panel on the Waste Management System.

3. Performance Goal Related to Licensing and Performance Confirmation and Strategy for Achieving the Goal

Performance Goal

4.1.1 Monitor the DOE's proposed performance confirmation plans to help ensure that uncertainties identified as part of the site recommendation process are addressed.

Strategy for Achieving Goal

The Board will accomplish its goal by doing the following:

Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, the TSPA, and the site recommendation.

Reviewing performance-confirmation plans and meeting with DOE personnel to discuss aspects of the plans.

Performance Measurement

The Board believes that measuring its effectiveness by directly correlating improvements in the DOE program with Board actions and recommendations would be ideal. However, the Board has no implementing authority, so it cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome for the DOE program is, in

most cases, (1) subjective and (2) an imprecise indicator of Board performance because implementation of Board recommendations by the DOE is outside the Board's direct control. Therefore, to measure its performance in a given year, the Board has developed performance measures. For each annual performance goal, the Board considers the following.

1. Were the reviews, evaluations, and other activities undertaken under the auspices of the goal completed?

2. Were the results of the reviews, evaluations, and other activities communicated in a timely, understandable, and appropriate way to Congress and the Secretary of Energy?

If both measures are met, the Board's performance in meeting the annual goal will be judged effective. If only one measure is met, the performance of the Board in achieving that goal will be judged minimally effective. Failing to meet both performance measures without sufficient and compelling explanation will result in a judgment that the Board has been ineffective in achieving that performance goal.

The Board will use its evaluation of its own performance from the current year, together with its assessment of current or potential key issues of concern related to the civilian radioactive program, to establish its annual performance objectives and develop its budget request for subsequent years. The results of the Board's performance evaluation are included in the Board's annual summary report to Congress and the Secretary.

Board Operations

The Board is composed of 11 members appointed by the President who serve on a part-time basis; are eminent in a relevant field of science or engineering, including environmental sciences; and are appointed solely on the basis of distinguished service. Because of the comprehensive nature of the program and the part-time availability of the members, Congress authorized the Board to maintain a small professional staff of 10 full-time employees to support the Board's comprehensive review of the DOE program. In addition to the members and professional staff, the Board maintains a small administrative staff that supports its activities.

The full Board meets three or four times each year. The Board has organized itself into panels that meet as needed. The Board also gathers information from field trips to the Yucca Mountain site, visits to contractor laboratories and facilities, and informal meetings with individuals working on the project. On the basis of the information gathered throughout the year, the Board issues its findings in letters and reports.

FY 2001 Performance Plan Resource Allocation

The Board's budget request for fiscal year 2001 is $3,200,000. Of that amount, $1,583,285 will be allocated to activities related to site characterization and $526,886 will be allocated to activities related to packaging and transportation. The activities are described in detail in the attached annual performance plan. That total represents 67 percent of the Board's total budget. The remaining 33 percent is allocated to administrative and information technology support, communication to Congress and the Secretary, and public outreach.

The budget allocations for site characterization and for transportation and packaging consist primarily of the salaries of Board members and technical staff. They also include travel to the project site at Yucca Mountain to meet with project staff and the expenses related to conducting meetings.

Appendix J
Nuclear Waste Technical Review Board Fiscal Year 2002 Performance Plan (March 2001)

NWTRB General Goals and Strategic Objectives

The national goal for radioactive waste management established by Congress in the Nuclear Waste Policy Act of 1982 and the Nuclear Waste Policy Amendments Act of 1987 is safe disposal of civilian spent nuclear fuel and high-level radioactive waste in a permanent geologic repository at a suitable site or sites. In the acts, Congress directed the Department of Energy (DOE) to characterize a site at Yucca Mountain, Nevada, to determine its suitability as the potential location of a permanent repository for high-level radioactive waste. Congress charged the Nuclear Waste Technical Review Board with reviewing the technical and scientific validity of the Secretary of Energy's activities associated with achieving this goal, including characterizing the site and packaging and transporting the waste. The Board's general goals have been established in accordance with its congressional mandate.

General Goals

To accomplish its congressional mandate, the Board has established four general goals.

1. Ensure that technical and scientific activities undertaken by the DOE related to determining the suitability of the Yucca Mountain site as the possible location of a permanent repository and predicting the performance of a potential repository establish a sound technical basis for a decision on whether to recommend the site for repository development.

2. Ensure that technical and scientific activities undertaken by the DOE related to designing the repository and waste packages are well integrated and establish a sound technical basis for designing the repository system, including the engineered barrier system (EBS).

3. Ensure that technical and scientific activities undertaken by the DOE related to packaging, handling, and transporting spent nuclear fuel and high-level radioactive waste to a permanent repository are well integrated and establish a sound technical basis for designing and operating a waste management system.

4. Ensure that long-term technical and scientific activities undertaken by the DOE, including performance confirmation and design modifications, establish a sound technical basis for reducing uncertainties related to repository performance, operating a repository, and revising repository and waste package designs. (Will apply only if the site is found suitable and a site recommendation is approved.)

Strategic Objectives

To achieve its general goals, the Board has established the following long-term objectives.

1. Objectives Related to Site Suitability and Predicting Repository Performance

1.1 Evaluate the technical and scientific validity of DOE studies, testing, and analyses supporting a decision on whether to recommend the Yucca Mountain site.

1.2 Evaluate the hydrologic, geologic, chemical, and other natural processes at the Yucca Mountain site that establish the foundation for predicting repository performance.

1.3 Review the technical and scientific validity of models used to predict repository performance.

1.4 Evaluate the DOE's progress in developing a safety strategy for the Yucca Mountain site.

1.5 Review the *Record of Decision* for the final environmental impact statement (EIS) for a potential Yucca Mountain site.

2. Objectives Related to the Engineered Repository System

2.1 Evaluate repository and waste package designs, including the technical bases for the designs.

2.2 Review the progress and results of materials testing being conducted to address uncertainties about waste package performance.

2.3 Assess the integration of science and engineering in the DOE program, paying particular attention to the effects of site-characterization studies (e.g., modeling, testing, and analyses of thermal, mechanical, and chemical effects) on repository and waste package designs.

3. Objectives Related to the Waste Management System

3.1 Evaluate the accuracy and reasonableness of analyses, methods, and major assumptions used by DOE in estimating health and safety risks associated with transporting spent nuclear fuel and high-level radioactive waste.

3.2 Review the adequacy of requirements for developing the transportation infrastructure necessary to move significant amounts of spent nuclear fuel from individual reactor sites to a DOE storage or disposal site. Compare these requirements with current transportation capabilities, and determine the effort needed to develop a large-scale transportation capability.

3.3 Review the adequacy of the DOE's plans for safely handling and packaging spent nuclear fuel and high-level radioactive waste for transport to a permanent repository.

3.4 Evaluate the effectiveness of the DOE's efforts to integrate the various components of the waste management system (packaging, handling, transport, storage, and disposal of the waste).

3.5 Review the DOE's plans for addressing public safety concerns and for enhancing safety capabilities along transportation corridors. This includes activities related to development of plans (e.g., route selection), coordination, accident prevention (e.g., improved inspections and enforcement), and emergency response.

*4. Objectives Related to Long-Term Activities (*Will apply only if the site is found suitable and a site recommendation is ratified)

4.1 Monitor performance-confirmation activities undertaken by the DOE that are designed to reduce uncertainties related to repository performance, including corrosion testing.

4.2 Monitor performance-confirmation activities undertaken by the DOE, and evaluate the need to revise repository or waste package designs on the basis of the results of such activities.

Performance Goals for FY 2002

The Board's performance goals for fiscal year (FY) 2002 have been developed to further the achievement of the Board's general goals and strategic objectives. Because some of the general goals and strategic objectives relate to work and activities that will be undertaken in the future, they may not have corresponding annual performance goals in any

given year. For example, the following performance goals for FY 2002 relate primarily to DOE activities supporting a DOE decision on whether to recommend the Yucca Mountain site to the President, the design of a potential repository and waste package, and transportation planning.

1. Performance Goals Related to Site Suitability and Predicting Repository Performance and Strategy for Achieving Performance Goals

Performance Goals

1.1.1 Review for technical validity the technical and scientific components of a DOE site recommendation report (if applicable).

1.1.2 Monitor the DOE's efforts to quantify uncertainties related to estimates of repository performance.

1.2.1 Monitor the results of flow-and-transport studies being conducted to obtain information on the potential performance of the saturated zone as a natural barrier in the repository system.

1.2.2 Evaluate geologic, hydrologic, and geochemical information obtained from the enhanced characterization of the repository block at Yucca Mountain.

1.3.1 Determine the strengths and weaknesses of the total system performance assessment (TSPA).

1.3.2 On the basis of an evaluation of the natural processes at work at the Yucca Mountain site, recommend additional work needed to address uncertainties, including particular attention to estimates of the rate and distribution of water seepage into the proposed repository under proposed repository design conditions.

1.3.3 Evaluate the DOE's quantification of uncertainties and conservatisms used in TSPA.

1.3.4 Recommend additional measures for strengthening the DOE's repository safety case.

1.3.5 Evaluate data from drift-scale heater test.

1.4.1 Review plans and work carried out on natural and engineered analogs to the repository system.

Strategy for Achieving Goals

The strategy for achieving performance goals for fiscal year 2002 is similar to that used and proven successful in previous years. The Board will accomplish its goals by doing the following:

Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, the TSPA for site recommendation, and the site recommendation.

Meeting with contractor's principal investigators on technical issues, including those related to climate change, unsaturated and saturated zone flow and transport, seepage, and the biosphere.

Holding public meetings with DOE and contractor personnel at least three times a year involving the full Board and holding several meetings with individual Board panels.

Visiting and observing ongoing laboratory investigations, including the facilities at Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Sandia National Laboratory, and the engineered-barrier test facility. Observing field investigations.

Meeting with other entities carrying out research on, or providing input to, scientific and technical issues related to waste disposal, including the Nuclear Regulatory Commission (NRC) and its contractors, the Southwest Research Institute, The Nye County Early Warning Drilling Program, the Environmental Protection Agency, and the State of Nevada Nuclear Waste Projects Office.

2. Performance Goals Related to the Engineered Repository System and Strategy for Achieving Performance Goals

Performance Goals

2.1.1 Monitor the DOE's development of analytical tools for assessing the differences between different repository designs.

2.1.2 Evaluate the accuracy and completeness of the technical bases for repository and waste package designs.

2.1.3 Evaluate the extent to which the DOE is using the technical bases for modifying repository and waste package designs.

2.1.4 Monitor and evaluate the DOE's progress in developing a technical basis for modified or novel design features.

2.1.5 Evaluate data from corrosion and waste package environment studies on the predicted performance of materials being proposed for the EBS.

2.1.6 Assess the integration of scientific studies with engineering designs for the repository and the waste package. In particular, monitor the results of ongoing thermal tests and evaluate DOE plans for using the test results to support models of the thermally disturbed region near the repository and for deciding on spacing between emplacement drifts, degree of preclosure ventilation, and closure date of the potential repository.

2.1.7 Evaluate the DOE's efforts in identifying natural and engineered analogs.

Strategy for Achieving Goals

The Board will accomplish its goals by doing the following:

Evaluating the technical bases for the EBS design by reviewing technical documents and databases (e.g., the controlled design assumption document and the technical database), paying particular attention to the technical bases for making and inspecting final closure welds of the waste package and methods for making sections of the drip shields. Meetings will be held with project personnel as necessary to obtain clarification and confirmation.

Evaluating the technical bases for repository design by reviewing DOE documents and databases, paying particular attention to design features developed to promote drainage, control ventilation, and protect workers in the exhaust end of the ventilation system.

Evaluating repository and waste package designs to identify which parts (if any) of the designs do not have a technical basis.

Evaluating the technical basis for the DOE's work on alternative design features.

After identifying the corrosion mechanisms most important to performance of the overall repository system, reviewing the common database (literature, laboratory, and field data) and judging the adequacy of the database for a decision on site recommendation.

3. Performance Goals Related to the Waste Management System and Strategy for Achieving Performance Goals

Performance Goals

3.1.1 Monitor efforts by the NRC to update estimates of risk associated with transportation of spent nuclear fuel and high-level radioactive waste.

3.1.2 Evaluate the operation of the entire repository facility, including the surface and subsurface components.

3.2.1 Evaluate the effects of "off-normal" events at the surface facility and how the events could affect the ability of the facility to receive waste shipments.

3.2.2 Evaluate the effects of reduced receiving capacity at the repository surface facility on the nationwide transportation system.

3.3.1 Examine the ability of storage casks and containers, including multipurpose canisters, to serve as disposal casks and containers in a repository.

3.3.2 Evaluate effects of human errors in risks associated with packaging and transporting spent nuclear fuel and high-level radioactive waste.

3.4.1 Evaluate logistics capabilities of the transportation system.

3.4.2 Monitor progress in implementing new technologies for improving transportation safety for spent nuclear fuel and high-level radioactive waste (e.g., electronic braking, wheel-bearing monitoring).

3.4.3 Review criteria for waste acceptance for storage to ensure that accepted material has been suitably characterized for subsequent disposal.

3.4.4 Evaluate the DOE's plans for enhancing safety capabilities along transportation corridors, and review the DOE's planning and coordination activities (e.g., route selection), accident prevention activities (e.g., improved inspections and enforcement), and emergency response activities.

Strategy for Achieving Goals

The Board will accomplish its goals by doing the following:

Meeting with the American Association of Railroads (AAR), individual railroad companies, and railroad infrastructure manufacturers to determine the current state of rail infrastructure, and noting the effects of a sustained transportation campaign on the railroad industry.

Attending meetings of the DOE-sponsored Transportation External Working Group to determine how well the DOE is working to implement Section 180(c) of the Nuclear Waste Policy Act.

Holding meetings of the Board's Panel on the Waste Management System, as appropriate.

4. Performance Goals Related to Long-Term Activities and Strategy for Achieving Performance Goals (Will apply only if the site is found suitable and a site recommendation is ratified.)

Performance Goals

4.1.1 Monitor DOE's proposed plans for performance confirmation to help ensure that uncertainties identified as part of the site recommendation process are addressed.

4.1.2 Monitor design modification activities undertaken by DOE.

Strategy for Achieving Goals

The Board will accomplish its goals by doing the following.

Reviewing critical documents provided by the DOE and its contractors including contractor reports, process model reports, the TSPA for site recommendation, and the site recommendation.

Reviewing performance-confirmation plans and meeting with DOE personnel to discuss aspects of the plans.

Performance Measurement

The Board believes that measuring its effectiveness by directly correlating improvements in the DOE program with Board actions and recommendations would be ideal. However, the Board has no implementing authority, so it cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome for the DOE program is, in most cases, (1) subjective and (2) an imprecise indicator of Board performance because implementation of Board recommendations by the DOE is outside the Board's direct control. Therefore, to measure its performance in a given year, the Board has developed performance measures. For each annual performance goal, the Board considers the following.

1. Were the reviews, evaluations, and other activities undertaken under the auspices of the goal completed?

2. Were the results of the reviews, evaluations, and other activities communicated in a timely, understandable, and appropriate way to Congress and the Secretary of Energy?

If both measures are met, the Board's performance in meeting the annual goal will be judged effective. If only one measure is met, the performance of the Board in achieving that goal will be judged minimally effective. Failing to meet both performance measures without sufficient and compelling explanation will result in a judgment that the Board has been ineffective in achieving that performance goal.

The Board will use its evaluation of its own performance from the current year, together with its assessment of current or potential key issues of concern related to the civilian radioactive program, to establish its annual performance objectives and develop its budget request for subsequent years. The results of the Board's performance evaluation are included in the Board's annual summary report to Congress and the Secretary.

Board Operations

The Board is composed of 11 members appointed by the President who serve on a part-time basis; are eminent in a relevant field of science or engineering, including environmental sciences; and are appointed solely on the basis of distinguished service. Because of the comprehensive nature of the program and the part-time availability of the members, Congress authorized the Board to maintain a small professional staff of 10 full-time employees to support the Board's comprehensive review of the DOE program. In addition to the members and professional staff, the Board maintains a small administrative staff that supports its activities.

The full Board meets three or four times each year. The Board has organized itself into panels that meet as needed. The Board also gathers information from field trips to the Yucca Mountain site, visits to contractor laboratories and facilities, and informal meetings with individuals working on the project. On the basis of the information gathered throughout the year, the Board issues its findings in letters and reports.

FY 2002 Performance Plan Resource Allocation

The Board's budget request for fiscal year 2002 is $3,100,000. Of that amount, $1,490,556 will be allocated to activities related to site characterization and $437,753 will be allocated to activities related to packaging and transportation. The allocation for these activities represents 62 percent of the Board's total budget. The remaining 38 percent is allocated to administrative and information technology support, communication to Congress and the Secretary of Energy, and public outreach.

The budget allocations for site characterization and for transportation and packaging consist primarily of the salaries of Board members and technical staff. They also include travel to the project site at Yucca Mountain to meet with project staff and the expenses related to conducting meetings.