JUN 10 1993

MEMORANDUM FOR: The Chairman
Commissioner Rogers
Commissioner Curtiss
Commissioner Remick
Commissioner de Planque

FROM: James M. Taylor
Executive Director for Operations

SUBJECT: NATIONAL ACADEMY OF SCIENCES COMMITTEE ON TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARD, MAY 27-29, 1993, LAS VEGAS, NEVADA

On May 27-29, 1993, the National Academy of Sciences (NAS) Committee on Technical Bases for Yucca Mountain Standard held its first meeting in Las Vegas, Nevada. The NRC was represented at this meeting by the NRC liaison to the Committee, other staff of the Division of High-Level Waste Management, a staff member from the Office of the General Counsel, and a member of Commissioner Curtiss' staff. The 15 member Committee indicated its intent to complete the study, requested in the Energy Policy Act of 1992, within 18 months. The Committee emphasized the importance of public involvement in the study and noted that Committee meetings will be open to the public with a large number of meetings to be held in Nevada to facilitate public participation.

This first meeting focused on defining the scope of the project and developing a workplan for conducting the study. The Committee emphasized that it does not consider it within the Committee's mandate to (1) make recommendations on the suitability of the Yucca Mountain site, (2) determine "how safe is safe enough," or (3) develop a standard; instead its mandate is to provide expert scientific guidance and recommendations regarding the technical basis of the Environmental Protection Agency (EPA) high-level waste disposal standards for Yucca Mountain. With these exceptions, the Committee emphasized that it is free to question all assumptions underlying the regulatory framework for high-level waste disposal. The Committee heard from EPA on the history of radiation waste disposal standards and from over 20 representatives of federal, state, and county governments, the Nuclear Waste Technical Review Board, the nuclear electric industry, environmental and public interest organizations, Indian tribal representatives, the American Nuclear Society, and members of the general public regarding issues to be considered in the development of recommendations. The NRC staff presentation is included as an enclosure. Presentations made by other contributors are available from the Executive Director for Operations' office. Individual Committee members and numerous speakers stressed the need to consider the standard in the licensing framework within which it will ultimately be implemented. Of particular interest to the NRC, a question was raised by one Committee member and several presenters as to whether NRC subsystem requirements (10 CFR 60.113) represent dual regulation. NRC staff responded by explaining the regulatory history of the development of subsystem requirements and the role these requirements play

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in enhancing the Commission's confidence in making a licensing decision with reasonable assurance. It is unclear whether the Committee will pursue this issue in the future.

The Committee created working groups from within its membership to focus on key issues raised in the Energy Policy Act. The priority that the Committee will give to issues beyond those discussed in the Energy Policy Act will be decided at future meetings. In addition, the Committee is arranging for consultants to conduct literature reviews in the areas of (1) international approaches to health-based high-level waste disposal standards, (2) human intrusion, (3) effectiveness of active and passive institutional controls, and (4) long-term prediction of disruptive natural events as a basis for input to Committee discussions. All Committee findings and recommendations will be subjected to peer review. The Committee asked the NRC staff and others to provide information on identified subjects and to participate in future meetings. The next meeting is planned in late August or early September focusing on the adequacy of health-based standards. The NRC staff plans to provide such information to the Committee consistent with the Commission's previous positions on these issues and will raise to the Commission's attention any new matters of policy.

Original signed by
James M. Taylor James M. Taylor
Executive Director
for Operations

Enclosure:
NRC Presentation to the NAS

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OFC	NMSS*	NMSS*	EDO	EDO
NAME	GArlotto	RMBernero	HThompson	JMTaylor
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OFC	HLHP	C	HLWM	C	OGC	E	HLWM	E
NAME	MFederline/cj		JJLinehan		WCReamer		BJYoungblood	
DATE	06/3/93		06/2/93		06/03/93		06/3/93	
OFC	NMSS		NMSS		EDO		EDO	
NAME	GArlotto		RMBernero		HThompson		JMTaylor	
DATE	06/4/93		06/6/93		06/ /93		06/ /93	

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NATIONAL ACADEMY OF SCIENCES COMMITTEE ON TECHNICAL BASES
FOR YUCCA MOUNTAIN STANDARDS
MAY 27, 1993

U.S. NUCLEAR REGULATORY COMMISSION STAFF VIEWS ON ENVIRONMENTAL STANDARDS FOR DISPOSAL OF HIGH-LEVEL WASTES

Margaret V. Federline, Chief
Hydrology and Systems Performance Branch
Division of High-Level Waste Management
U.S. Nuclear Regulatory Commission

I. INTRODUCTION

Thank you for the opportunity to present the U.S. Nuclear Regulatory Commission (NRC) staff's views on the major issues involved in developing standards for disposal of high-level wastes (HLW). Under the provisions of the Nuclear Waste Policy Act (as well as earlier legislation), the NRC is one of three Federal agencies with a role to play in disposal of HLW. The Department of Energy has the responsibility for actual disposal of HLW -- developing a repository and operating it. The U.S. Environmental Protection Agency (EPA) has been charged with developing the environmental standards that will be used to evaluate the safety of the repository developed by DOE. NRC is the implementor -- the regulatory agency that will determine whether DOE's proposal does, in fact, comply with the requirements of EPA's standards.

The NRC's regulatory role causes the NRC to have a strong interest in both the form and the content of HLW standards. Of course, the NRC's first interest is protection of public health and safety. We look to EPA's standards to define an adequate level of public health protection. When implementing EPA's standards, the NRC staff's major concern is with the clarity of the standards and the practicality of evaluating compliance with them during licensing. However, the NRC staff also recognizes a strong national interest in proceeding with HLW disposal in a manner that is adequately safe. The NRC staff therefore is concerned that the standards should provide a level of safety that is sufficient to adequately protect future generations, but is not so stringent that demonstrating compliance with the standards becomes needlessly costly or time consuming. With those basic concerns in mind, let me now turn to the basic safety goal for HLW disposal, and then discuss the major issues the NRC staff believes will be important in formulating standards to achieve that basic goal.

II. THE BASIC SAFETY GOAL

More than a decade ago, the Nuclear Waste Policy Act set up a national program for development of deep geologic repositories for disposal of high-level radioactive wastes (HLW). This decision was not reached lightly. A wide range of alternative disposal technologies, ranging from subseabed disposal to disposal in space, had earlier been evaluated by the U.S. Department of Energy (DOE). After selection of repository disposal as the preferred technology, the safety of deep geologic disposal of HLW was reviewed twice by the U.S. Nuclear Regulatory Commission (NRC). First, the Waste Confidence Decision of 1984 found reasonable assurance that safe disposal of HLW in a repository is technically feasible. Then, in 1990, the NRC reviewed and reaffirmed its earlier views on the technical feasibility of safe repository disposal. And, the U.S. has not been alone in its pursuit of repository disposal. Other nations with substantial nuclear power programs have also endorsed the concept of disposal of HLW in deep geologic repositories.

One might reasonably ask the question "On what basis has this generation, today, selected repository disposal and evaluated its safety?" The answer lies, I think, in what can be called the "Societal Pledge to Future Generations." The Pledge is really very simple. First, it assumes that future societies will be just as concerned as we are today about the potential health hazards of radiation exposure. No more and no less. The Pledge then promises to provide future societies with the same protection from radiation we would expect for ourselves. No more and no less. The Pledge further promises to provide that protection in a way that does not impose burdens on future societies. In other words, future societies will not need to take special precautions to protect themselves from the radioactive materials we generate today. Instead, we will do today whatever is necessary to ensure an adequate level of radiation protection. This Pledge is, I believe, what decision-makers in the U.S. and other nations had in mind when deep geologic disposal was selected as the preferred technology and was declared to be safe.

Of course, the Pledge I just described is rather general and lacks many important details. Development of those details, in the form of recommendations for environmental standards, is the charter of this panel of the National Academy of Sciences. Many difficult issues must be addressed by the panel, including several that I will discuss in a moment. I think, however, that the difficulty of some issues can be reduced by accepting the Societal Pledge I described. When considering environmental standards, we should not try to forecast possible cures for cancer, capabilities to detect and correct genetic abnormalities, long-term changes in societal lifestyles and preferences, and so on. It will be difficult enough to predict the geologic evolution of a repository site. Trying to also predict human and societal evolution over thousands of years, and to litigate those predictions during licensing, seems to me to be both unproductive and unnecessary. Instead, we should assume that human beings and their social institutions will remain much as they are today and, based on that assumption, we should provide for the future the same protection from radiation we would demand for ourselves. Trying to speculate about the ways in which humans or societies might change over thousands of years in the future, and to tailor standards to those changes, seems a very difficult undertaking with little chance of success.

III. THE ISSUES

As I see it, there are at least seven major issues that need to be addressed by this panel. Let me discuss each of these issues.

(1) Health-based versus technology-based standards. Any environmental standard should have as its underlying basis a safety goal for the allowable health risk to an individual or a population. Perhaps the most fundamental issue facing this panel is the way in which the safety goal should be determined. When EPA developed its 1985 standards, the underlying safety goal was largely based on EPA's analyses of the waste isolation capabilities of several hypothetical HLW repositories. EPA estimated the health effects that might be caused by those repositories, compared that level of health effects to the estimated impacts of unmined uranium ore, natural background radiation and similar reference points, and then required that any real repository perform at least as well as EPA's hypothetical repositories. Thus, the safety goal underlying EPA's 1985 standards can be termed "technology-based" because it was derived from EPA's analyses of the waste isolation capabilities of repositories.

The advantage of a technology-based safety standard is that it largely eliminates questions about whether the projected impacts of a repository will be "as low as reasonably achievable" (ALARA). After all, the whole purpose of a technology-based standard is to require the best level of performance that a particular technology is thought to be able to provide. Thus, a technology-based standard can largely eliminate any need for a time-consuming and controversial ALARA analysis during the licensing review for a specific repository. The disadvantage of a technology-based standard is the potential for such a standard to be overly stringent if EPA misjudges the waste isolation capability of repositories or the costs of achieving compliance. Failure to recognize the potential for gaseous release of carbon-14 from an unsaturated zone repository illustrates the vulnerability of technology-based standards when applied to a new or evolving technology like HLW disposal. There also is no guarantee that a purely technology-based standard would be adequately protective.

In contrast to EPA's technology-based safety goal, the International Commission on Radiological Protection (ICRP) has recommended a "health-based" safety goal. The ICRP examined other risks accepted by society and, on that basis, developed recommended dose and risk limits for individuals who might be exposed to releases from a repository in the future. The ICRP's recommendations can be characterized as "health-based" because they represent the judgment of the ICRP as to the highest level of health risk that any person should ever be subjected to, regardless of the costs or technical difficulties of achieving compliance.

The Energy Policy Act asks this panel to consider whether a "health-based standard" would be reasonable. In my view, use of the term "health-based" refers to the type of safety goal recommended by the ICRP, in contrast to the technology-based health goal previously adopted by EPA. As I stated earlier, one of the most fundamental issues facing this panel is whether a health-based safety goal, like that recommended by the ICRP, would provide a reasonable basis for EPA's HLW standards and whether such a basis would be preferable to the technology-based approach previously used by EPA.

In the NRC staff's view, EPA should reduce the emphasis placed on technical achievability when deriving its standards. The "carbon-14 issue" illustrates the vulnerability of technology-based standards to new information. For a new undertaking, like a HLW repository, there is a real potential for technology-based standards to be unreasonably stringent if all significant releases cannot be identified and included in the derivation of those standards. On the other hand, there is no guarantee that technology-based standards will be adequately protective. For these reasons, the NRC staff has recommended to EPA that much more emphasis be placed on health-based reasoning when deriving EPA's HLW standards.

(2) Individual versus population protection. The second major issue facing this panel involves the type of radiation protection to be emphasized by EPA's standards -- protection for individuals or protection for the population as a whole. EPA's 1985 standards emphasized protection of populations by imposing "containment requirements" that limited the cumulative amount of radioactive material released over 10,000 years. In contrast, the Energy Policy Act now asks whether a standard, "based upon doses to individual members of the public," would be reasonable.

EPA's decision to base its 1985 standards on population impacts rather than on protection of individuals was EPA's most significant departure from the traditional concepts of radiation protection, from the recommendations of advisory groups like the ICRP, and from the practices of other nations. EPA's defense of its decision was two-fold -- practicality and a desire to emphasize waste containment rather than dilution.

EPA's practicality concern deserves close attention by this panel. Ten years ago, the Waste Isolation Systems Panel of the National Academy of Sciences warned that large individual doses can occur if humans consume contaminated groundwater in the vicinity of a HLW repository. The reason is simple -- groundwater flow rates are too low to provide significant dilution of potential releases. When trivial doses were estimated for a repository at Hanford, it was assumed that releases would be diluted in the Columbia River. There is no Columbia River near Yucca Mountain. In fact, at Yucca Mountain, consumption of groundwater may be the most likely pathway for repository releases to reach humans. Since groundwater flow provides little dilution of releases, unacceptably large doses may be predicted to occur unless a Yucca Mountain repository performs much better than would have been required by EPA's 1985 standards.

There are strong arguments in favor of an individual protection standard, either as a supplement to EPA's cumulative release limits, or as a replacement for those release limits. One of the first principles of radiation protection has always been to provide an adequate level of protection for each individual potentially exposed to radiation. Questions have been raised about EPA's 1985 standards because those standards depart from that tradition. When this panel considers whether to recommend adoption of an individual dose standard, the panel will also need to face the challenge of finding a practical way to make such a standard workable for a repository where no large river is available to dilute potential releases, but which has clear advantages for containment of wastes.

The NRC staff considers that radiation protection for individuals should be a part of EPA's standards. However, it will be very important to ensure that an individual protection standard is applied in a reasonable manner. An individual protection standard should not attempt to protect all individuals, under all conceivable circumstances, at all times in the future. For example, it does not seem reasonable to try to protect a hypothetical farm family located at the boundary of a Yucca Mountain repository, when it is unlikely that such a farm family will ever exist. Instead, a more realistic scenario would involve exploitation of groundwater near Yucca Mountain as a supplement to the municipal water supply for regional populations. Water consumers in the region would then form the critical group whose doses would be limited by an individual protection standard.

(3) Fundamental versus derived standard. Development of environmental standards usually begins with establishment of an underlying basic safety goal, expressed in terms of an allowable dose or health risk to an individual or a population. However, it is not necessary to express the standard directly in terms of that fundamental goal. Instead, the standard can be expressed in terms of a derived quantity, such as quantity or concentration of radioactive material released to the environment. The advantage of a derived, release limit standard is simplicity. Evaluations of compliance need not predict who will live where, or

how they will live, for thousands of years into the future. The disadvantage of a derived standard is the possibility that conditions near a repository will be different from those assumed when deriving the standard from the basic safety goal. If so, the actual health risk caused by releases from a repository might be significantly different from the basic safety goal.

As we all know, EPA's 1985 standards were expressed in terms of release limits derived from EPA's analyses of the expected performance of hypothetical repositories. Those release limits were controversial, at least in part, because the release limits were derived using a "world-average" biosphere that bore little resemblance to the biosphere likely to exist near Yucca Mountain. Thus, the actual number of health effects that might be caused by releases from Yucca Mountain might also bear little resemblance to EPA's health effects goal. Now, the Energy Policy Act asks this panel to consider whether a standard "based upon doses" to individual members of the public is reasonable. I interpret the phrase "based upon doses" to allow this panel to consider derived standards, such as limits on concentrations of radionuclides released to the environment, as well as standards that directly limit doses. The issue before this panel is whether the simplicity of derived standards, and the relative ease of evaluating compliance with them during licensing, outweighs the potential for derived standards to depart from the underlying basic safety goal.

The NRC staff has supported a derived standard (e.g., a limit on radionuclide releases) because such a standard would be easier to implement during licensing than a fundamental standard expressed in terms of doses or health risks. Of course, if a derived standard is to be used, it would be necessary to avoid unrealistic assumptions in the derivation of the standard. A fundamental (dose or health risk) standard would also be acceptable, provided that such a standard could be implemented using some type of "static" or "reference" biosphere. The NRC staff would object to any fundamental standard that permitted unlimited speculation about future human locations, lifestyles and societal conditions.

(4) Active institutional control. EPA's 1985 standards assumed that active institutional controls (guarding or monitoring a site and remedial activities) will not be relied upon for more than 100 years after repository closure as the means to achieve acceptable waste isolation. The Energy Policy Act now asks this panel to advise EPA on the potential for post-closure oversight to prevent an unreasonable risk of breaching the repository's barriers or of causing unacceptable radiation doses to the public.

The advantage of relying on active institutional controls is the potential to reduce the near-term cost of achieving and demonstrating compliance with the environmental standards for Yucca Mountain. Some probabilistic projections, especially those involving human intrusion, will likely be contentious during a licensing review and substantial efforts may be needed to demonstrate acceptable repository performance. Societal practices such as monitoring drinking water quality could provide effective protection of populations near a repository, and credit for such practices could be beneficial in demonstrating repository safety.

The disadvantage of reliance on active controls is the history of loss of such controls which raises questions about the wisdom of relying on institutions to ensure repository safety. Historical examples of durable institutions generally involve functions that societies find useful (e.g., maintaining records), and it is difficult to project the willingness of future societies to perpetually monitor a repository site.

The NRC's regulations for geologic repositories have not assumed that active institutional controls would be effective in preventing human intrusion for more than 100 years after facility closure. This assumption appeared to be prudent for a HLW repository, since no practical method has ever been identified to guarantee that such active institutional controls will persist or will continue to be effective. "Passive" institutional controls, however, such as monuments, markers and land-use records, are likely to persist and be effective in deterring future human intrusion into a repository.

(5) Probabilistic standards. The cumulative release limits of EPA's 1985 standards applied to virtually all causes of releases, including human intrusion. Concerns about the scientific predictability of intrusion is reflected in the Energy Policy Act's identification of post-closure oversight and human intrusion as subjects for this panel's review. Predicting the probabilities of some rare geologic events, such as volcanic activity at Yucca Mountain, could prove nearly as troublesome as predictions of human intrusion. Therefore, I encourage this panel to include rare geologic events, along with human intrusion, when considering whether it is possible to make scientifically supportable predictions of potential repository disruptions.

In probabilistic risk assessments, the probability that an event will occur cannot always be determined from the historical frequency of occurrence of similar events. For rare events, the estimated probabilities are often values that represent an individual's degree of belief (grounded on some theoretical or empirical foundation) that the events will occur. Although such probability estimates might not be scientifically verifiable in the most rigorous sense, they have provided an adequate basis for past regulatory decisions (e.g., regarding seismic potential in the eastern United States). Thus, it is reasonable to expect that a probabilistic standard will prove workable during licensing. Nevertheless, some of the events of concern for predicting the performance of a repository may be even more speculative than events dealt with in the past, and could be difficult to evaluate during licensing. In the NRC staff's view, implementing probabilistic standards during repository licensing will be challenging, but should ultimately prove to be feasible.

(6) As low as reasonably achievable (ALARA). EPA's 1985 standards did not contain a specific requirement that projected releases be ALARA. EPA's containment requirements, which were derived from analyses of the waste isolation capabilities of hypothetical HLW repositories, were effectively "generic" ALARA levels. In contrast, an explicit ALARA requirement is a prominent feature of the recommendations of international advisory organizations.

The principal advantage of an explicit ALARA requirement would be consistency with other radiation protection standards. The disadvantage would be significant difficulties in evaluating compliance with such a criterion. The large uncertainties in projected repository performance would make any case-specific ALARA analysis highly speculative, especially if the performance of real or hypothetical alternative sites were to be considered.

The NRC staff would object to any broad-based requirement that repository releases be demonstrated to be ALARA, especially if such a requirement were applied to site selection. The NRC's regulations now contain a requirement for consideration of alternatives to the major design features of a repository. Any more extensive ALARA analysis is likely to prove speculative and unworkable.

(7) 10,000-year period of concern. The containment requirements of EPA's 1985 standards applied only for the first 10,000 years after repository closure. In contrast, the recommendations of some international advisory groups and the regulations of some other nations are open-ended, restricting individual doses and risks in perpetuity. While not specifically addressed by the Energy Policy Act, questions have been raised about the time period for which environmental standards should be applied at Yucca Mountain.

The advantage of a 10,000-year cut-off can be stated very simply -- practicality. With a 10,000-year cut-off, the licensing process does not need to consider very speculative long-term geologic and climatic changes that might disrupt repository performance. On the other hand, some of the hazardous constituents of high-level waste have half-lives exceeding 10,000 years, and releases of those materials could pose a significant human health hazard well beyond 10,000 years. Previously, EPA reasoned that a repository that is able to meet its standards for the first 10,000 years after disposal would be likely to perform well for longer times, as well. It should be noted that, when EPA's standards were challenged in a Federal court, the court did find that EPA's explanation of its 10,000-year limit was adequate.

The NRC staff prefers that any numerical HLW standard be applied only for a limited time after disposal (e.g., 10,000 years). The farther into the future one tries to predict repository performance, the more uncertain those predictions will be. In the NRC staff's view, the very large uncertainties inherent in estimating releases over very long times makes it impractical to make a scientifically rigorous demonstration of compliance with numerical regulatory limits. Instead, potential releases that might occur after the regulatory period should be estimated by DOE and disclosed in a suitable format, such as an Environmental Impact Statement.

IV. CONCLUDING REMARKS

In conclusion, let me return to my earlier remarks about the basic Societal Pledge we are making to future generations. We are <u>not</u> promising to predict every nuance of future society's attitudes toward, or concerns about, radiological hazards. Nor are we trying to forecast the full range of potential changes in societal lifestyles and potential modes of exposure to releases from a repository. We are simply promising to provide future humans with the same type of radiological protection, and the same level of safety, that we would demand for ourselves. If this panel can focus its deliberations on determining the safety standards we would find acceptable today, I think reasonable and workable recommendations for HLW disposal standards can be developed. I wish you great success in your deliberations, and I offer you any support from the staff of the NRC that you might find helpful in your efforts.

RESUME

FRANK A. SPANE, JR.

Staff Scientist, Site Characterization & Assessment Section
Environmental Sciences Department
Battelle, Pacific Northwest Laboratories

EDUCATION

B.S., Geology, Washington State University, 1969
M.S., Hydrogeology, Colorado State University, 1972
Ph.D., Hydrology, University of Nevada-Reno, 1977

RELEVANT EXPERIENCE

Dr. Spane joined Battelle-Northwest in August 1989 as a staff scientist. His professional experience includes applied research, project management, technical supervision of hydrogeologic investigations. At Battelle-Northwest, his focus has been on: development and evaluation of hydraulic test methods suitable for hydrogeologic characterization investigations at contaminated ground-water sites; review of Remedial Action Plans (RAP) and preparation of Technical Evaluation Reports (TER) for former uranium processing plant (UMTRA) facilities for the U.S. Nuclear Regulatory Commission, technical support for a variety of Hanford Site hydrogeologic investigations, and project management of off-site migration studies of potential ground-water contaminants within the upper-confined aquifer system on the Hanford Site.

PRIOR PROFESSIONAL EXPERIENCE

Other selected experience prior to joining Battelle-Northwest includes:

- NAGRA (Nationale Genossenschaft fuer die Lagerung radioaktiver Abfaelle), Baden, Switzerland - August 1987 to August 1989. Project manager and technical supervisor of a number of hydrogeological investigations including: performance of a tracer-dilution test within a deep crystalline test horizon; evaluation of computer software and data acquisition system needs to support hydrogeologic investigation programs; and assessment and installation of multi-level, long-term monitoring systems. Principal contributing author in development of work programs for hydrologic test investigations within a planned underground radioactive repository/test facility. Preparation of budgetary/credit proposals to support various hydrologic test studies. Principal technical reviewer within the Field Operations Department for a number of hydrogeologic subcontractor investigations, including: hydraulic test analysis for intervals influenced by multi-phase conditions; analysis of long-term monitoring pressure data; use of borehole geophysical methods to determine hydraulic conductivity distribution; and evaluation of the effects of test equipment compliance on low-permeability, test formation response.

- Rockwell/Westinghouse Hanford Operations, Richland, Washington - January 1978 to July 1987. During this employment period served in a number of capacities in support of the Basalt Waste Isolation Program (BWIP), including: Staff

Hydrologist; Technical Advisor to the Drilling and Hydrologic Testing Group; and Manager and Team Leader for Hydrologic Field Testing Studies.

Work responsibilities included: primary and contributing author for major program documents in support of Hanford Site licensing applications to the Nuclear Regulatory Commission; supervised the hydrologic field testing and hydrochemical sampling of deep basalt horizons; development of conceptual ground-water flow models based on selected hydrochemical and hydrological parameters; design, analysis, and documentation of hydrologic tests conducted in low and high permeability geologic horizons; development of computer codes for converting field formation pressure measurements to appropriate hydraulic head parameters; and evaluation of the effects of borehole conditions and test system configuration on transient test response and analysis.

- Hydro-Search, Inc., Reno, Nevada - February 1971 to January 1978 (1/2 time during graduate school studies between 2/71 and 7/74). Work responsibilities included the planning, performance, interpretation, and report writing of a number of consulting projects in the areas of: aquifer contamination assessment, water-resource evaluation and environmental impact, water-quality assessment, wastewater plant siting, open-pit mine slope stability, delineation and monitoring of subsurface tailings-pond leachate contamination, water-well design and rehabilitation, analysis of aquifer test data, geologic mapping, and geophysical applications with respect to aquifer contamination assessment, ground-water and geothermal resource evaluation, and engineering studies.

  Served as team leader for Sierra Geophysical Services, Inc. (affiliated with Hydro-Search, Inc.). Work responsibilities included the design, supervision, and interpretation of field geophysical surveys conducted for engineering projects, ground-water development, aquifer contamination assessment, and geothermal exploration in the western United States.

TRAINING

- Hazardous Waste Site Health & Safety Training (40-Hour Course)
  Instructing Organization: Urie Environmental Health Inc., Wheatridge, Colorado

- Pressure Transient Analysis in Tight Rocks
  Instructing Organization: Oil and Gas Consultants International, Inc., Tulsa, Oklahoma.

- Fluid Flow in Fractured Rocks
  Instructor: Paul A. Witherspoon; Instructing Organization: The National Water Well Association, Dublin, Ohio

PUBLICATIONS
(complete list available upon request)

Spane, F.A., Jr. and S.K. Wurstner, 1992, DERIV: A Program for Calculating Pressure Derivative for Use in Hydraulic Test Analysis, Pacific Northwest Laboratory, PNL-SA-21569.

Spane, F.A., Jr. and P.D. Thorne, 1992, An Evaluation of Slug Interference Tests For Aquifer Characterization at the Hanford Site, Pacific Northwest Laboratory, PNL-SA-20978, Richland, Washington

Spane, F.A., Jr., 1992, Hydraulic Test Results for Savage Island Wells 699-32-22B, 699-42-E9A, and 699-42-E9B, Pacific Northwest Laboratory, PNL-8173, Richland, Washington.

Spane, F.A., Jr., 1992, Applicability of Slug Interference Tests Under Hanford Site Conditions: Analytical Assessment and Field Test Evaluation, Pacific Northwest Laboratory, PNL-8070, Richland, Washington.

Spane, F.A., Jr., 1990, Description and Results of Tracer Tests Conducted For A Deep Fracture Zone Within Granitic Rock At the Leuggern Borehole, Nagra Technical Report, NTB 90-05, Nagra, Baden, Switzerland.

Spane, F. A., Jr., 1990, Leuggern Phase 2 Test Program: Preliminary Analysis and Description of Naphtionat Tracer Injection and Natural Outflow/Discharge Test Phase, Nagra Interner Bericht, NIB89-50, Nagra, Baden, Switzerland.

Spane, F.A., Jr., 1989, Leuggern Phase 2 Test Program: Preliminary Analysis and Description of Eosin Tracer Injection and Recovery Test Phase, Nagra Interner Bericht, NIB 89-46, Nagra, Baden, Switzerland.

Spane, F.A., Jr., 1989, Leuggern Phase 2 Test Program: Preliminary Analysis and Description of Uranin Tracer Injection and Recovery Test Phase, Nagra Interner Bericht, NIB 89-07, Nagra, Baden, Switzerland.

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Spane, F.A., Jr., 1987, Potentiometric Map and Inferred Lateral Groundwater Flow Direction for the Mabton Interbed, Hanford Site, Washington State -- January 1986, SD-BWI-TI-335, Rockwell Hanford Operations, Richland, Washington.

Spane, F.A., Jr. and P.D. Thorne, 1986, Comparison of Calculated and Observed Hydrostatic Pressure Measurements at Borehole DC-8, RHO-BW-ST-74 p, Rockwell Hanford Operations, Richland, Washington.

Spane, F.A., Jr., 1986, Preliminary Evaluation of Piezometer Responses at DC-19, DC-20, and DC-22 During Construction of DC-23W, SD-BWI-TI-313, Rockwell Hanford Operations, Richland, Washington.

Spane, F.A., Jr. and R.B. Mercer, 1985, HEADCO: A Program for Converting Observed Water Levels and Pressure Measurements to Formation Pressure and Standard Hydraulic Head, RHO-BW-ST-71 P, Rockwell Hanford Operations, Richland, Washington.

Spane, F.A., Jr and P.D. Thorne, 1985, "The Effects of Drilling Fluid Invasion on Hydraulic Characterization of Low-Permeability Basalt Horizons: A Field Evaluation", Environmental Geology and Water Sciences, vol. 7, no. 4, pp. 227-236.

Thorne, P.D. and F.A. Spane, Jr., 1985, "A Comparison of Under-Pressure and Over-Pressure Pulse Tests Conducted in Low-Permeability Basalt Horizons at the Hanford Site, Washington

Ståte", published in the proceedings of the 17th International Congress, International Association of Hydrogeologists, Tucson, Arizona, January 7-12, 1985.

Spane, F.A., Jr., P.D. Thorne, and W.H. Chapman-Riggsbee, 1983. Results and Evaluation of Experimental Vertical Hydraulic Conductivity Testing at Boreholes DC-4 and DC-5, SD-BWI-TI-136, Rockwell Hanford Operations, Richland, Washington.

Strait, S.R., F.A. Spane, R.L. Jackson, and W.W Pidcoe, 1982, Hydrologic Testing Methodology and Results from Deep Basalt Boreholes, RHO-BW-SA-189 P, Rockwell Hanford Operations, Richland, Washington; paper presented at the Geological Society of America Regional Meeting, Bozeman, Montana, May 6-7, 1982.