NUREG-1243

Ground-Water Protection Activities of the U.S. Nuclear Regulatory Commission

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

Ground-Water Protection Group

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Ground-Water Protection Group

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Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) provides for ground-water protection through regulations and licensing conditions that require prevention, detection, and correction of ground-water contamination. Prepared by the interoffice Ground-water Protection Group, this report evaluates the internal consistency of NRC's ground-water protection programs. These programs have evolved consistently with growing public concerns about the significance of ground-water contamination and environmental impacts. Early NRC programs provided for protection of the public health and safety by minimizing releases of radionuclides. More recent programs have included provisions for minimizing releases of nonradiological constituents, mitigating environmental impacts, and correcting ground-water contamination. NRC's ground-water protection programs are categorized according to program areas, including nuclear materials and waste management (NMSS), nuclear reactor operation (NRR), confirmatory research and standards development (RES), inspection and enforcement (IE), and agreement state programs (SP).

Based on analysis of existing ground-water protection programs within NRC, the interoffice Ground-water Protection Group has identified several inconsistencies between and within program areas. These inconsistencies include: (1) different definitions of the term "ground-water," (2) variable regulation of nonradiological constituents in ground water, (3) different design periods for ground-water protection, and (4) different scopes and rigor of ground-water assessments. The second inconsistency stems from differences in statutory authority granted to the NRC. The third inconsistency is rationalized by recognizing differences in perceived risks associated with nuclear facilities. The Ground-water Protection Group will document its analysis of the remaining inconsistencies and make recommendations to reconcile or eliminate them in a subsequent report.

NRC MISSION STATEMENT

The mission of the U.S. Nuclear Regulatory Commission (NRC) is to assure that nonmilitary uses of nuclear materials in the United States--as in the operation of nuclear power plants or in medical, industrial, or research applications --are carried out with proper regard and provision for the protection of public health and safety and of the environment, the safeguarding of nuclear materials and facilities from theft and sabotage, and safe transport and disposal of nuclear materials and wastes. The NRC accomplishes its mission through the licensing of nuclear reactor operations and other possession and use of nuclear materials, the issuance of rules and regulations governing licensed activities, and inspection and enforcement actions.

FOREWORD

This report was prepared by members of an interoffice Ground-water Protection Group. The Group was chartered under the direction of John Davis, Director of the Office of Nuclear Material Safety and Safeguards (NMSS), to coordinate groundwater protection activities within NRC. Dr. Philip S. Justus, Acting Chief of the Geotechnical Branch in the Division of Waste Management, is responsible for Group activities. Michael Weber (NMSS) coordinates the Group and was lead author of this report. Other contributing authors include Thomas Nicholson (RES), Ray Gonzales (NRR), and Rex Wescott (NRR). Questions and comments on the report should be directed to:

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GROUND-WATER PROTECTION ACTIVITIES OF THE U.S. NUCLEAR REGULATORY COMMISSION

Chapter 1: INTRODUCTION

Since the early 1970's, recognition of the need to protect ground-water from contamination by human activities has increased substantially. This recognition has been fueled by identification of sites such as "Love Canal" at Niagara, New York, and the Stringfellow acid pits in California. Although the magnitude of the ground-water contamination problem has not been fully quantified, ground-water contamination by inorganic and organic chemicals, radionuclides, and/or microorganisms has been identified in every State (OTA, 1984).

Regulatory programs of the U.S. Nuclear Regulatory Commission have evolved to accommodate growing concerns about the need for ground-water protection. Early programs of the Commission emphasized protection of the public health and safety from radiological hazards associated with commercial nuclear facilities. In the mid-1970's, the Commission expanded its programs to consider potential environmental impacts in addition to protection of the public health and safety and to identify mitigative measures for these impacts under the National Environmental Policy Act of 1969 (NEPA). Consistent with its mission to protect the public health and safety and the environment, the Commission has further modified its regulatory programs to provide for increased protection of ground-water.

This report was prepared by the Ground-water Protection Group (GWPG), an inter-office committee composed of representatives with expertise or knowledge about ground-water protection from the offices of Nuclear Material Safety and Safeguards (NMSS), Nuclear Reactor Regulation (NRR), Nuclear Regulatory Research (RES), Executive Legal Director (ELD), Inspection and Enforcement (IE), and State Programs (SP). The Primary objective of the Group is to coordinate ground-water protection activities at the staff level by ensuring information transfer and by assessing NRC programs for ground-water protection. In addition, the GWPG provides a focal point within the NRC to communicate with groups outside of the Commission about ground-water protection. The GWPG was convened in October of 1985 by the Director of NMSS in response to direction from the Executive Director for Operations. Responsibility for GWPG activities resides with the Chief of the Geotechnical Branch in the Division of Waste Management of NMSS.

Consistent with the coordinating role of the GWPG, this report describes ground-water protection activities of the NRC in three primary program areas: nuclear reactors (NRR), fuel cycle and waste management (NMSS), and research (RES). Based on these descriptions, the report assesses inconsistencies between major ground-water programs. The assessment provides the foundation for recommendations and conclusions of the GWPG, which will be documented in a later report. Questions or comments on the report should be directed to Michael Weber of the Geotechnical Branch, who may be contacted at telephone number (301) 427-4746.

Regulatory Approach for Ground-water Protection

Ground-water is defined in NRC regulations for high-level radioactive waste disposal (10 CFR Part 60) as all subsurface water, whereas other NRC and federal programs may define ground-water as subsurface water that exists only in the saturated zone below the regional water table. Early NRC regulatory programs provided for ground-water protection indirectly by controlling releases of radionuclides to unrestricted areas for public protection. More recent regulatory programs directly provide for ground-water protection by establishing maximum limits of contaminants in ground-water at certain facilities and by requiring specific design and operational practices intended to protect ground-water quality.

The NRC provides for ground-water protection through regulations and licensing actions that require detection, correction, and prevention of ground-water contamination. NRC programs emphasize prevention of ground-water contamination rather than just detection and correction of contamination, recognizing the technical limitations and large costs associated with corrective actions for ground-water contamination. Prevention may be accomplished through requirements for design, siting, operation, and inspection of nuclear facilities, through encouragement of alternatives that eliminate the contaminating activity, through process and operational changes that eliminate potential sources of contamination, and through recovery and recycling of potential contaminants. Ground-water monitoring for detection of contamination is also necessary at some facilities to ensure that preventive measures are indeed effective in protecting ground-water quality. Detection of contamination may precipitate corrective actions as the third component of NRC's programs for ground-water protection.

Consistent with NRC's general mission of protecting the public health and safety and the environment from commercial nuclear facilities, the Commission has emphasized protection of ground-water from radiological contaminants rather than nonradiological contaminants. Protective measures required by NRC for radiological constituents, however, have generally protected ground-water from the accompanying nonradiological constituents. Under general authority provided by the National Environmental Policy Act, NRC regulates nuclear facilities to ensure that they are constructed and operated in a manner that minimizes both radiological and nonradiological impacts on the environment, including impacts on ground-water quality from nonradiological contamination.

In many instances, NRC establishes site-specific license conditions to protect ground-water from radiological and nonradiological contamination. For example, upper control limits are established for nonradiological constituents in ground-water at in situ uranium solution mines to protect ground-water outside mining zones. If concentrations exceed specific control limits, mine operators are required to evaluate the excursion and take corrective action to prevent migration of contaminated ground-water. Through appropriate combinations of requirements for prevention, detection, and correction of ground-water contamination, NRC has implemented regulatory programs for ground-water protection at commercial nuclear facilities.

Chapter 2: GROUND-WATER PROTECTION PROGRAMS OF NMSS

Ground-water transport is recognized as the principal pathway of concern for migration of radiological and nonradiological contaminants from wastes generated, disposed, or accidentally released from activities regulated by the Office of Nuclear Material Safety and Safeguards (NMSS). These activities include disposal of low-level and high-level radioactive wastes; and operation of uranium recovery, fuel fabrication, and uranium hexafluoride conversion facilities. NMSS's general approach to ground-water protection is to prevent contamination through consideration of design and operational features that control or mitigate contaminant releases before contamination occurs. Specific actions for ground-water protection required by NRC regulations, however, vary based on the characteristics of the activities.

This chapter discusses ground-water protection pograms of the Office of Nuclear Material Safety and Safeguards, including management and disposal of uranium recovery wastes; low-level and high-level radioactive wastes; and wastes generated at fuel cycle facilities. For each of these program areas, the chapter briefly summarizes (1) a historical perspective about ground-water protection; (2) regulations and regulatory guidance for ground-water protection; (3) current technical capabilities in NMSS programs for ground-water protection; and (4) current activities relevant to ground-water protection at NMSS-licensed facilities.

Waste Management Programs

Uranium Recovery

Historical Perspective

Since the early 1940's, commercial mills throughout the United States have processed uranium ores. The most voluminous wastes of the uranium milling process are the tailings and liquors used to slurry these tailings into surface disposal impoundments. Uranium mill tailings consist of leached ore solids, process chemicals, solubilized ore constituents not retained by the milling process, and reaction products that form during milling. The composition and characteristics of uranium mill tailings solutions vary as a function of ore composition and milling processes. Mill tailings solutions contain moderate to high concentrations of soluble salts, radionuclides, heavy metals, and transition metals and are characterized by high oxidation potentials, high ionic strengths, and high or low pH's (Weber and Dam, 1985).

Early uranium mills discharged mill tailings in slurry form into nearby streams and swamps. Direct discharge of tailings solutions to surface water bodies under controlled conditions continued until as recently as 1977 (White, 1984). In response to increasingly stringent regulatory requirements in the early 1960's, uranium mills altered tailings disposal practices by discharging uranium mill tailings into surface impoundments.

Although the potential effects of tailings seepage from impoundments were recognized, seepage into the ground was considered an acceptable method for disposal because investigators believed that chemical processes (e.g., ion exchange and chemical precipitation) would remove most of the contaminants from the tailings solutions. Seepage of tailings solutions may have accounted for more than 80% of the liquid loss from early impoundments (Merritt, 1971). Early impoundments were not lined to reduce seepage because impoundments that allowed seepage could be constructed considerably smaller (up to 10 times smaller) than lined impoundments that only allowed evaporation. In the absence of stringent ground-water protection regulations, seepage of uranium tailings solutions degraded the quality of shallow ground-water beneath and adjacent to the mills. Other surface-based uranium recovery operations (e.g., heap leaching) may also have caused ground-water contamination because design and operational practices did not minimize seepage.

In the mid- to late-1970's, in situ solution mining of subterranean uranium ore bodies emerged as an alternative technology to recover uranium. This technology consists of installing injection and recovery wells in uranium ores below the water table, leaching uranium from the ore by injecting chemicals, pumping the uranium-bearing solution to the surface, and concentrating the uranium using processes similar to those used at conventional uranium mills. Although this technique eliminates the need to excavate and crush uranium ore, in situ solution mining occurs within ore zones that typically constitute aquifers prior to initiation of mining. Thus, ground-water quality is degraded within the ore zones until licensees restore the aquifers after mining.

The Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) provided EPA with authority to promulgate generally applicable environmental standards and NRC with authority to implement a regulatory program for uranium and thorium tailings management. In 1980, NRC promulgated regulations for management of mill tailings that required mills to control the effects of tailings solution seepage on ground-water quality through design and corrective actions (cf. 10 CFR Part 40, Appendix A). EPA promulgated final standards in 1983 for management of uranium mill tailings at both active sites (licensed sites as of 1978) and inactive sites (abandoned uranium processing sites). Consistent with trends in environmental protection, EPA's regulations for active uranium mills require more stringent protection of ground-water through detailed requirements for impoundment design, ground-water monitoring, and corrective action for ground-water contamination. These regulations require tailings impoundments to be designed, constructed, and operated in a manner that minimizes seepage of tailings solutions. As a secondary protection approach, the regulations provide for active monitoring and corrective actions in response to observed contamination. NRC is presently developing a proposed rule to conform its regulations to those promulgated by EPA for active uranium mills as provided by UMTRCA. As the first step in this process, NRC issued an Advanced Notice of Proposed Rulemaking on November 26, 1984, requesting comments on the Commission's approach to incorporate EPA's ground-water protection requirements for uranium mills (49 FR 46425). In addition, NRC is a concurring agency in decisions by the Department of Energy (DOE) to cleanup inactive uranium tailings sites to attain compliance with EPA standards.

At in situ uranium solution mines, NRC regulations and guidance provide for ground-water protection through a combination of ground-water quality monitoring, corrective action, and restoration. During operation of in situ mines, ground-water quality near ore zones is monitored to ensure that excursions of contaminated ground-water do not occur. If such excursions are detected, operators are required to implement corrective actions to restore ground-water quality outside of the leaching zone. After leaching ceases, operators restore ground-water quality within the leached zone and adjacent areas to its original quality or to within other appropriate limits.

Regulations and Regulatory Guidance

EPA and NRC regulations in 40 CFR Part 192 and 10 CFR Part 40, respectively, provide for ground-water protection from contamination associated with uranium recovery operations. EPA regulations for uranium tailings management at inactive sites are contained in 40 CFR Part 192, Subparts A through C. Subparts A and B provide standards for remedial actions and cleanup activities at 24 inactive uranium processing sites and contaminated vicinity properties. Although these regulations do not provide specific criteria for ground-water protection, Subpart C describes a methodology for systematically evaluating the hydrogeology of sites as a basis for selecting and implementing actions to restore and protect ground-water resources. Specifically, Subpart C recommends that site investigations determine background ground-water quality, rate and direction of contaminated ground-water migration, and extent of existing contamination. Based on these determinations, the guidance admonishes DOE, with the concurrence of NRC, to determine the need for remedial actions for ground-water protection from existing and potential contamination. If such a need is determined, the guidance provides that specific implementation of remedial actions consider the cost and technical feasibility of the actions, probability of human exposure to contaminants, and value of contaminated resources.

EPA is currently planning to develop new standards for ground-water protection at UMTRAP sites in response to a decision by the Tenth Circuit Court of Appeals. On September 3, 1985, the court concluded that EPA unlawfully delegated to DOE and to the states its own rulemaking authority by not promulgating generally applicable standards for ground-water protection. The court remanded the guidance relevant to ground-water protection in Subpart C of 40 CFR Part 192 and directed EPA to treat toxic chemicals that pose a ground-water risk as it did in the regulations for active uranium mill sites (40 CFR Part 192, Subpart D). EPA anticipates that the new standards will be consistent with both the active site standards and the numerical standards originally proposed for UMTRAP sites (Elkins, 1985).

The EPA methodology described in Subpart C has been generically adopted by DOE and NRC through the DOE-NRC Memorandum of Understanding for participation in the Uranium Mill Tailings Remedial Action Project. In concurring on DOE's plans for remedial actions at UMTRAP sites, NRC ensures that the actions comply with EPA's remedial action standards, including planned actions for prevention of ground-water contamination. Following remedial action, NRC will license the sites for long-term maintenance and surveillance.

Subpart D of 40 CFR Part 192 provides EPA regulations for active uranium processing sites. Ground-water provisions of these regulations incorporate by reference substantive portions of EPA regulations for hazardous waste management, including impoundment and liner design specifications (40 CFR Part 264.221), ground-water protection standards (§264.92), closure performance standards (§264.111), and corrective action requirements (§264.100). This collection of requirements provides a dual approach for ground-water protection. The primary approach is to prevent contamination through a liquids management strategy to minimize the volume of liquid available within impoundments and minimize seepage from the impoundments through design and operation. The secondary approach constitutes a phased monitoring and corrective action strategy, in which operators monitor ground-water quality and implement corrective actions to control detected ground-water contamination. As noted previously, NRC is currently revising 10 CFR Part 40, Appendix A to incorporate ground-water protection provisions contained in 40 CFR Part 192.

Relevant NRC regulations are contained in criteria 1, 2, 3, 5, 7, 9, 11, and 12 of Appendix A to 10 CFR Part 40. Criterion 5 provides that the quality of ground-water resources be protected from deterioration beyond their best current or potential uses. As described in the criterion, operators are required to protect ground-water through a combination of design and operational features, including installation of low-permeability liners, recycling of tailings solutions, dewatering of tailings, and neutralization of tailings solutions to promote immobilization of toxic and radiological contaminants. The other criteria provide for a variety of features that contribute to the protection of ground-water, including site selection, consolidation of waste sites, consideration of below-grade disposal, ground-water monitoring, financial assurance, site ownership, and long-term surveillance.

Since the late 1970's, NRC has developed regulatory guidance to aid uranium mill licensees in implementing the regulations. NRC is currently considering the need to develop additional guidance in light of pending revisions to 10 CFR Part 40, Appendix A. Table 1 describes existing regulatory guidance relevant to ground-water protection at active uranium mills and in situ solution mines. Although comparable guidance has not been specifically developed for the inactive uranium mill program (Uranium Mill Tailings Remedial Action Project - UMTRAP), the concepts and approaches described in the guidance listed in Table 1 may be applicable to UMTRA Project reviews. In addition, NRC has developed Standard Review Plans for NRC reviews of Remedial Action Plans developed by DOE, including a review plan for water protection aspects of DOE's planned actions to cleanup and control inactive uranium processing sites (NRC, 1985).

Technical Capabilities

The Low-Level Waste and Uranium Recovery Projects Branch in the Division of Waste Management administers NRC regulation of active uranium recovery operations and participation in the UMTRA Project. The Uranium Recovery Field Office (URFO) in Denver, Colorado, administers the daily regulation of active uranium recovery operations as a field extension of NRC Region IV. Although the Division of Waste Management develops and approves programmatic policies and regulations, URFO licenses, inspects, and approves activities of active uranium recovery operations within nonagreement states (see Chapter 6). The Low-Level Waste and Uranium Recovery Projects Branch of the Division of Waste Management discharges NRC responsibilities in the UMTRA project with functional support from the Geotechnical Branch (WMGT), Engineering Branch (WMEG), and URFO. Both Geotechnical Branch and URFO staff are presently reviewing DOE's planned actions for ground-water protection at UMTRA sites. After September 30, 1986, URFO will perform all reviews of ground-water protection at UMTRA sites.

Table 1 Regulatory guidance related to ground-water protection for active uranium mills and in situ solution mines

Regulatory Guides

"Guidelines for Modeling Ground-water Transport of Radioactive and Nonradioactive Contaminants at Tailings Disposal Sites," Draft Regulatory Guide ES 115-4, May 1983.

"Guidelines for Ground-Water Monitoring at In Situ Uranium Solution Mines," Draft Regulatory Guide ES 114-4, June 1983.

"Design, Construction, and Inspection of Embankment Retention Systems for Uranium Mills," Regulatory Guide 3.11, December 1977.

"Radiological Effluent and Environmental Monitoring at Uranium Mills," Regulatory Guide 4.14, April 1980.

"Hydrogeologic Characterization of In Situ Uranium Solution Mines," Draft Regulatory Guide ES 113-4, under development.

"Preparation of Environmental Reports for Uranium Mills," Regulatory Guide 3.8, October 1982.

"Standard Format and Content of License Applications for Uranium Mills," Regulatory Guide 3.5, November 1977.

"Standard Format and Content of License Applications, including Environmental Reports, for In Situ Uranium Solution Mining," Regulatory Guide 3.46, June 1982.

Staff Technical Positions

"Uranium Mill Tailings Management," Branch Position, Uranium Recovery Licensing Branch, May 1977.

"Design, Installation, and Operation of Natural and Synthetic Liners at Uranium Recovery Facilities," Staff Technical Position, Uranium Recovery Branch, 1981.

"Hydrogeologic Characterization of Uranium Solution Mines and Mill Tailings Disposal Sites," Branch Technical Position WM-8203, Uranium Recovery Branch, July 1982.

During Fiscal Year 1986, hydrogeologists and geologists in the Geotechnical Branch of the Division of Waste Management review and assess uranium recovery projects, including revision of NRC's regulations for uranium milling and participation in the UMTRA project. Additional hydrogeologists, geochemists, and geologists in the Geotechnical Branch may also support site-specific ground-water assessments. During the same period, hydrogeologists and geologists in the URFO review uranium recovery projects. Pacific Northwest Laboratory (PNL) consults for the Geotechnical Branch in the areas of geochemistry and contaminant transport. Oak Ridge National Laboratory and Williams and Associates provide technical assistance to URFO in hydrogeology for assessment of uranium recovery activities. At the conclusion of FY86, most staff working on uranium recovery projects within the Geotechnical Branch plan to shift their area of emphasis to low-level waste and high-level waste projects.

Current Activities

The Division of Waste Management is currently working on several activities relevant to ground-water protection at uranium recovery facilities, including (1) rulemaking to conform NRC regulations in 10 CFR Part 40 to the EPA standards in 40 CFR Part 192, (2) joint development with EPA of guidance for establishing Alternate Concentration Limits at active uranium mills, (3) preparation of Technical Evaluation Reports for water resources protection at UMTRAP sites, (4) technical assistance for modeling contaminant transport, (5) technical assistance for development of the computer code MIGRAT for simulating contaminant migration in variably-saturated porous media, and (6) development of regulatory guidance about ground-water protection at in situ uranium mines.

The NRC staff is currently developing a proposed rule to conform NRC's regulations in 10 CFR Part 40, Appendix A, to EPA's standards in 40 CFR Part 192. NRC published an Advanced Notice of Proposed Rulemaking on November 26, 1984, that requested comments on NRC's proposed approach to incorporate EPA's ground-water protection standards. Based on public comments and internal assessments, the staff has proceeded to develop a proposed rule. Following publication of the proposed rule, the staff plans on assessing public comments on the proposed rule and preparing final regulations accordingly.

EPA's regulations for active uranium processing sites require concentrations of contaminants to remain below regulatory limits established on a case-specific basis. Licensees may pursue less stringent limits, Alternate Concentration Limits, if it can be demonstrated that the contaminants will not pose a substantial hazard to humans or the environment provided the concentrations remain below the Alternate Concentration Limits at the edge of tailings impoundments. The NRC staff is working with staff and contractors of EPA's Office of Solid Waste and Emergency Response to develop a methodology for making such demonstrations based on the criteria listed for consideration in 40 CFR Part 264.94(b). Along with this methodology, EPA is developing case studies to illustrate satisfactory demonstrations for Alternate Concentration Limits, including one demonstration for an abandoned uranium tailings site.

As another ground-water protection activity in uranium recovery, NRC staff prepares detailed assessments of the hydrogeologic characteristics and reviews DOE's plans for remedial actions at UMTRA sites. The NRC staff documents decisions regarding the suitability of DOE's remedial action plans in Technical

Evaluation Reports (TERs). Draft TERs indicate inadequacies and uncertainties in DOE's plans that require additional analysis to remedy. When finalized at the time of NRC concurrence with DOE's plans, TERs document the basis for the concurrence decision with respect to ground-water protection on a site-specific basis. The TERs also document any deviations taken by the staff in reviewing DOE's plans from the review approach described in the Standard Review Plan. A complete TER has been completed for the UMTRA site at South Salt Lake, Utah, while others are being prepared for UMTRA sites at Shiprock, New Mexico; Riverton, Wyoming; and Lakeview, Oregon (cf. bibliography; Weber, 1985).

In support of NRC's assessment of ground-water contamination at active and inactive uranium recovery sites, NRC has contracted with Pacific Northwest Laboratory to develop conceptual models that describe geochemical interactions of ground-water contaminants with aquifer materials. Such information may be essential to estimate contaminant concentrations defensibly and to aid NRC in identifying geochemical data needs for uranium recovery sites. Descriptions of geochemical interactions may also be critical in the development of Alternate Concentration Limits described above. PNL is proceeding with model development in conjunction with analysis of laboratory and field information from uranium mill sites to develop realistic models that are validated based on field information.

NRC has also contracted Oak Ridge National Laboratory (ORNL) to develop the computer code MIGRAT to simulate contaminant migration from tailings impoundments through variably-saturated porous media. The code is an extension of the TRUST code, which was previously developed for NRC to model ground-water flow. ORNL has developed pre- and post-processing software to aid users in creating MIGRAT models and interpreting results. After the MIGRAT package is fully developed and implemented on NRC computer facilities, NRC staff plan to use the code to evaluate ground-water flow and contaminant transport in the vicinity of uranium mill tailings impoundments in support of licensing and generic assessments. MIGRAT may also be used by the staff to simulate potential contaminant transport at LLW sites.

The Division of Waste Management is presently preparing guidance on setting upper control limits for ground-water contaminants at in situ uranium solution mines. These upper control limits are applied at in situ mines to detect excursions of contaminated ground-water from the mining zone. Under contract to NRC, ORNL is preparing a summary of the history of excursions at selected in situ uranium solutions mines in the United States. This document (NUREG/CR-3967) discusses methodologies for identifying and controlling ground-water excursions. The preliminary draft of the document indicates that the solution mining industry is capable of monitoring and controlling lateral excursions of contaminated ground-water in ore-zone aquifers. The report also concludes that the incidence of vertical excursions can be significantly reduced by testing well field units through pressurization (i.e., injection of water without extraction) of the ore zone aquifer prior to injecting lixiviant.

Low-Level Radioactive Waste

Historical Perspective

Since the mid-1940's, operators of nuclear facilities have been generating and disposing of low-level radioactive wastes (LLW). As defined in the Low-Level

Radioactive Waste Policy Amendments Act of 1985, LLW means radioactive material that is not high-level radioactive waste, spent nuclear fuel, or tailings or wastes produced from the extraction or concentration of uranium or thorium from ores primarily processed for their source material content. Low-Level radioactive waste from nuclear fuel cycle facilities includes contaminated clothing, packaging, rags, ion exchange resins, filters, decontamination liquids, and detergents. Research and medical radioactive waste comprises a subordinate fraction of LLW.

Recognizing potential radiological hazards associated with solid LLW, the government began burying these wastes in shallow trenches or dumping them at sea to isolate the wastes from humans. Because land disposal was less controversial, most solid LLW was buried on land rather than at sea. Liquid LLW was discharged to streams and rivers.

Early land disposal sites were chosen for convenience and expediency, rather than geologic and hydrologic considerations. Even if water contacted the LLW and leached radionuclides, geochemical processes, such as ion exchange and sorption, were relied upon to attenuate the migration of radionuclides. The first commercial LLW burial sites began receiving wastes in the early 1960's. By the late-1960's and early 1970's, failures of the early sites to isolate LLW from the biosphere became apparent when radionuclides were observed in seepage and surface water emanating from the sites. Water that infiltrated through trench caps accumulated in trenches at Oak Ridge, Tennessee (federal facility), and West Valley, New York, until the trenches overflowed. Because the wastes were not uniformly compacted at the time of burial, differential subsidence after closure caused trench cover collapse that promoted infiltration (Fischer and Robertson, 1984).

Early monitoring programs were insufficient to detect all radionuclide migration from the trenches. Improved monitoring programs indicated radionuclide migration in ground-water was occurring much faster than had been predicted along three primary pathways: seepage through trench covers, lateral ground-water migration, and vegetation uptake of radionuclides. In addition, characterization of buried LLW indicated the presence of hazardous nonradiological contaminants, such as cleaning solvents and complexing agents.

Regulations and Regulatory Guidance

In response to growing public concern about shallow land burial of LLW, the U.S. Congress passed the Low-Level Radioactive Waste Policy Act of 1980. This act stated the Federal Government's policy that each State is responsible for providing for the disposal of LLW generated within its borders and that LLW can be most safely and efficiently managed on a regional basis. The Low-Level Radioactive Waste Policy Act also provided for state compacts for LLW disposal.

NRC promulgated regulations in 10 CFR Part 61 for LLW disposal in 1982. These regulations were based on the lessons learned during the first three decades of land disposal of LLW. The regulations provide for ground-water protection through minimization of leachate formation by avoiding prolonged contact between the wastes and infiltrated water. The regulations rely on siting requirements for ground-water protection to keep water away from the waste, to reduce the volume of contaminated water, and to provide long ground-water travel times sufficient for the decay of most radionuclides if they are released from LLW trenches.

NRC's regulations for commercial disposal of LLW provide for ground-water protection through the performance objective for protection of the general population in §61.41 and the technical requirements in Subpart D. The general population performance objective limits releases of radionuclides to ground-water and other transport media to concentrations that will not yield an annual dose in excess of 25 millirems (whole body), 75 millirems to the thyroid and 25 millirems to any other organ, to any member of the public. With respect to this objective, radionuclide concentrations in ground-water are limited at and beyond the site boundary because an individual could consume water from a well located immediately downgradient from the facility.

NRC's standards also rely on a combination of siting and design requirements that keep water away from LLW, result in low volumes of contaminated water, and provide for ground-water travel times to the biosphere that are long enough for many of the radionuclides contained in the waste to decay to acceptable levels. Site suitability requirements in 10 CFR Part 61.50(a) relevant to ground-water protection include the following provisions: (1) disposal sites shall be capable of being characterized, modeled, analyzed, and monitored; (2) disposal sites must provide sufficient depth to the water table to preclude ground-water intrusion into the waste, unless diffusion is the dominant process for contaminant migration away from the waste; and (3) aquifers and other hydrogeologic units beneath the site shall not discharge to the surface within site boundaries. Relevant design requirements in 10 CFR Part 61.51(a) include: (1) covers must be designed to minimize infiltration, to direct percolating water away from the disposed waste, and to resist degradation by geologic and biotic processes; and (2) disposal sites must be designed to minimize contact of percolating or standing water with wastes after disposal.

Unlike the uranium recovery program, EPA has not yet promulgated generally applicable environmental standards for the management and disposal of LLW. However, EPA is considering developing regulations for LLW management that are similar to regulations for hazardous waste management (48 FR 39563). As discussed in the regulations section for uranium recovery, EPA's standards for hazardous waste management provide a two-tiered approach for ground-water protection. The first tier of this approach requires disposal facilities to be designed, constructed, and operated to prevent migration of wastes. This is generally accomplished by installing synthetic liners beneath landfills. In contrast, NRC's regulations for LLW disposal require certain waste types to be contained individually (e.g., in LSA containers) and all waste (regardless of containment) to be emplaced in freely-drained trenches. NRC and EPA staff have mutually recognized the apparent conflict and are currently evaluating the adequacy of current approaches to provide for ground-water protection.

Application of EPA's second tier of the approach is generally consistent with NRC's regulations for LLW management. This second tier for ground-water protection at hazardous waste sites consists of progressive monitoring and corrective action, in which actions are implemented to correct contamination as described in 40 CFR Part 264.100. Similarly, in 10 CFR Part 61.53(b), NRC requires that LLW site operators plan for corrective measures if monitoring indicates that such measures are necessary to meet the performance objectives in Subpart C (10 CFR Part 61.40-44). Unlike EPA's regulatory programs for hazardous waste disposal, however, these corrective actions are not triggered by exceedences of specific concentration limits in ground-water. Consequently, NRC's regulations may not directly provide for ground-water protection from nonradiological and radiological contaminants, even though they do provide for protection of the public health and safety through the performance objectives and siting criteria.

NRC has developed a regulatory guide and several technical positions to implement the regulations in Part 61. This guidance is listed in Table 2. The most significant guidance with respect to ground-water protection at LLW disposal sites is contained in the Branch Technical Position on Site Suitability, Selection, and Characterization (NUREG-0902) and in the Technical Position Paper on Near-Surface Disposal Facility Design and Operation (1982). This guidance emphasizes the fundamental concepts described in Part 61, including suitable site selection and design to minimize contact between LLW and water. NRC may develop additional guidance about ground-water protection at LLW sites depending on current reviews of existing LLW sites and evaluations of the adequacy of NRC's regulations to provide for ground-water protection.

NRC also reviews and approves, as appropriate, applications to dispose of small quantities of LLW by disposing of the wastes on the site where they were generated. Applications for small quantity LLW disposal may also be approved for offsite disposal under certain conditions. Such applications are filed under the provisions of 10 CFR Part 20.302, primarily for one-time disposals of LLW. Since many of the applications entail burial of the waste in relatively shallow trenches, NRC staff reviews applications to ensure adequate protection of ground-water from waste disposal. The reviews focus, in part, on ground-water protection from the standpoint of protecting individuals who might extract ground-water immediately downgradient of the radioactive waste. NRC staff independently assesses potential impacts of ground-water contamination at these sites based on conservative assumptions of hydrogeologic parameters, source terms, and exposure variables (e.g., rate of ingestion and period of exposure).

Technical Capabilities

Technical capabilities for assessing ground-water protection at LLW disposal sites are primarily contained in the Division of Waste Management, with additional capabilities in the Division of Fuel Cycle and Material Safety in NMSS and the Division of Radiation Programs and Earth Sciences in RES. In the Division of Waste Management, the Low-Level Waste and Uranium Recovery Projects Branch (WMLU) provides project management for assessments of ground-water protection at LLW sites. Staff in the Hydrology Section of the Geotechnical Branch (WMGT) support WMLU by assessing hydrogeologic characteristics and performance of LLW disposal sites and developing LLW regulations and regulatory guidance. Additional review capabilities are supplied by the Geology/Geophysics and Geochemistry Sections of the Geotechnical Branch on an as needed basis. Staff in the Engineering Branch (WMEG) also contribute to ground-water protection projects through review and assessment of waste packaging and disposal facility design, construction, and operation.

Hydrogeologists in the Hydrology Section develop regulatory guidance, review current technology for LLW disposal, assess experiences at existing LLW disposal

Table 2 Regulatory guidance for low-level waste disposal based on 10 CFR Part 61

"Standard Format and Content of Environmental Reports for Near-Surface Disposal of Radioactive Waste," Regulatory Guide 4.18, June 1983.

"Site Suitability, Selection, and Characterization," Branch Technical Position, Low-Level Waste Licensing Branch, NUREG-0902, 1982.

"Near-Surface Disposal Facility Design and Operation," Technical Position Paper, Low-Level Waste Licensing Branch, 1982.

"Low-Level Waste Burial Ground Site Closure and Stabilization," Draft Position Paper, Revision 2, Low-Level Waste and Uranium Recovery Projects Branch, June 1984.

"Standard Format and Content of License Applications for Near-Surface Disposal of Radioactive Waste," Draft Branch Technical Position WM-005, Low-Level Waste and Uranium Recovery Projects Branch, March 1986.

sites, and review applications made to the NRC for LLW disposal activities. Additional WMGT staff may be applied to resolve other earth science and engineering issues related to ground-water protection at LLW disposal sites. Engineers and a hydrogeologist in the Engineering Branch (WMEG) review waste package design and performance, as well as LLW facility design, construction, and operation. WMEG and WMGT staff are involved in ground-water protection projects for LLW disposal on a project-specific basis. Project managers in the Low-Level and Uranium Recovery Projects Branch administer reviews of individual LLW disposal sites and development of regulatory guidance, such as staff technical positions and regulatory guides.

In cooperation with the Division of Fuel Cycle and Material Safety, Division of Waste Management staff also review applications for onsite disposal of LLW. Such applications are filed under the provisions in 10 CFR Part 20.302, which allow disposal of radioactive waste in nonconventional situations provided that the waste will not pose unacceptable risks to humans.

Current Activities

The passage of the Low-Level Radioactive Waste Policy Amendments Act of 1985 has required specific actions within the Division of Waste Management relevant to ground-water protection. Resultant activities include: (1) development of procedures and technical review capabilities for reviewing license applications for LLW disposal, (2) accelerated preparation of regulatory guidance on alternative methods for LLW disposal, and (3) development of guidance for petitions to declare wastes below levels of regulatory concern. In addition to these required activities, NRC is assessing ground-water conditions at sites used previously for LLW disposal and evaluating migration of nonradiological hazardous constituents at existing LLW disposal sites.

The Low-Level Radioactive Waste Policy Amendments Act of 1985 requires NRC to process and review applications for LLW disposal facilities within 15 months of their receipt. The NRC staff is currently developing procedures and technical review capabilities to prepare for receipt of license applications with the intent of accomplishing this statutory objective. Preparations include the development of a Safety Evaluation Report for a hypothetical shallow land burial site for LLW disposal. Based on this evaluation and 10 CFR Part 61, the staff will develop a Standard Review Plan that will provide uniform procedures for consistent reviews of license applications for LLW disposal facilities. Concurrent with these activities, the staff is preparing a Standard Format and Content Guide for license applications and accompanying Environmental Reports. This guide will describe acceptable types and amounts of information to be contained in applications for LLW disposal licenses. Because of the importance of ground-water protection from land disposal activities, each of these projects will focus in part on appropriate design, construction, operation, and monitoring of LLW disposal facilities, as well as hydrogeologic site characterization.

Several states are currently assessing alternative methods for storage and disposal of LLW because of inadequate protection of ground-water provided by early shallow land burial sites for LLW. Based on experiences at older LLW shallow land burial sites such as West Valley and Oak Ridge, states have begun considering alternatives to shallow land burial. These alternatives include above-ground storage in concrete tumuli or bunkers, mined cavity disposal, and shallow land burial enhanced by engineered features. NRC is currently developing guidance about information needs and assessment procedures for licensing reviews of these alternative approaches for LLW disposal. In addition to any special performance objectives that may be developed for these alternatives, disposal facilities that implement these alternatives will also be required to comply with the siting requirements in 10 CFR Part 61. Because ground-water may be a significant pathway for contaminant migration from LLW disposal sites, this guidance focuses, in part, on ground-water protection afforded by alternatives to shallow land burial.

NRC staff is currently assessing whether some LLW may be safely disposed of through techniques other than shallow land burial or similar techniques for long-term containment. Such types of wastes may be generically classified as "below regulatory concern." This assessment considers potential impacts of low concentration wastes disposed of by such methods as landfilling and incineration. Radiological doses from ground-water contamination resulting from these methods will be a primary consideration in evaluating petitions to exempt waste streams as being below NRC regulatory concern.

The NRC staff is currently assessing older commercial LLW disposal sites that have contaminated ground-water. The objective of these assessments is to determine what inadequacies of siting, design, and operation contributed to the contamination. Lessons learned from these assessments of previous contamination will be used to improve ground-water protection programs at LLW disposal sites. Because ground-water contamination has been observed at older sites, alternative disposal methods that rely more strongly on engineered barriers may appear more effective in protecting ground-water than shallow land burial has been in the past. Shallow land burial sites that have caused ground-water contamination, however, were constructed and operated without the requirements imposed by 10 CFR Part 61. In addition, requirements in Part 61 were specifically formulated to avoid problems observed at older sites. Thus, LLW shallow land burial in conformance with the Part 61 requirements should be more effective in protecting ground-water, despite disappointing performance of LLW sites operated in the 1950's, 60's, and 70's.

Disposal of LLW that contains hazardous nonradiological wastes has stimulated concerns about potential contamination of ground-water at LLW sites by nonradiological constituents. Because of existing limitations of its statutory authority, NRC has not specifically regulated nonradiological constituents at LLW sites other than requiring that the wastes be treated to minimize their nonradiological hazardous characteristics (§61.56(a)(8)). Concerns about mixed wastes stem from differences between NRC's regulatory approach for LLW management and EPA's approach for hazardous waste management. The NRC staff is evaluating this concern by (1) identifying hazardous constituents in LLW streams and (2) assessing nonradiological contamination of ground-water at LLW disposal sites. Based on ground-water monitoring results, it appears that LLW disposal sites at Sheffield and Barnwell have caused nonradiological ground-water contamination (NRC, 1986a). Interpretations of ground-water monitoring data at these sites are complicated, however, by potential contamination caused by other activities, such as hazardous waste disposal near Sheffield and gasoline storage at Barnwell. The evaluation has also indicated that mixed wastes comprise a small percentage (e.g., 2-3%) of the total volume of LLW generated annually and that LLW generators have modified processes to reduce the amount of hazardous materials in LLW (Bowerman et al., 1985). In addition, the siting, design, and operation of the older LLW disposal sites where contamination has been observed did not comply with the requirements of 10 CFR Part 61. Thus, ground-water contamination by nonradiological hazardous constituents at older sites probably does not represent the performance of newer sites operated in compliance with Part 61. NRC staff is also evaluating the need for additional requirements to assure ground-water protection from both radiological and nonradiological contamination at LLW sites.

High-Level Radioactive Waste

Historical Perspective

Ground-water transport is considered the most significant post-closure pathway of potential radionuclide migration from high-level radioactive waste (HLW) repositories to the biosphere. Unlike low-level and uranium recovery wastes, commercial HLW has not been disposed of in the United States. Thus, a historical perspective of HLW disposal does not provide examples of disposal activities that failed to protect ground-water resources as with uranium recovery and low-level wastes. Rather, the history of commercial HLW management provides insight into public concerns and technical issues about HLW disposal. The term HLW includes spent fuel direct from commercial power reactors, as well as more concentrated radioactive wastes containing fission products produced from reprocessing spent fuel. Because of its high radioactivity and longevity, HLW must be isolated from the biosphere for tens to hundreds of thousands of years.

During and immediately after World War II, U.S. defense programs produced the first significant quantitites of HLW as a byproduct of atomic weapons production. Commercialization of nuclear power in the mid-1950's increased the number of operating reactors and, consequently, the amount of spent fuel and its rate of generation. During the 1950's and 1960's, the nuclear industry and federal government paid little attention to disposal of HLW because of the philosophy that existing technology would be sufficient to dispose of the wastes safely (Hewlett, undated). The need for a viable permanent disposal facility for long-lived radioactive wastes was recognized in 1969, however, when a fire at the weapons component facility at Rocky Flats, Colorado resulted in large volumes of materials contaminated with plutonium.

This recognition led to the selection of the Carey Salt Mine at Lyons, Kansas, as the first candidate repository for HLW. Effects of HLW disposal on salt had been studied at the Carey Mine several years prior to its nomination in 1970. The project to dispose of HLW at Lyons was abandoned two years later, however, in response to public outcry and two hydrogeologic issues: (1) potential migration of radionuclides through unplugged boreholes that had been drilled through the salt for exploration and development of the mine, and (2) anomalous disappearance of a large volume of water injected into a salt mine nearby (OTA, 1985).

Since 1975 the federal government has pursued several alternatives for HLW storage and disposal. The focus of these alternatives has been on the development of deep mined geologic repositories for commercial HLW disposal as part of the National Waste Terminal Storage (NWTS) program. The passage of the Nuclear Waste Policy Act of 1982 (NWPA) reaffirmed this focus by establishing a comprehensive program for selection, characterization, and construction of repositories. In addition to repository activities, NWPA charged DOE with the responsibility to study the need for Monitored Retrievable Storage (MRS) for HLW prior to its disposal in a repository. DOE is presently evaluating sites for the first respository and screening potential areas for a second repository.

Regulations and Regulatory Guidance

The Nuclear Waste Policy Act of 1982 defines the authority and responsibilities of the three primary federal agencies involved with permanent disposal of HLW: DOE, EPA, and NRC. The primary purpose of NWPA was to establish a focused program to dispose of HLW using deep mined geologic repositories. Under the Act, DOE is required to recommend potential HLW repository sites for site characterization. After approval of site recommendations by the President, DOE will initiate detailed studies to characterize the sites and determine the viability of repository construction and operation. Based on site characterization information, DOE will then select a site for the first commercial HLW repository and submit a license application for authorization of construction to the NRC. The earliest application is expected in 1990. Prior to DOE's license application, NRC consults with DOE to avoid significant delays in the HLW disposal program that may arise because of misinterpretations of NRC's regulations and substantial omissions and oversights of DOE's characterization program.

NWPA directs EPA to promulgate generally applicable environmental standards for protecting the environment from releases of radioactive material from mined geologic repositories. EPA promulgated final standards for HLW disposal in 1985 in 40 CFR Part 191 (50 FR 38084). With respect to ground-water protection, the standards provide three performance objectives for safe disposal of HLW. The first objective (§191.13) restricts cumulative releases of radionuclides from the repository to the biosphere. The second objective (§191.15) prohibits the exceedance of specified doses to individuals, including consumers of ground-water from wells near the repository. Both of these objectives indirectly protect ground-water at a distance from the repository because their compliance requires that radionuclide concentrations be limited in ground-water that may be contaminated by releases from the repository. In contrast, the third objective (§191.16) protects ground-water quality directly by prohibiting exceedances of concentration limits for radionuclides released from the repository in special sources of ground-water near the repository. EPA defines special sources of ground-water consistent with its Groundwater Protection Strategy (EPA, 1984). In addition, the standards provide criteria for determining significant sources of ground-water (as opposed to special sources), such as a minimum transmissivity of 200 gpd/ft^2, maximum total dissolved solids concentration of 10,000 mg/l, and a maximum depth of 2500 feet.

The Nuclear Waste Policy Act directs NRC to promulgate requirements and criteria to apply in approving or disapproving repository license applications. NRC's regulations for HLW disposal in geologic repositories are contained in 10 CFR Part 60. These regulations are currently being revised to conform with the final EPA standards. As required by NWPA, NRC's and EPA's regulations provide for the use of a system of multiple barriers in the design and siting of repositories. In addition to providing siting criteria, 10 CFR Part 60 stipulates performance objectives and operational requirements consistent with the multiple-barrier approach. Relevant to ground-water protection, the regulations incorporate the EPA standards discussed above and an additional performance objective in §60.113 that the ground-water travel time from the disturbed zone around the repository to the accessible environment exceed 1,000 years. Thus, the regulations protect ground-water resources beyond the boundary of the accessible environment for at least 1,000 years, or such other period as the Commission may specify or approve. The disturbed zone is the portion of the repository system that is significantly perturbed by the construction of the repsoitory or the emplacement of the HLW. The boundary of the accessible environment includes the land surface, surface water bodies, and ground-water beyond a maximum lateral distance of 5 kilometers from the repository.

In addition, NRC's regulations also provide for protection of ground-water between emplaced waste and the accessible environment through performance objectives for waste package containment and releases from the repository. Regulations in §60.113(a)(1) require that HLW waste packages substantially contain waste for 300 to 1,000 years. NRC's regulations in §60.113(a)(1) also prohibit releases from waste packages and packing materials above an annual release rate of 1 part in 100,000 based on the radionuclide inventory at 1,000 years. In combination, these requirements protect ground-water near the repository by containing waste for a sufficient period of time to allow many of the high specific activity radionuclides to decay to low levels and by restricting the rate of release to ground-water after waste packages begin to fail.

NRC's regulations in 10 CFR Part 60 also provide siting criteria that are used to assess the desirability of choosing a particular site for HLW disposal. These criteria are classified into groups of favorable conditions and potentially adverse conditions. The conditions relevant to ground-water protection, listed in Table 3, qualitatively determine the natural capacity of a site to protect ground-water resources by isolating the HLW for the long time periods required to allow for natural decay of radionuclides to less pernicious concentrations.

In addition to ground-water protection through regulations, NWPA specifically recognizes the importance of water resources near sites considered for HLW disposal. Section 124 of the Act requires DOE to consider whether purchasing of water rights near a repository may adversely affect the development of an area near the repository. DOE may need to acquire water rights to site, construct, and operate a repository. Most of the sites being considered by DOE for the first HLW repository are located in western states, where water availability directly influences development potential. Section 124 reflects Congress' concern that the acquisition of water rights to develop the repository should not adversely affect the potential development of the region surrounding the repository. NWPA directs DOE to implement appropriate measures to mitigate any adverse impacts caused by water rights acquisition.

NRC is currently developing regulatory guidance to aid DOE in identifying the types of information that the staff considers will be necessary for defensible licensing of a repository. This regulatory guidance is provided in several primary forms including detailed reviews of DOE's site assessments, Regulatory Guides, and Staff Technical Positions. To date, NRC has developed two technical positions that primarily address aspects of ground-water protection: (1) Draft BWIP Site Technical Position 1.1 on Hydrologic Testing (12/83) and (2) Draft Generic Technical Position on Groundwater Travel Time (6/86). Examples of regulatory guidance that address aspects of ground-water protection in addition to other topics include NRC's Draft Site Characterization Analysis of the BWIP Site (4/83), Issue-Oriented Site Technical Positions (9/84), and other generic

Table 3 Siting criteria relevant to ground-water protection from high-level radioactive waste disposal (paraphrased from 10 CFR Part 60.122)

Favorable Conditions

- Hydrogeologic processes that would not affect or would favorably affect the ability of the repository to isolate the waste

- For disposal in the saturated zone, favorable hydrogeologic characteristics, including

  - host rock with low vertical and horizontal permeability
  - downward or dominantly horizontal hydraulic gradients in host rock and surrounding units
  - low vertical permeability and hydraulic gradient between host rock and surrounding units

- For disposal in the unsaturated zone, favorable hydrogeologic characteristics, including

  - low moisture flux through the host rock
  - water table sufficiently below the underground facility
  - laterally extensive, low-permeability units overlying the host rock
  - freely-draining host rock
  - climate in which precipitation is a small fraction of potential evapotranspiration

- Pre-waste emplacement ground-water travel times to the accessible environment substantially in excess of 1,000 years

Potentially Adverse Conditions

- Potential human activities that adversely affect the ground-water flow system

- Potential natural phenomena that would create large surface impoundments that could change the regional ground-water flow system

- Structural deformation that may adversely affect the regional ground-water flow system

- Potential changes in hydrologic conditions that would affect radionuclide migration to the accessible environment

- Potential climatic changes that would change hydrologic conditions

- Presence of ground-water resources of greater value than surrounding areas or whose extraction is currently or potentially feasible

Table 3 (Continued)

Potentially Adverse Conditions

- Evidence of drilling on the site for any purpose.
- Ground-water conditions that would require special engineering measures in repository design and construction.
- Potential water table rise to saturate the underground facility.
- Potential perched water bodies that may saturate the underground facility or provide faster flow paths to the accessible environment from an underground facility in the unsaturated zone.
- Potential migration of radionuclides in a gaseous state through unsaturated media to the accessible environment.

technical positions including Borehole and Shaft Sealing (2/86) and In Situ Testing during Site Characterization (12/85). As new information is learned about repository sites under consideration, NRC will continue to develop regulatory guidance to ensure effective and timely resolution of potential licensing issues (NRC, 1986b).

Technical Capabilities

Hydrogeologists in the Geotechnical Branch of the Division of Waste Management review DOE's site characterization activities and support development of regulations and regulatory guidance. Hydrogeologic projects include assessing hydrogeologic characterization data and plans, formluating conceptual and mathematical models of ground-water flow and radionuclide transport, reviewing technical documents that present DOE's positions, and preparing regulatory guidance on matters related to ground-water protection. These hydrogeologists work in teams with geologists, geochemists, rock mechanics engineers, mining engineers, and performance analysts to address interdisciplinary issues inherent in assessments of sites for HLW disposal. Staff in the Repository Projects Branch manage the HLW projects conducted within the Geotechnical Branch.

Supporting the staff hydrogeologists, three consulting firms complement the expertise and capabilities of the NRC team by assisting reviews of hydrologic testing plans and results, models of repository performance, and quality assurance programs. These consultants include Nuclear Waste Consultants, Williams and Associates, and Sandia National Laboratory. NRC staff assign short- and long-term technical assistance projects to the consultants ranging from technical document reviews to development and execution of mathematical models of ground-water flow and contaminant transport. In addition, the capabilities of the staff hydrogeologists are enhanced by staff members in the Office of Nuclear Regulatory Research, who occasionally contribute to staff assessments and who manage confirmatory research projects.

Current Activities

In early 1985, NRC staff reviewed nine Draft NWPA Environmental Assessments (EAs) that DOE prepared in support of site nomination. The staff will review the final EAs in 1986 to determine how DOE responded to major comments on the draft EAs by NRC. Of the major comments prepared by the staff review in 1985, several comments identified concerns about DOE's estimation of ground-water travel time and characterization of hydrogeologic conditions. For example, at the Hanford Site in southcentral Washington, staff reviews questioned the validity of ground-water travel times in flood basalts that substantially exceeded 10,000 years because of limitations in the knowledge of the hydrogeologic characteristics. At the Davis Canyon site in southeastern Utah, the reviews identified concerns about the direction of hydraulic gradients that determine, in part, ground-water velocities. In addition to major comments such as these, the staff reviews identified a series of more-detailed comments relevant to ground-water protection, ranging from concerns about geologic structure to radionuclide transport.

Review of DOE's Site Characterization Plans for sites approved by the President constitutes the next major milestone of NRC's participation in the HLW program. These plans describe DOE's current understanding of site hydrogeology and present

DOE's assessment of information needs, strategies, testing methods, analytical methods, and quality assurance plans for collecting and analyzing information necessary to license the site. In preparation for NRC review of these documents, the staff is reviewing available site information, identifying issues needing resolution, and preparing regulatory guidance. As part of ongoing pre-licensing consultations with the DOE, the NRC staff is evaluating the status of DOE's efforts to demonstrate compliance with NRC regulations in 10 CFR Part 60. The objective of these evaluations is to identify unresolved issues and information needs. These activities are partially accomplished through detailed document reviews and participation in public meetings between DOE and NRC. In hydrology, current issues range from definition of critical parameters such as effective porosity to acceptable analytical approaches for determination of ground-water travel times.

With respect to regulatory guidance, NRC is completing a generic technical position on the staff's interpretation of the ground-water travel time performance objective in 10 CFR Part 60.113. The position describes a suitable stochastic approach for demonstrating compliance with the 1,000-year ground-water travel time criterion. This guidance should help DOE in identifying site information needs and in formulating approaches for repository performance assessment. The staff expects to notice the availability of the Groundwater Travel Time Technical Position in the Federal Register in 1986, following the issuance of proposed amendments to 10 CFR Part 60 to conform NRC regulations with EPA's HLW standards.

Uranium Fuel Cycle Facilities

Similar to the history of uranium milling in the United States, operators of commercial fuel cycle facilities have grown aware of the need for ground-water protection. These facilities have impounded large volumes of process solutions to avoid offsite releases of radioactive effluents. Although the need for lining such impoundments is apparent today, older impoundments were not lined to prevent seepage and the resulting ground-water contamination.

The light-water reactor (LWR) uranium fuel cycle includes the following activities: uranium mining and milling, uranium hexafluoride (UF_6) conversion, isotopic enrichment, uranium oxide (UO_2) fuel fabrication, reactor operation, storage and transportation of fresh and spent fuels, and disposal of spent fuels. For the purpose of this discussion, fuel cycle facilities are restricted to UF_6 conversion and UO_2 fuel fabrication. Reactor operation, spent fuel disposal, and LLW generation are discussed elsewhere in this report. In addition, the NRC does not license isotopic enrichment facilities or uranium mining, unless the mining is performed in conjunction with uranium milling such as in situ solution mining.

There are two primary processes to convert yellowcake (concentrated uranium salts) from uranium mills to UF_6: a dry process and a wet process. The dry process produces UF_6 through reduction, hydrofluorination and fluorination in fluidized bed reactors, and then fractional distillation of crude UF_6. The wet process produces a more refined product by first using solvent extraction to purify the uranium prior to reduction and the other steps of the dry process. Unlike the dry process, the wet process produces large quantities of liquid effluents with high concentrations of nitrate, fluoride, uranium, and other constituents. Because they cannot practically be released to surface water, some of these effluents have been stored in large unlined surface impoundments at the facilities. Of the two commercial UF_6 conversion facilities, the one that uses the wet process has caused some ground-water contamination beneath and downgradient from the site.

The 16 fuel fabrication plants in the United States also produce liquid effluents that may contaminate ground-water if improperly managed. The most common process for converting UF_6 to UO_2 is the ammonium diuranate (ADU) process. The ADU process consists of hydrolysis, reaction of UO_2F_2 with ammonium hydroxide to precipitate ADU, filtration of ADU, and heating (calcining) of ADU with steam and hydrogen to form UO_2. Similar to the UF_6 conversion process, the ADU process generates liquid effluents that contain high concentrations of nitrate, fluoride, calcium, uranium, and other constituents. These effluents are stored onsite in lined and unlined surface impoundments.

Recognizing the potential for ground-water contamination, the NRC has required through licensing actions fuel cycle licensees to decommission unlined impoundments and has encouraged construction of new impoundments with synthetic liners and leachate detection systems. Groundwater monitoring at facilities with lined impoundments indicates that even lined impoundments may cause ground-water contamination. Because liquid effluents must be eliminated prior to final reclamation and decommissioning of the facility to accomplish long-term stability, the NRC staff has encouraged licensees to consider alternative processes that decreased the generation of or eliminate hazardous radiological and nonradiological effluents, thus reducing the risk of ground-water contamination. For example, substitution of the dry process of UF_6 conversion for the wet process may be desirable because the dry process generates smaller quantities of liquid effluents. At the conversion facility using the wet process, the licensee has initiated a program to irrigate grasslands with liquid effluents to increase evaporation and transpiration of the water and decrease the available hydraulic head that promotes seepage from waste impoundments.

NRC ground-water protection efforts are hampered at fuel cycle facilities, however, by ambiguity about regulatory responsibility for nonradiological contaminants such as nitrate and fluoride. NRC encourages licensees to control groundwater contamination by nonradiological contaminants to prevent radiological releases and minimize environmental impacts under general authority of the National Environmental Policy Act (NEPA). NRC has established action levels for ground-water contamination at fuel cycle facilities (e.g., 10 mg/l for nitrate (as N)) because migration of nonradiological contaminants is generally viewed as a precursor to migration of radiological contaminants. At sites above aquifers containing good quality ground-water, NRC considers the drinking water quality criteria from 40 CFR Part 141 as appropriate limits to potential groundwater contamination. Based on the migration of nonradiological constituents detected by ground-water monitoring, NRC requires corrective action to prevent significant radiological contamination. State regulatory agencies claim control over non-radiological contamination, however, under authority granted by the Resource Conservation and Recovery Act (RCRA), Safe Drinking Water Act (SWDA), and other federal and State statutes. State enforcement of corrective actions for non-radiological contamination of ground-water is hampered because of dubious legal authority to control fuel cycle facilities because their effluents contain radioactive materials regulated by NRC under the Atomic Energy Act. As a result of dual regulatory controls between States and NRC, licensees are often reluctant to implement corrective actions without full approval and enforcement by both State and federal regulatory agencies.

Regulatory guidance relevant to ground-water protection at fuel cycle facilities includes Regulatory Guide 4.16 and a Branch Technical Position on decommissioning limits for contaminated soils. Regulatory Guide 4.16 provides guidance on the design and evaluation of synthetic liner and leak detection systems for surface impoundments. The Branch Technical Position provides maximum concentration limits for radionuclides in soil contaminated by accidental spills and discharges of uranium fuel cycle effluents. Uncontrolled soils containing concentrations of contaminants above those identified in the position may cause ground-water contamination by leaching.

Staff in the Division of Fuel Cycle and Material Safety review licensee proposals for impoundment designs, ground-water monitoring programs, corrective actions, and other aspects relevant to ground-water protection at fuel cycle facilities. A consulting hydrogeologist with many years experience with fuel cycle operations provides technical assistance to the NRC staff on ground-water issues. In addition, staff in the Division of Waste Management and Office of Nuclear Regulatory Research aid in staff reviews on an as-needed basis.

Well Logging

In addition to established NMSS programs for ground-water protection, the Commission proposed regulations in 10 CFR Part 39 on April 8, 1985, for control of radioactive well-logging activities (50 FR 13797). Although such activities had been controlled previously by NRC, the staff identified the need to propose new comprehensive and consistent regulations applicable to well-logging operations. The regulations proposed in Part 39 provide requirements for licensing equipment control, radiation safety security, records, and notification. Three provisions of the proposed regulations are directly relevant to ground-water protection: stabilization requirements for irretrievable well-logging sources (§39.15), prohibition of radioactive tracer studies in fresh water aquifers (§39.45), and restrictions on the use of sealed sources in wells without surface casing (§39.51).

In accordance with Section 39.15, licensees would be required to make reasonable attempts to recover sealed, radioactive well-logging sources that may lodge in wells and to prevent recovery operations that may damage the integrity of the sealed source. If the sealed source is irretrievable, Part 39 would require licensees to immobilize and seal irretrievable sources with a cement plug, to install a whipstick or other drilling deflection device above the immobilized source, and to mark the location of the irretrievable source permanently at the well surface. These actions are required to minimize inadvertent releases of radioactive materials in the sealed source during and after attempts to recover the logging source. Without such measures, future drilling activities may damage the integrity of the sealed source, thus releasing radionuclides to drilling fluids and the general environment. Similarly, humans could ingest water contaminated by a damaged radioactive source if the borehole was not closed properly prior to abandonment.

In addition, the regulations proposed in Part 39 would restrict the use of radioactive tracers in fresh water aquifers and sealed cooling sources in uncased wells. Section 39.45 would prohibit injection of licensed radioactive material into fresh water aquifers, unless the licensee is specifically authorized to do so by the Commission. Section 39.51 would also prohibit the use of sealed logging sources in wells without surface casing designed to protect fresh water aquifer zones, unless the Commission specifically approves procedures for protecting these zones. These proposed regulations provide for protection of groundwater resources to minimize the possibility that fresh water aquifers would be contaminated by tracer injection or accidental releases from sealed sources.

After promulgation by the Commission, well logging activities under 10 CFR Part 39 will continue to be regulated by NRC staff in the Fuel Cycle Division at Headquarters and in the NRC Regional Offices. The staff currently expects promulgation of the regulations in calendar year 1986.

Chapter 3: GROUND-WATER PROTECTION PROGRAMS OF NRR

The Office of Nuclear Reactor Regulation (NRR) has developed requirements for protection of the public health and safety and the environment from radionuclide releases to ground-water. These requirements indirectly provide for protection of ground-water resources by minimizing potential releases of contaminants through redundant designs and controlled operation. NRR staff evaluates ground-water resources underlying nuclear power plants in both the staff's Environmental Statements (ESs) and Safety Evaluation Reports (SERs).

Since 1980, the primary ground-water concern in the ESs has been analysis of Class 9 accident liquid pathways. This is an analysis of the consequences (often by comparison with a generic site) that would result if a core-melt accident would release radionuclides to ground-water beneath a reactor. Another major ground-water concern has been the effect of onsite pumping of ground-water on the quantity and quality of ground-water pumped offsite. The third major concern is the effect of cooling reservoirs and impoundments on ground-water quality and water levels.

Groundwater data in SERs are used to verify the applicant's design basis ground-water level, which is the highest elevation that the water table may be expected to rise to during the life of the plant. This level is most often used to determine ground-water-induced loads on subsurface portions of safety-related structures. The staff also analyzes the consequences of postulated liquid radioactive material spills in SERs, which requires collection and analysis of ground-water data. For this analysis, the staff evaluates hydrogeologic parameters as well as attenuative properties of affected porous media to estimate maximum radionuclide concentrations at nearby public water supplies that may result from postulated accidents.

Class-9 Accident Evaluation

Following the accident at Three Mile Island in 1979, NRR hydrologists evaluated the feasibility of containing contaminated ground-water onsite and the potential for contaminant migration offsite (Nicholson, 1979). Since this accident, NRR ground-water-related activities have focused almost entirely on evaluating Class 9 accidents in ESs through technical assistance contracts, publication of NUREGs, and issuance of SRPs (or ESRPs). The "Liquid Pathway Generic Study" (NUREG-0440), which was published in February 1978, is the most comprehensive study to date performed by the staff of liquid pathway consequences from a core-melt accident. NRR staff performed this study to compare the consequences of a core-melt accident at a floating nuclear plant with those from a land-based plant.

Since July 1980, the staff has evaluated radiological exposure pathways to man (including ground-water) from postulated core-melt accidents in environmental statements. Procedures for addressing the consequences of ground-water pathway releases have been under development by the staff during the period since July 1980. These procedures were recently published in the "Environmental Standard

Review Plan for ES Section 7.1.1, Environmental Impacts of Postulated Accidents Involving Releases of Radioactive Materials to Ground-Water" (NUREG-1165). This NUREG lists the type of information that the staff evaluates and highlights useful references for the evaluation. It also provides procedures for consistent staff reviews of applicant analyses of radiological impacts of releases to ground-water. "Simplified Analysis for Liquid Pathway Studies" (NUREG-1054) provides procedures for calculating doses to humans and for making comparison with generic sites, including a computer code for transport analysis.

A core-melt accident could result in releases of radioactive contaminants to ground-water. In order to protect regional water supplies, isolation of the ground-water underlying the failed reactor building would be necessary. NRR staff identified installation of bentonite slurry walls as a possible means of isolating contaminated ground-water and awarded a contract to Argonne National Laboratory, to determine the feasibility of using slurry walls. Results of the Argonne study were published in May 1982 in the report entitled "Accident Mitigation: Slurry Wall Barriers." In a follow-up study, Argonne investigated alternative methods for isolating and controlling contaminated ground-water, including (1) ground-water freezing, (2) aquifer dewatering, (3) water injection, (4) recovery drain systems, (5) recovery well systems, (6) grouting, and (7) sheet piling. In September 1982, Argonne submitted their follow-up report entitled "Accident Mitigation: Alternative Methods for Isolating Contaminated Groundwater." Although these investigations showed that some of the methods could be effective in isolating contamination, the report concluded that the performance of mitigative measures is highly dependent on site-specific factors.

Determination of Design Basis Ground-water Level

Groundwater levels are a necessary input to structural and geotechnical reviews of nuclear power plants. Not only is the highest possible water level important for structural analysis, but water levels are also required for consideration of other external factors such as slope stability and liquefaction potential.

Guidance to applicants for evaluating subsurface hydrostatic loads on structures was first provided in the 1972 publication of the "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants." Although, "A Guide For the Organization and Contents of Safety Analysis Reports," published by the AEC in 1966 mentioned parameters for radionclide transport analysis, maximum ground-water levels and the resulting loads were not addressed. Review procedures for the NRC staff were first described in Section 2.4.13 of the Standard Review Plan (SRP) (NUREG-75/987, 11/24/75). The SRP described ground-water information requirements for determination of the design basis ground-water level. Evaluation of dewatering systems was only briefly mentioned. Beginning in 1975, the staff reviewed seven plant sites with safety-related dewatering systems. Due to the complexity of issues associated with such systems, NRR staff wrote a Branch Technical Position (BTP) entitled "Safety-Related Permanent Dewatering Systems," HGEB-1 (formerly HMB/GSB-1). The BTP addressed issues such as estimating and confirming permeability values, operational monitoring requirements, overloading of the dewatering system from pipe breaks, and single failure criteria.

Determination of Radionuclide Transport Characteristics

The 1966 AEC publication described above also recognized the potential for contamination of ground-water by releases of radioactive materials at nuclear power plants. Relevant to ground-water protection, the guide required:

(1) "The absorption and drainage characteristics of water in surface and underground areas, and the depths, estimated direction, and rates of flow of underground waters."

(2) "The characteristics of wells within the area, including depths and yields wherever nearby wells are an important source of water for human consumption or for agricultural purposes."

Later versions of the "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants" and Standard Review Plans provided more details regarding specific data requirements. Present requirements call for information such as estimates and justification for coefficients of dispersion, adsorption, ground-water velocities, travel times, gradients, permeabilities, and porosities. Piezometric levels between the site and existing or known future surface and ground-water users should be described and be consistent with site characteristics. Potential pathways of contaminant transport to ground-water users should also be identified.

In 1980, the American Nuclear Society (ANS) published "The American National Standard for Evaluation of Radionuclide Transport in Ground Water for Nuclear Power Sites," ANSI/ANS 2.17. This standard provides detailed guidance for obtaining information required in the SRP. For example, it contains a "Definitions" section of ground-water terms, specifications for ground-water monitoring programs, and mathematical equations for estimating radionuclide concentrations under various hydrologic conditions. Although the draft of this guide is referenced in the 1981 revision of the SRP, it has yet to be adopted as a part of a Regulatory Guide or SRP.

Ground-water Supply for Nuclear Power Plants

The requirement that wells supplying a safety-related source of water be of seismic category I design has generally discouraged the use of ground-water as a safety-related water supply. However, "The American National Standard for Evaluation of Ground Water Supply for Nuclear Power Sites," ANSI/ANS 2.9-1980, was published in April 1980 along with ANS 2.17. This standard provides detailed guidance for assessing ground-water availability and well reliability from a hydrologic standpoint. Similar to ANSI/ANS Standard 2.17, Standard 2.9 has not yet been incoporated into Regulatory Guides or SRPs.

Nonradiological Ground-Water Aspects of EIS Preparation

NRR staff reviews potential environmental impacts of nuclear power plant construction and operation under the National Environmental Policy Act of 1969 (NEPA). These reviews are conducted in accordance with the Environmental Standard Review Plan (ESRP) published in May 1979 as NUREG-0555. ESRP Section 2.3.1 provides guidance for preparing hydrologic descriptions in the ES and ESRP 4.2

provides guidance for preparing ES sections on Water Use Impacts and the Impacts Due to Hydrologic Alterations. Both of these ESRP sections require that ground-water impacts be assessed. Because of the wide variety and generally minor nature of nonradiological ground-water impacts related to nuclear power plant construction and operation, no explicit guidance has been developed for assessing potential nonradiological impacts on ground-water quality. Some of the various ground-water related nonradiological impacts that NRC has assessed in the past include monitoring for salt water intrusion, tile field flooding due to a high water table induced by a reservoir, seepage of reservoir effluent into ground-water, and drawdown effects on adjacent wells.

Chapter 4: GROUND-WATER PROTECTION ACTIVITIES OF RES

Ground-water protection activities of the Office of Nuclear Regulatory Research (RES) involve both standards development and confirmatory research projects in three program areas: (1) radioactive waste management, (2) reactor siting and emergency response, and (3) national and international technical committee activities. Waste management activities are further subdivided into project areas for (1) uranium recovery (UR), (2) low-level radioactive waste (LLW), (3) high-level radioactive waste (HLW), and (4) fuel cycle facilities. Specific RES projects, which are not developed solely from a ground-water viewpoint, can be categorized into these subdivisions.

RES staff in the Earth Sciences and Waste Management Branches conduct various research and standards development projects described in this chapter. Technical standards for ground-water protection written by RES staff originate either as Branch Technical Positions or from the results of confirmatory research. All projects support NRC licensing activities in response to statements of user need from individual licensing offices. RES staff study ground-water flow and contaminant transport in conjunction with contractors (e.g., HYDROCOIN) or with other NRC staff (e.g., evaluation of remedial actions at West Valley). Most confirmatory research studies, however, are conducted by RES contractors with RES staff serving as project managers. The specific objectives, tasks, and reporting requirements for these research projects are stated in the individual Statements of Work (SOWs).

After briefly summarizing technical issues about ground-water protection, this chapter describes current and recently completed RES projects related to ground-water protection. The RES staff and contractors technical capabilities are also described.

Technical Issues

RES staff identifies ground-water protection issues (1) in response to Congressional mandates (e.g., Low-Level Waste Policy Act of 1985), (2) derived from licensing experience (e.g., ground-water monitoring at in situ uranium solution mines), or (3) determined from confirmatory research findings (e.g., University of Arizona research on unsaturated flow and transport). The overall goal of RES ground-water research is to resolve technical ground-water flow and contaminant transport issues sufficiently to facilitate nuclear facility licensing. Confirmatory research and standards development projects are initiated to realize this goal through identification of technical information needs, development of requirements and technical guidance for ground-water protection, and study of hydrogeologic and hydrochemical systems. As a result of ongoing research projects and lessons learned at operating commercial nuclear facilities, the need for characterizing and assessing ground-water flow and transport systems is now recognized for most nuclear fuel cycle facilities.

Ground-water protection projects involving confirmatory research or standards development have been conducted in all major aspects of the nuclear fuel cycle by RES staff. Table 4 lists technical issues which have been identified by NRC staff as needing confirmatory research. Individual research projects are developed to resolve these issues in support of licensing decisions. Although each issue was identified to address a specific licensing topic, research findings are generally transferable to other regulatory programs with similar hydrogeologic issues.

Standards Development

Uranium Recovery

NRC regulations in 10 CFR Part 40 provide requirements for operation of commercial uranium recovery (UR) facilities including conventional uranium mills, in situ uranium solution mines, and other activities. Specifically, Appendix A to 10 CFR Part 40 stipulates criteria that provide for ground-water protection. In conjunction with NMSS, RES staff develop Regulatory Guides (RGs) to provide specific guidance to applicants by interpreting NRC regulations for ground-water protection at UR facilities and by disseminating confirmatory research results. Draft RGs ES 113-4, ES 114-4, and ES 115-4 provide guidance about hydrogeologic characterization of in situ uranium solution mines, ground-water monitoring at in situ solution mines, and modeling ground-water transport of radioactive and nonradioactive contaminants at tailings disposal sites, respectively. Future work is anticipated on completing Draft RG ES 113-4 for hydrogeologic characterization of in situ uranium solution mines.

Low-Level Waste Disposal

NRC regulations in 10 CFR Part 61 provide requirements for land disposal of low-level radioactive waste (LLW). Subpart D of Part 61 provides specific ground-water criteria for siting LLW disposal facilities. RES staff has recently developed a draft standard format and content guide for LLW facilities to provide regulatory guidance based on criteria contained in Part 61. Ground-water issues discussed in this guide were identified from RES studies of LLW waste disposal facilities at West Valley, New York and Maxey Flats, Kentucky. In addition, the guidance is also based on recent findings from unsaturated zone and trench case studies performed for RES by the Massachusetts Institute of Technology and Lawrence Berkley Laboratory. Future RES activity is anticipated to complete the guide and issue it for public comment. RES staff is presently assisting NMSS in consulting with DOE on the remedial actions and waste disposal options proposed for the West Valley Pilot Project, which involves ground-water flow and contaminant transport characterization and analysis.

High-Level Waste Disposal

High-Level radioactive waste (HLW) disposal is currently the most active area for ground-water protection research in the NRC. NRC's regulations for HLW disposal are codified in 10 CFR Part 60. Ground-water flow and transport analyses comparise much of the rationale that supports NRC's HLW disposal regulations. RES developed the initial regulations in conjunction with NMSS staff and is currently involved in revising the regulations in Part 60. RES staff recently developed siting criteria for HLW disposal in the unsaturated zone, which include such hydrogeologic criteria as: low-moisture flux through the host rock; the

Table 4 Hydrogeologic issues addressed by confirmatory research and standards development

Characteristics of ground-water flow and contaminant transport in low-permeability porous media, fractured media, and variably-saturated media.

Ground-water transport behavior of radiological and nonradiological constituents at uranium mill tailings sites and in situ uranium solution mines.

Feasibility, design, and performance of mitigative techniques to interdict contaminated ground-water.

Design of ground-water monitoring programs at in situ uranium solution mines.

Simulation of ground-water flow and contaminant transport in saturated and unsaturated fractured media.

Evaluation of field and laboratory characterization techniques for assessing unsaturated fractured media.

Validation of ground-water flow and transport models using field and experimental data.

Development of stochastic methods to characterize spatial variability and simulate ground-water flow in unsaturated media.

Ground-water dating and hydrochemical methods for characterizing ground-water flow systems.

Design and performance of infiltration-limiting trench covers.

Design and performance of borehole seals to prevent preferential pathways for ground-water flow and contaminant transport.

Evaluation of radioactive ore bodies as natural analogues for geochemical and transport phenomena important to radioactive waste disposal.

presence of a low-permeability, laterally continuous layer above the host rock; freely-drained host rock; and the absence of perched water bodies that may either saturate the underground facility containing the waste or decrease ground-water travel times from the waste to the accessible environment (see Chapter 2 for a more-detailed discussion of HLW siting criteria). In NUREG-1046, RES staff published the technical rationale for these criteria, which was based on confirmatory research results from University of Arizona research and RES staff technical analyses.

Working with NMSS staff, RES staff developed Regulatory Guide 4.17 to describe the types and formats of information expected from DOE in Site Characterization Reports. Chapter 5 of Regulatory Guide 4.17 describes hydrogeologic information to be included in the report, including characterization of the ground-water flow system, potential radionuclide releases, identification of the accessible environment and credible release pathways, analysis of ground-water travel times, ground-water monitoring and verification program, and assessment of hydrochemistry. RES staff is presently attending NRC-DOE technical meetings on hydrogeologic licensing issues at candidate HLW disposal sites. This participation allows for timely identification of issues that require confirmatory research in support of licensing assessments. RES staff is also participating in the development of staff technical positions that provide regulatory guidance by interpreting NRC's regulations in 10 CFR Part 60 and that incorporate pertinent confirmatory research results.

Reactor Siting and Emergency Response

Although often considered a pathway of subordinate importance, radionuclide transport in ground-water from nuclear power plants may constitute a significant pathway depending on site- and release-specific characteristics. Ground-water conditions may also affect the structural stability of commercial plant structures. NRC regulations relevant to ground-water protection for nuclear power plants are contained in 10 CFR Part 100. Criterion §100.10 identifies specific ground-water pathway concerns. The "Report of the Siting Policy Task Force" (NUREG-0625) recommended that Part 100 be revised by requiring reasonable assurance that interdictive measures are feasible to limit ground-water contamination resulting from Class-9 accidents. Class-9 accidents comprise a class of accidental releases of radionuclides to ground-water as a result of partial or total melting of the reactor core and movement through the containment vessel. Evaluation of this recommendation was deferred until research on source terms and ground-water mitigative techniques was completed.

Under contract to RES, Pacific Northwest Laboratory documented the results of ground-water studies of implementing alternative interdictive strategies in "Mitigative Techniques for Ground-Water Contamination Associated with Severe Nuclear Accidents" (NUREG/CR-4251). This report provides detailed information about mitigative techniques for ground-water contamination, including strategies, case studies, costs, and important hydrogeologic variables in selecting interdictive strategies (Oberlander et al, 1985).

NRC's hydrogeologic design criteria for reactors are codified in 10 CFR Part 50. Specifically, Criteria 2 and 4 of Appendix A of Part 50, and Appendix B of Part 50 provide the regulatory basis for the development of draft Regulatory Guide FP(ES) 811-4, "Safety-Related Permanent Dewatering Systems for Nuclear

Power Plants," which was issued for comment in September 1979. RES staff than revised the draft RG to accommodate public comments. Finalization and release of the RG by RES has been postponed in response to requests from NRR.

Well Logging

In conjunction with NMSS staff, RES staff developed regulations proposed by the NRC in 10 CFR Part 39 for licenses and radiation safety requirements for well-logging. The Commission proposed these regulations in April of 1985. Following the close of the public comment period on the proposed regulations in October 1985, RES staff assessed public comments and incorporated appropriate revisions to the proposed regulations. RES staff expects that the rulemaking for well-logging should be completed in 1986.

Significant Ground-Water Research Findings

The following section describes significant ground-water research findings that aided resolution of technical issues and, in certain cases, led directly to development of NRC regulations or regulatory guidance.

Uranium Recovery

Research at Pacific Northwest Laboratories (PNL) on "Predictive Geochemical Modeling of Contaminant Concentrations in Plume Migrations from Uranium Mill Tailings Waste Impoundments" (FIN B-2292) and on "Methods of Minimizing Ground-Water Contamination from In Situ Leach Uranium Mining" (FIN B-2379) produced significant research findings which contributed to the development of Regulatory Guides ES 114-4 an ES 115-4.

Key regulatory issues addressed in FIN B-2379 for in situ uranium solution mining were (1) hydrogeologic characterization of in situ mine sites, (2) monitoring to detect excursion of contaminated ground-water from mining zones, and (3) practical methods of aquifer restoration following in situ mining. This research helped to identify the characteristics of effective ground-water monitoring programs, including selection of chemical constituents to serve as indicators of contaminant migration. PNL researchers investigated the relative effectiveness of aquifer restoration methods after mining, including: (1) natural restoration, (2) ground-water sweeping, (3) surface treatment and re-injection, and (4) in situ restoration (cf. Bibliography; NUREG/CRs-3104, -3134, -3103, and -3709]. RES and NMSS staff are currently incorporating results from this research project into regulatory guidance on in situ uranium solution mining.

For assessment of leachate movement for uranium mill tailings (FIN B-2292), PNL researchers evaluated several key hydrogeologic issues, including: (1) determination of the short- and long-term mineralogical and hydrological changes that occur when acidic tailings solutions contact sediments, (2) identification of the contaminants that migrate from uranium tailings impoundments, (3) characterization of sediments/solution interactions that may attenuate movement of contaminants, and (4) prediction of constituent concentrations in contaminated effluents and ground-water. Valuable research products derived from research conducted under FIN B-2292 include: (1) laboratory and geochemical models to estimate contaminant concentrations and mobility; (2) characterization of attenuative mechanisms such as sorption, precipitation and other chemical interactions, (3) determination of the effects of acid tailings solutions on linear composition and permeability, and (4) validation of predictive models using field data [cf. Bibliography; NUREG/CRs-3890, -1495, -3078, -4061, -4782, -2360, and -4682]. These research findings supported the development of Regulatory Guide ES 115-4, which provides guidance on modeling contaminant transport in ground-water at uranium tailings sites (see Table 1).

Low-Level Waste Disposal

Research at the University of California at Berkley (FIN B-3042) produced significant findings that resolved site issues dealing with infiltration into LLW burial trenches, trench resaturation and subsequent failure, and contaminant transport mechanisms. The project entitled "Unsaturated Zone Hydrology at the Maxey Flats LLW Disposal Facility, Kentucky" concluded that recharge into trenches occurred through trench covers rather than by lateral ground-water flow. Research results from this project also aided delineation of the extent of buried LLW by measuring tritium uptake into the overlying vegetative cover. These and other related research findings contributed to better design, construction, and monitoring of trench covers at Maxey Flats. In conjunction with other research projects, this study also aided investigators in characterizing the mobility and source of organic contaminants in leachate from LLW sites. Lessons learned from RES projects at Maxey Flats and West Valley provided part of the foundation for development of the siting and performance criteria in 10 CFR Part 61 and related guidance.

High-Level Waste Disposal

Research at the University of Arizona (FIN B-7291) on "Unsaturated Flow and Transport Through Fractured Rock" produced significant research results that supported revisions to 10 CFR Part 60 to include provisions for disposal of HLW in the unsaturated zone (50 FR 29641). Significant research findings were published in NUREG/CR's-3206, -3608, and -4042 and were used in NRC staff reviews of DOE's Draft Environmental Assessment for the Yucca Mountain Site in Nevada. Analyses of the results from the University of Arizona research have also aided in the identification of potential licensing issues. Notable issues under study include: (1) potential significance of vapor phase transport in the unsaturated zone, (2) importance of liquid and vapor sampling to characterize ground-water chemistry and radionuclide transport behavior, (3) predominance of fracture or matrix flow relative to ground-water travel time evaluation, and (4) effects of heat generated by HLW decay on ground-water flow and transport in the unsaturated zone.

University of Arizona researchers have also assessed ground-water flow and transport equations, models, and field characterization techniques for unsaturated fractured media. Their research findings have provided RES and NMSS staff with technical evaluations of state-of-the-art techniques for characterizing unsaturated fractured media. At a RES-sponsored workshop on this topic, DOE and NRC investigators identified significant research issues that attest to the importance of continuing research about ground-water flow and transport in unsaturated fractured media.

Fuel Cycle Facilities

RES studies with the New York State Geological Survey (NYSGS) and the U.S. Geological Survey (USGS) on the geology and hydrology of the West Valley site (FIN's B-6352 and B-7066) contributed to the NMSS staff review of DOE's Environmental Assessment and remedial action plans at the West Valley Pilot Project. Relevant research findings are summarized in a joint report by RES and NMSS staff entitled "Information on the Confinement Capability of the Facility Disposal Area at West Valley, New York" (NUREG-1164). Research at the West Valley site resolved outstanding hydrogeologic issues (e.g., whether sand lenses in the Lavery Till act as preferential pathways for radionuclide transport) and identified new issues (e.g., the significance of onsite slumping and gully development) (Nicholson and Hurt, 1985). In a companion document, RES staff assisted NMSS contractors in preparing a "Research Plan for Investigating Radionuclide Migration at the West Valley Facility Disposal Area" (Clapp and Herber, 1985). This report outlines a suggested plan for resolving remaining technical issues at West Valley. NRC's recent review and comments on DOE's Environment Assessment for the disposal of wastes at West Valley were partially based on RES research results and staff assessments.

Reactor Siting and Emergency Response

Research studies by Pacific Northwest Laboratory on "Mitigative Techniques for Ground-Water Contamination Associated with Severe Nuclear Accidents" (FIN B-2454) resulted in significant findings that assisted NRR's liquid pathway assessments. As discussed previously, results of this research may also provide a technical basis for potential revisions to 10 CFR Part 100. Published in NUREG/CR-4251, these results indicate that mitigative techniques are available to interdict plumes of contaminated ground-water. The research concluded, however, that considerably more site-specific hydrogeologic information than presently available may be needed at some sites to design and implement the mitigative measures effectively (Oberlander et al, 1985). The study also evaluated generic site conditions that would affect the selection and performance of alternative mitigative techniques. The study indicated certain generic characteristics as favorable for implementing mitigative techniques (e.g., presence of a shallow low-permeability hydrogeologic unit in which to "key" the slurry wall barriers), whereas others are obviously unfavorable (e.g., highly karstic hydrogeologic units). In addition to their potential utility to commercial nuclear plant operations, the PNL research findings have already been used by NRC staff in reviews of remedial actions at uranium recovery sites and at West Valley, New York. The study also highlighted other technical issues such as the need to implement ground-water monitoring programs to provide the data necessary for executing emergency responses and to verify field performance of mitigative measures.

Current Research Activities

NRC ground-water research Projects are summarized in the "Federal Ground-Water Projects Directory" issued by the Interagency Advisory Committee on Water Data. Several current projects focus on validating ground-water flow and transport models. Recent RES-sponsored symposia focused on this topic to evaluate whether model predictions can be considered reliable for the time periods of concern with radioactive wastes. In addition, RES staff participates in the HYDROCOIN project, which dwells on the important issue of ground-water flow and transport model validation for waste disposal facilities. RES staff are also participating in INTRAVAL, a new international cooperative effort to evaluate the use of geosphere models for performance assessment. Future work is anticipated in both national and international cooperative programs dealing with ground-water characterization and modeling studies.

RES staff have also initiated projects that are evaluating the capability of stochastic methods to assess hydrogeologic property variability and resulting flow and transport perturbations in fractured and unsaturated media.

Research results from these projects will be directly incorporated into regulatory guidance for both HLW and LLW licensing assessments. In contrast, ground-water research projects are not currently being conducted or planned in reactor siting, fuel cycle, and uranium recovery program areas. The following sections describe current research projects in the LLW and HLW program areas.

Low-Level Waste Disposal

Principal hydrogeologic issues associated with shallow land burial of LLW include: (1) performance of waste packages under various hydrogeologic conditions, (2) determination of realistic contaminant source terms considering anticipated future waste streams and hydrogeologic conditions, (3) identification of post-closure infiltration and release pathways, (4) evaluation of potential transport of radiological and nonradiological constituents, and (5) assessment of hydrogeologic characterization techniques. Cover infiltration may ultimately control trench performance and transport of contaminants away from shallow land burial facilities. Current research is focusing on site characterization methods to evaluate ground-water table fluctuations, ground-water flow and transport modeling, ground-water quality, and attenuative properties of both saturated and unsaturated porous media.

(1) TITLE: Stochastic Analysis of Solute Transport in Unsaturated Soils (FIN 8-8956)

CONTRACTOR: Massachusetts Institute of Technology

PRINCIPAL INVESTIGATOR: Dr. Lynn Gelhar

OBJECTIVE: To predict large-scale mean behavior of heterogeneous, unsaturated porous media using stochastic methods and to relate variability of ground-water flow and solute concentrations to the variance of the field properties.

(2) TITLE: Validation of Stochastic Flow and Transport in Unsaturated Soils (FIN B-2882)

CONTRACTOR: Pacific Northwest Laboratory
New Mexico State University

PRINCIPAL INVESTIGATORS: Dr. Glendon Gee (PNL) and Dr. Peter Wierenga (NMSU)

OBJECTIVE: To validate the stochastic theory being developed under FIN 8-8956 that would enable adequate modeling of LLW sites in the unsaturated zone and to determine appropriate site characterization techniques and derived properties to predict radionuclide transport.

(3) TITLE: Control of Ground-Water Entry at Near-Surface LLW Disposal Facilities (FIN B-8958)

CONTRACTOR: University of California - Berkeley

PRINCIPAL INVESTIGATOR: Dr. Robert Schulz

OBJECTIVE: To evaluate designs that control deep ground-water percolation through trench covers, which causes trench saturation, leaching of trench wastes, and subsequent ground-water transport.

(4) TITLE: Demonstration of Performance Modeling of LLW Shallow Land Disposal Facilities (FIN 8-2862)

CONTRACTOR: Pacific Northwest Laboratory

PRINCIPAL INVESTIGATOR: Dr. David Robertson

OBJECTIVE: To demonstrate, in a regulatory context (10 CFR Part 61), present capabilities to simulate expected LLW shallow land disposal site performance under humid conditions and to assess existing capabilities to model ground-water flow and contaminant transport at LLW sites.

High Level Waste Disposal

The technical research issues for HLW focus on (1) determination of ground-water travel times under pre-waste emplacement conditions, (2) assessment of site characterization methods, and (3) evaluation of models used in performance assessment for alternative geologic media (e.g., bedded salt, tuff, and basalt) and hydrogeologic conditions. RES staff are also considering post-closure aspects such as borehole sealing and long-term performance of the hydrogeologic system.

(1) TITLE: Confirmatory Research Related to Ground-Water Dating (FIN B-6628)

CONTRACTOR: University of Arizona

PRINCIPAL INVESTIGATOR: Dr. Stanley Davis

OBJECTIVE: To determine the capabilities and limitations of radioisotopic, stable isotopic, and hydrochemical dating methods for characterizing high-level waste sites.

(2) TITLE: Vapor Transport of Radionuclides in Unsaturated Fractured Rock (FIN 8-7291)

CONTRACTOR: University of Arizona

PRINCIPAL INVESTIGATOR: Dr. Daniel D. Evans

OBJECTIVE: To evaluate the transport of volatile radionuclides by gaseous diffusion/convection and transport of solutes present as aerosols in ground-water through air-filled pores by diffusion/convection, as well as the importance of unsaturated zone properties to this transport.

(3) TITLE: Unsaturated Flow and Transport through Fractured Media (FIN B-7291)

CONTRACTOR: University of Arizona

PRINCIPAL INVESTIGATOR: Dr. Daniel D. Evans

OBJECTIVE: To assess state-of-the-art methods for characterization of fractures, fracture flow, and ambient unsaturated conditions, and to evaluate computer models for ground-water flow and contaminant transport in partially-saturated, fractured media.

(4) TITLE: Rock Mass Sealing (FIN 8-6627)

CONTRACTOR: University of Arizona

PRINCIPAL INVESTIGATOR: Dr. Jaak Daemen

OBJECTIVE: To assess existing technology for sealing boreholes and shafts in order to prevent such openings from becoming preferential pathways for the migration of radionuclides. Also to identify appropriate techniques to test performance of shaft and borehole seals.

(5) TITLE: Computer Calculations in Support of the HYDROCOIN Study (FIN A-1404)

CONTRACTOR: Sandia National Laboratory

PRINCIPAL INVESTIGATOR: Paul Davis

OBJECTIVE: To assist NRC staff in support of an international effort investigating the accuracy and suitability of ground-water flow codes to be utilized in performance assessment studies of LLW and HLW disposal sites.

(6) TITLE: Investigation of Coupled Interactions in Geothermal and Hydrothermal Systems for Assessment of HLW Isolation (FIN B-3046)

CONTRACTOR: Lawrence Berkeley Laboratory

PRINCIPAL INVESTIGATOR: Dr C. F. Tsang

OBJECTIVE: To assess coupled process interactions in geothermal and hydrothermal systems and to determine whether and under what conditions these interactions are important to isolation of HLW.

(7) TITLE: Flow of Ground-Water and Transport of Contaminants through Saturated Fractured Geologic Media from HLW Repositories (FIN D-1163)

CONTRACTOR: In Situ Incorporated

PRINCIPAL INVESTIGATOR: Ted Way

OBJECTIVE: To assess methods and techniques for characterizing saturated, fractured geologic media.

National and International Committee Activities

RES staff represents the NRC staff on several national and international committees that focus on aspects of ground-water protection. These committees include the Ground-Water Subcommittee of the Interagency Advisory Committee on Water Data, ASTM committee on Soil and Rock (D18), Federal Ground-Water Glossary Working Group, and the standards writing committees ANS 2.9 and 2.17 of the American Nuclear Society dealing with ground-water supply radionuclide transport at reactor sites. RES staff also participates in international committees that focus on activities related to ground-water protection including the IAEA committee on Safety Guide S7, entitled "Hydrogeological Aspects of Nuclear Power Plant Siting," and international cooperative projects INTRACOIN, HYDROCOIN, and INTRAVAL.

RES Staff and Contractor Capabilities

The Earth Sciences Branch staff capabilities include hydrogeology, geotechnical engineering, and geology. Waste Management Branch staff capabilities include hydrology, geochemistry, and waste project analysts. The emphasis of ESB and WMB activities is on formulating, developing, and executing confirmatory research and standards development projects that facilitate NRC licensing reviews. This emphasis requires RES staff assistance in licensing actions to understand and identify important ground-water protection issues. RES staff visit RES contractors to monitor their performance actively and to assess research findings for timely incorporation into licensing reviews. RES staff have also utilized ground-water flow and transport codes to develop assessment capabilities and to participate in international committee projects (e.g., INTRACOIN and HYDROCOIN). In addition, RES staff develop regulatory guides and rulemaking actions based upon research results, information garnered from assisting in licensing activities, and NMSS and NRR branch technical positions. Representing the NRC staff, RES staff also participate in federal and international technical committees that assess ground-water flow and transport phenomena. Principal RES contractor expertise on ground-water resides at the University of Arizona, Pacific Northwest Laboratory, University of California at Berkeley, New Mexico State University, Massachusetts Institute of Technology, Sandia National Laboratory, Lawrence Berkeley Laboratory, and In Situ Incorporated.

Chapter 5: INSPECTION AND ENFORCEMENT

Well-formulated regulatory programs for ground-water protection may be ineffective without proactive programs for inspection and enforcement. One third of NRC's resources are expended to conduct inspection programs to verify licensee compliance with NRC regulations and license conditions and to evaluate the effectiveness of compliance. These programs are conducted under the auspices of the Office of Inspection and Enforcement (IE), with technical support from NMSS and NRR. Although IE headquarters staff develop uniform inspection procedures and policies, most of NRC's inspection activities are conducted by personnel at Regional offices and nuclear facilities. Three types of inspections are conducted: routine inspections to ensure implementation of safety programs, reactive inspections to respond to problems or to determine root causes of problems, and self-directed inspections to evaluate the overall safety afforded by compliance programs. Inspection activities are weighted in favor of those activities that are most significant in terms of protection of the public health and safety and the environment.

With respect to ground-water protection, NRC inspects nuclear facilities to ensure that they are complying with ground-water-related license conditions and technical specifications, such as upper control limits at in situ uranium solution mines or design basis ground-water levels at nuclear power plants. These conditions and specifications represent site-specific applications of NRC's regulations to protect ground-water resources. The conditions are incorporated into facility licenses by NRR staff for commercial reactor operations and by NMSS staff for fuel facilities and materials licensees.

NRC enforces compliance with these conditions through periodic inspections, administrative orders, and enforcement actions. Frequently, enforcement actions are precipitated as a result of failure of licensees to take corrective actions to remedy violations identified earlier. For example, NRC fined the Union Carbide Corporation of Grand Junction, Colorado, for failing to submit plans for corrective actions for contaminated seepage and surface water (EA 83-108). Inspection and enforcement round out NRC's programs for ground-water protection by ensuring compliance with regulations and specific conditions of NRC licenses.

Chapter 6: AGREEMENT STATE PROGRAMS

NRC's Office of State Programs (SP) administers agency communications with regional, State, local, and Indian tribal agencies for purposes other than inspections and emergency planning. NRC has agreements with 28 States by which the States assumed regulatory responsibility over byproduct and source materials and small quantities of special nuclear material. Four Agreement States regulate uranium milling and mill tailings*. All of the Agreement States except two have authority to regulate low-level radioactive waste disposal. The three operating LLW disposal facilities are in Agreement States. SP staff periodically reviews these programs to confirm that they are adequate to protect public health and safety and are compatible with corresponding NRC programs. NRC also provides Agreement States with technical assistance through SP in areas of legislation, regulation, licensing, inspection, and enforcement. SP provides training for State personnel in such areas as health physics, well-logging, uranium milling, radiography, nuclear medicine, inspection procedures, transportation, licensing practices, and special topics in licensing.

Relative to ground-water protection programs, NRC staff conducts periodic reviews of State Radiation Control programs, including programs for ground-water protection at nuclear facilities. These facilities are licensed by the States and required to meet equivalent standards to those in Appendix A of 10 CFR Part 40 and in 10 CFR Part 61 for uranium recovery and LLW disposal, respectively. SP staff recommends appropriate modifications to ground-water protection programs that are not compatible with NRC programs or are not adequate to protect the public health and safety and the environment. SP staff also channels technical assistance to States from technical staff in NMSS and NRR on ground-water protection issues. For example, NRC provided two States with technical assistance about reviewing closure plans for uranium mills in 1985. Extensive technical assistance was provided to Kentucky on development of a closure plan for the Maxey Flats LLW site. As an example of specialized training offered through SP, NRC supports requests from Agreement State personnel to attend courses on ground-water pollution and hydrology.

*The Governor of New Mexico requested that NRC reassert its authority over uranium milling and mill tailings by letter of March 18, 1986.

Chapter 7: INCONSISTENCIES BETWEEN GROUND-WATER PROGRAMS

Besides describing the characteristics of ground-water protection programs within NRC, this report identifies inconsistencies that exist between these programs. Program descriptions in Chapters 2 through 6 provide the basis for identification of these inconsistencies. Although they are analyzed in this chapter, inconsistencies between ground-water protection programs within NRC will be assessed in greater detail in a subsequent report on recommendations of the Groundwater Protection Group.

The four inconsistencies identified by the Groundwater Protection Group based on the program descriptions in this report include:

(1) different definitions of the term "ground-water;"

(2) variable regulation of non-radiological constituents in ground-water;

(3) different design periods for ground-water protection; and

(4) different scopes and rigor of ground-water assessments.

The NRC staff uses the term "ground-water" differently in various regulatory programs. The only definition for ground-water codified by NRC is found in 10 CFR Part 60.2, which states that ground-water "means all water which occurs below the land surface." Thus for HLW disposal, NRC regulations provide for protection of both water in the saturated zone beneath the regional water table and water in the vadose zone above the water table. In contrast, other NRC programs consider that ground-water only exists in the saturated zone beneath the regional water table. These programs include the uranium recovery and fuel cycle programs under 10 CFR Part 40, reactor programs under 10 CFR Parts 50 and 100, and the LLW disposal program under 10 CFR Part 61. In conforming NRC's regulations for uranium recovery in 10 CFR Part 40, the NRC staff is considering adoption of EPA's definition of ground-water from the hazardous waste regulations in 40 CFR Part 260. In Part 260.10, EPA defines ground-water as "water below the land surface in a zone of saturation," which includes water in perched zones as well as water beneath the regional water table. Differences in the definition of ground-water are significant because they determine the resource to be protected by NRC's regulatory programs. By defining ground-water restrictively as water that exists beneath the regional water table, ground-water contamination, by definition, only occurs after contaminants have migrated through the vadose zone.

NRC programs for ground-water protection also differ in their regulation of nonradiological constituents in ground-water. Although programs control concentrations of radiological contaminants in ground-water, only NRC's programs for uranium recovery regulate concentrations of nonradiological contaminants in groundwater. For example, corrective actions may be required at in situ uranium solution mines if nonradiological contaminant concentrations exceed upper control limits. Similarly, using the 1983 EPA standards for active uranium mills (40 CFR Part 192, Subpart D), NRC regulates concentrations of both radiological and nonradiological hazardous constituents in ground-water contaminated by seepage from tailings impoundments. In contrast, NRC ground-water protection programs at other nuclear facilities have not regulated nonradiological contaminants. Recent NRC assessments of LLW disposal sites have identified ground-water transport of nonradiological contaminants (NRC, 1986a). At fuel cycle facilities, NRC encourages licensees to minimize nonradiological contamination of groundwater on the premise that nonradiological contamination heralds contamination by radiological contaminants. NRC does not directly regulate ground-water contamination by nonradiological constituents at nuclear power plants, although in some cases technical specifications are imposed in licenses to control nonradiological contaminants.

Inconsistency in regulation of nonradiological contaminants is caused by differences in NRC's authorizing legislation. NRC is required by the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) to implement EPA's regulations, which UMTRCA required to control both radiological and nonradiological hazards associated with uranium mill tailings. Similar legislative authority for directly regulating nonradiological contaminants in ground-water does not presently exist for NRC's other regulatory programs.

A third inconsistency between NRC's programs for ground-water protection is the disparity in the duration of periods for which protective measures must be designed. At nuclear power plants, protective measures are generally designed to remain effective on the order of decades, as long as the plants are in operation. In contrast, protective measures for uranium mill tailings are designed to be effective for 1,000 years, to the extent practicable, and in any case at least 200 years. The regulatory program for HLW disposal requires the longest design periods, in excess of 10,000 years. This inconsistency is created by differences in the duration and nature of hazards posed by nuclear operations and wastes. Unlike nuclear power plants where the potential for ground-water contamination may exist for several decades, potential contamination by HLW repositories persists well past 1,000 years. Barring occurrences of low probability events (e.g., Class-9 accidents), differences in the duration and nature of hazards appear to justify the inconsistency between design periods for groundwater protection programs.

The fourth major inconsistency between NRC's ground-water protection programs is the difference between the scopes and rigor of hydrogeologic site assessments. Groundwater protection at nuclear power plants is a subordinate concern compared with assuring that nuclear power plants are constructed and operated in a manner that protects the public health and safety. The major concern at nuclear power plants is large accidental releases of radionuclides to the atmosphere. Hydrogeologic assessments performed at reactor sites primarily support evaluations of reactor design and construction to assure safe operation, as well as evaluations of environmental impacts. The scope and rigor of such assessments are determined by the need to fulfill these two objectives. In comparison, groundwater transport is one of, if not the most important transport pathway for radiological and nonradiological contaminants at waste storage and disposal sites. Consequently, hydrogeologic assessments are prioritized in licensing and regulating disposal sites for LLW, HLW, UR, and fuel cycle wastes. This prioritization necessarily broadens the scope and increases the rigor of hydrogeologic assessments compared with those of reactor sites. Differences in scope and rigor also exist among programs for waste disposal to account for differences in perceived risk of injury to humans and the environment associated with the various types of waste. For example, computer codes used to simulate contaminant transport are rigorously verified, validated, and benchmarked for use in predicting performance of HLW repositories. Similar codes used for predictions at uranium recovery sites, however, are not routinely subjected to comparable verification, validation, and benchmarking because of lower perceived risks associated with exposure to contaminants from uranium tailings.

The significance of inconsistencies between the scopes and rigor of ground-water protection programs may only be realized after ground-water problems exist. For example, hydrogeologic assessments at uranium mill sites are generally much more rigorous than those performed at reactor sites. Even with the more rigorous assessments, additional hydrogeologic information is usually needed prior to implementing corrective action programs for ground-water contamination at mill sites. The need for additional hydrogeologic information to implement corrective actions at reactor sites would be expected to be more acute because less information would be available at the time contamination occurs. A recent RES study indicated that more-detailed hydrogeologic information such as baseline monitoring may be necessary at certain reactor sites to support design and implementation of corrective programs following Class-9 accidents (Oberlander et al., 1985).

Given the Group's purpose, the Groundwater Protection Group will focus on the first (definition of ground-water) and last (scopes and rigor of hydrogeologic assessments) inconsistencies identified in this chapter. The second inconsistency is created by differences in statutory authority, which is outside the purview of the Group. The third inconsistency is rationalized by recognizing differences in perceived risks associated with operation of nuclear facilities. The group's conclusions and recommendations will be presented in a subsequent report in the Fall of 1986.

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13. ABSTRACT (200 words or less)
The U. S. Nuclear Regulatory Commission (NRC) provides for ground-water protection through regulations and licensing conditions that require prevention, detection, and correction of ground-water contamination. Prepared by the interoffice Ground-Water Protection Group, this report evaluates the internal consistency of NRC's ground-water protection programs. These programs have evolved consistently with growing public concerns about the significance of ground-water contamination and environmental impacts. Early NRC programs provided for the protection of the public health and safety by minimizing releases of radionuclides. More recent programs have included provisions for minimizing releases of non-radiological constituents, mitigating environmental impacts, and correcting ground-water contamination. NRC's ground-water protection programs are categorized according to program areas, including nuclear materials and waste management (NMSS), nuclear reactor operations (NRR), confirmatory research and standards development (RES), inspection and enforcement (IE), and agreement state programs (SP).

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