LOW-LEVEL RADIOACTIVE WASTE RESEARCH PROGRAM PLAN

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ABSTRACT

The Office of Nuclear Regulatory Research, has developed a strategy for conducting research on issues of concern to the U.S. Nuclear Regulatory Commission (NRC) in its efforts to ensure safe disposal of low-level radioactive waste (LLW). The resulting program plan has been published in NUREG-1380. The plan provides an integrated framework for the LLW research program to ensure that the program and its products are responsive and timely for use in NRC's LLW regulatory program. The plan addresses technical and scientific issues and uncertainties associated with the disposal of LLW, presents program goals and ways for achieving them, establishes a long-term strategy for conducting the confirmatory and investigative research needed to meet these goals, and includes schedules and milestones for completing the research. Areas identified for investigation include waste form and other material concerns, failure mechanisms and radionuclide releases, engineered barrier performance, site characterization and monitoring, and performance assessment. The plan includes projects that (1) analyze and test actual LLW and solidified LLW under laboratory and field conditions to determine leach rates and radionuclide releases, (2) examine the radiological and chemical characteristics of decommissioning waste from nuclear power stations,(3) examine the short- and long-term performance of concrete-enhanced LLW burial structures and high-integrity containers, (4) investigate the long term effectiveness of disposal unit covers in controlling water infiltration into disposal units, (5) examine the information needed at time of closure for predicting future facility performance, (6) attempt to develop a predictive model of the rate of radionuclide release at the boundary of waste disposal units, (7) examine radionuclide transport behavior, pathways, uptake, and transfer coefficients of radionuclide releases from LLW disposal facilities, and (8) attempt to predict water movement and contaminant transport through low permeability saturated media and unsaturated porous media.

INTRODUCTION

As the agency charged with the regulation of commercial low-level radioactive waste (LLW) disposal, the Nuclear Regulatory Commission's (NRC's) task is to establish and implement the framework for licensing all aspects of LLW disposal facility siting, design, construction, operation, and closure to ensure that LLW disposal will present no undue risk to the public health and safety or the environment.

To meet its LLW disposal regulatory responsibilities, the NRC requires technical data and methods for evaluating the demonstrations made by license applicants that a proposed LLW disposal facility will isolate radioactive materials over the period of time that these wastes remain dangerous to the public. The data and methods that the NRC uses to review the submittals of license applicants must be independent of the assessment techniques and data bases developed by applicants in support of their submittals. The purpose of NRC's LLW research program is to furnish the independent data and methods as well as the technical understanding required by the LLW licensing office to ensure safe and effective radioactive waste management and disposal.

NRC's Office of Nuclear Regulatory Research (RES) has published a research plan for LLW (NUREG 1380) to ensure that the research program and its products are responsive and timely for use in the LLW regulatory program. This paper explains the regulatory and technical issues considered in developing NRC's LLW Research Plan and outlines the strategy for addressing those issues.

REGULATORY FRAMEWORK FOR DISPOSAL OF LLW

To regulate the safe disposal of LLW NRC must have a practical understanding of a complex set of scientific and technical variables, as well as the capability to apply this understanding in anticipating the outcome of their interactions. With this understanding and capability, the NRC staff should be able to evaluate the expected performance of a proposed LLW disposal facility against the performance objectives in 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," to determine whether the facility will be capable of isolating the hazardous components of LLW from the environment.

Part 61 contains procedural requirements, general performance objectives, and technical requirements applicable to any method of shallow land disposal of LLW. The performance objectives in Part 61 Subpart C specify that shallow land disposal facilities for LLW must be sited, designed,

operated, closed, and controlled after closure in a manner that protects the general population from releases of radioactivity during and after operation, the workers on-site from releases during operation, and the inadvertent intruder from releases after closure. Section 61.41 provides the overall performance objective for the safe disposal of LLW in terms of doses--limiting the dose to any member of the public from any release to less than 25 millirems/yr for the whole body, 75 millirems/yr to the thyroid gland, and 25 millirems/yr to any other organ. The performance objectives are the basis for the performance assessment for any LLW disposal licensing decision and thus are the driving force for the research proposed in NUREG 1380.

The technical requirements in Part 61 Subpart D also serve as impetus for the LLW research program. The technical requirements are established for each stage in the life of a potential near-surface LLW disposal facility, including the preoperational phase, operational phase, closure phase, observation and maintenance phase, and finally for the period of institutional control. One of the principal technical requirements driving the LLW research plan is paragraph 61.50(a)(2), which requires that an acceptable disposal site must be capable of being characterized, modeled, analyzed, and monitored. NRC must have the capability to independently model and analyze the disposal facility information presented by an applicant.

TECHNICAL ISSUES FOR LLW DISPOSAL

LLW disposal licensing decisions require a thorough understanding of the nature and form of the LLW intended for disposal, the surface and subsurface characteristics of the site where disposal is to occur, and how the various design features of the planned disposal facility will work with the site to enhance its isolation potential.

Clearly questions about the adequacy of a proposed LLW disposal facility begin with uncertainties regarding the characteristics and form of the LLW itself. The nature and form of LLW determine its potential source term and its potential for release of radioactivity or other hazardous materials, the overall long-term stability of the disposal site, the preferred engineered enhancements, and the likely pathways for release to the environment.

A fundamental problem in providing for safe disposal of LLW is that the term "low-level waste" refers to a wide range of radioactive wastes with an equally wide range of physical and chemical characteristics. All industries; hospitals; medical, educational, or research institutions; private or government laboratories; or facilities forming part of the nuclear fuel cycle (e.g., nuclear power plants, fuel fabrication plants) using radioactive materials as a part of their normal operational activities generate so-called low-level radioactive waste just as they generate other types of hazardous and nonhazardous wastes.

LLW consists of radioactive materials and other materials that have been in contact with the radioactive materials and thus are contaminated or suspected of being contaminated. It is generated in many forms, concentrations, and amounts. It ranges from trash that may be only slightly contaminated with radioactivity to highly radioactive materials such as activated structural components from nuclear power reactors. The form of the waste may be solid, liquid, or gaseous and it may include a variety of chemicals. LLW ranges in activity from thousands of curies per cubic meter to less than a few microcuries per cubic meter.

The LLW disposal site environment contributes another set of complex variables that, together with the characteristics of the LLW, must be understood in order to assess the performance of a proposed disposal facility. The site determines the physical and hydrologic environment into which the waste must be placed and in which it must maintain its integrity during the hazardous life of the LLW. Fig. 1 is a schematic of a shallow land disposal facility. The schematic indicates some of the natural and engineered characteristics of the site that affect the stability and long-term performance of the individual components as well as the overall LLW disposal facility. The major pathways for potential long-term radiological exposure to the public are also shown on the schematic and include potential leaching and transport of the waste by and into the ground water, deliberate or inadvertent human intrusion into the disposed waste, intrusion and dispersion by plants and animals, long-term erosion of the site by wind or water, and resulting radionuclide transport by surface water or the air.

RESEARCH PROGRAM STRATEGY

Most of the LLW research needs flow from the state of technical or scientific uncertainty in a specific area of disposal technology and reflect a recognition of the magnitude of the regulatory or licensing problems caused by the uncertainty. Consideration of the uncertainties and any corresponding threat to the public health and safety provides a basis for identifying research needs, for determining the level of research effort needed, and for determining when a specific piece of research has provided the required information or has reduced the level of uncertainty sufficiently for regulatory purposes.

Given the above, NRC has identified five major areas where research is considered important to provide information for LLW disposal licensing decisions. The areas are: (1) Waste Form and other Material Concerns, (2) Failure Mechanisms and Radionuclide Releases, (3) Engineered Barrier Performance, (4) Site Characterization and Monitoring, and (5) Performance Assessment. Following is a discussion of the major issues in each of these areas and a

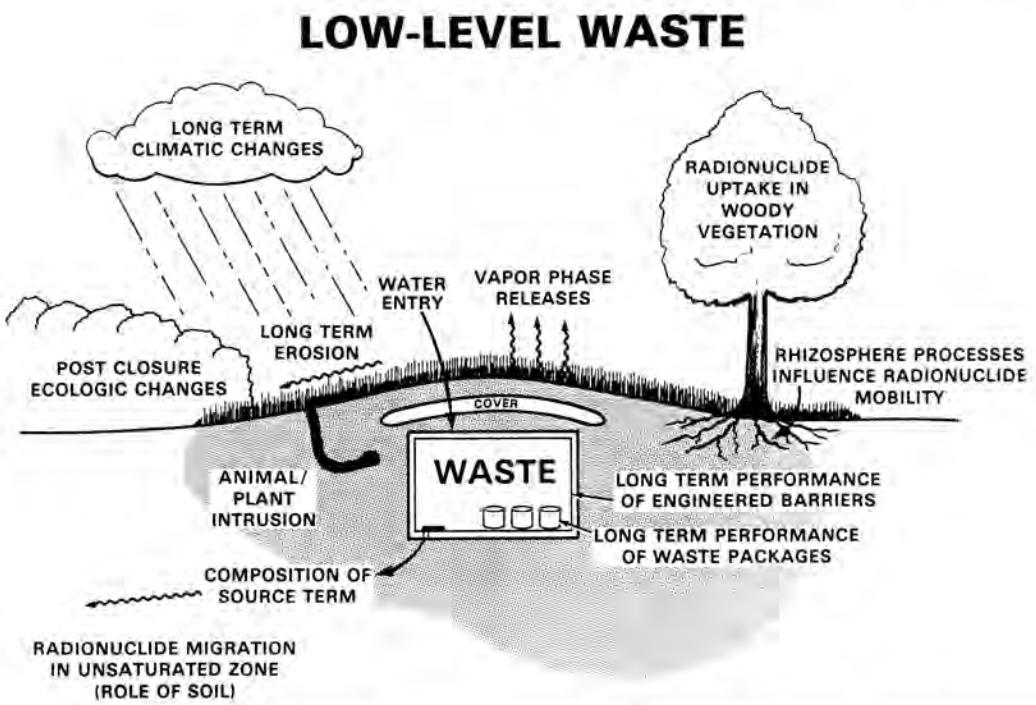

Fig. 1. Technical uncertainties associated with near surface disposal of low-level radioactive waste.

discussion of the research which is planned to resolve the issues.

WASTE FORM AND OTHER MATERIAL CONCERNS

Waste Characterization

In order for NRC to predict the behavior of LLW in the disposal environment, it is necessary for NRC to know as much as possible about the waste. However, unresolved technical and scientific issues exist regarding (1) the range of physical and chemical characteristics of commercial LLW, particularly the radiological and chemical characteristics of evaporator concentrates, decontamination waste, and decommissioning waste; (2) the characteristics of the biological component of hospital/laboratory LLW; and (3) the distribution and concentration of long-lived alpha and beta emitters in LLW from nuclear facilities.

To provide the necessary information, NRC plans to characterize low-level waste streams and solidified LLW for radionuclides and chemical content through the analysis of samples collected from actual operating nuclear power plants and other LLW generators. Various waste forms will be tested to determine if they comply with the guidance provided by the NRC branch technical position on radioactive waste classification and waste form and a proposed draft NRC regulatory guide on LLW form stability and manifest reporting.

Testing Methods to Ensure Regulatory Compliance

Safe disposal of LLW requires that the LLW disposed of at NRC-licensed disposal facilities meets the requirements for waste form and characteristics established in 10 CFR Part 61. If the NRC is to be able to ensure compliance with Part 61, confirmatory information is needed for the following: (1) reliability of existing methods for inspection of LLW at disposal facilities to verify compliance with Section 61.56 and disposal site requirements, (2) identification of process control parameters critical to dewatering and solidification of LLW, (3) reliability of methods for ensuring compliance with dewatering and solidification of LLW, (4) reliability of methods for determination of compliance with mixed waste requirements, (5) reliability of procedures for measurement of nonradiological hazardous material in LLW packages prior to disposal, (6) alternative techniques for LLW treatment where conventional techniques are unacceptable, and (7) reliability of existing screening tests on waste form.

The strategy for evaluating test methods will be to assess existing methods through literature reviews backed

by confirmatory laboratory work to establish the validity of existing test methods.

Decommissioning of Nuclear Facilities

Decommissioning of nuclear power plants will begin in the near future and will produce large amounts of LLW for disposal at commercial disposal facilities. The current level of knowledge regarding desommissioning waste is not extensive. Areas of uncertainty regarding decommissioning wastes include (1) the accuracy of the information for generation of decommissioning wastes because of the paucity of information available, (2) the technology of decommissioning of nuclear facilities, particularly the safety and costs of decommissioning, and (3) the distribution and concentration of radioactivity from decommissioning with the greatest concern being activation products at nuclear power plants.

In order to provide the desired information, NRC plans to sample and analyze products from the decommissioning of actual power plants. Attention will be given to (1) characterizing the distribution, curie quantity, and isotopes remaining prior to dismantlement/decontamination as well as the type and quantities of radioactive decommissioning waste, (2) determining estimates of unit cost for various decommissioning activities, and (3) assessing all information acquired from actual decommissioning operations to present an overview of the technology, safety, and costs for decommissioning all nuclear facilities with special emphasis on power reactors.

FAILURE MECHANISMS AND RADIONUCLIDE RELEASES

Waste Form Performance

LLW intended for disposal may take a variety of forms and each may interact differently with the disposal environment. Thus the characteristics of the waste form will contribute significantly to the overall performance of a disposal facility. In evaluating the performance of various waste forms, uncertainty lies in (1) the long-term performance of commercial LLW waste forms under disposal conditions; (2) the effect of chelating agents and nonradiological constituents on the release and transport of radionuclides from LLW, especially decontamination wastes; and (3) the leachability of activated metals from nuclear power stations and decommissioned nuclear facilities.

NRC plans to reduce uncertainties in these areas by conducting small-scale laboratory tests on actual solidified LLW waste forms from nuclear facilities followed by large-scale field tests in lysimeters. The proposed program focuses on four lines of investigation: (1) stability/leachability of solidified waste forms; (2) the effect of chelating agents and other waste constituents on decontamination LLW releases; (3) the effect of chemicals, radiation, and biodegradation on solidified LLW; and (4) the leachability of activated metals.

Radionuclide Releases

Tests to determine the potential release of radionuclides and other hazardous materials from different LLW forms have typically been conducted in laboratories. As a result, there is a need to (1) understand the relationship of laboratory leaching studies to actual field conditions that control radionuclide releases, and (2) validate the models for releases of radionuclides to the environment from LLW disposal facilities, particularly those dealing with high-volume heterogeneous trash and high-activity activated metals. Additional information is necessary to determine the regulatory applicability and usefulness of these tests and models.

NRC plans to characterize the physical and chemical processes that control releases of radionuclides, chelating agents, and other hazardous materials from LLW and then to develop mechanistic models that describe these processes. Emphasis will be given to (1) relating the results of laboratory leaching studies to actual field conditions that control releases, and (2) validating models for radionuclide releases from high-volume heterogeneous trash and high-activity activated metals.

ENGINEERED BARRIER PERFORMANCE

Long-Term Performance of High-Integrity Containers

Various styles and kinds of high-integrity containers (HIC) may be used for LLW disposal. There are outstanding questions regarding the performance of these containers and their the long-term capability of maintaining structural integrity and containing radionuclides. In particular, the effects of radiation on high-integrity containers, and the effect of biodegradation and microbial activity on high-integrity containers are not well understood.

NRC's strategy for resolving these questions is to conduct accelerated testing on a variety of materials, initially at a small scale. Promising HIC materials will then be tested at a large scale, with accelerated testing and long duration testing of replicate samples. Additional tests would be conducted on replicate samples to determine the ability of the materials to withstand structural loading and chemical/radiolytic attack.

Long-Term Concrete Performance

Since a number of States are considering LLW disposal facility designs which incorporate concrete structures, it is important to understand how the concrete will perform under disposal conditions. Unresolved issues concerning the performance of concrete include (1) predicting service

life for concrete structures, (2) the performance of barrier materials used in concrete, (3) the effect of gamma irradiation on concrete, (4) mathematical modeling of radionuclide transport through concrete, and (5) the degree of chemical retardation provided by concrete, particularly with new concrete formulations.

Much like the research strategy for evaluating the anticipated performance of HICs, NRC plans to conduct accelerated tests on a variety of concrete formulations, initially on a small scale, then moving to tests on a larger scale for the most promising formulations NRC plans to emphasize determining (1) the service life of materials, (2) the performance of barrier materials added to concrete, (3) the degree of chemical retardation provided by concrete, and (4) mathematical models for predicting radionuclide movement through concrete.

Long-Term Cover Performance

In licensing a LLW disposal facility, the NRC must be able to assess how the cover will contribute to the overall performance of the facility. Outstanding issues regarding the evaluation of cover performance include (1) control of water entry through covers, particularly when there is subsidence, (2) the distance over which a capillary barrier is effective; (3) the reliability of existing methods used for determining compliance of LLW disposal facility earthen liners and covers with regulatory requirements; (4) the erosion protection design criteria for long-term stabilization of LLW disposal facilities; (5) the reliability of existing infiltration evaluation methods for determining compliance with design specifications; (6) the load deformation responses of components that contribute to the successful performance of an LLW disposal facility; and (7)the long-term performance of engineered barriers against inadvertent intrusion.

NRC's strategy for resolving these uncertainties regarding the performance of the covers at LLW disposal facilities has been and continues to be focused on humid region problems where there is potential for infiltration of significant amounts of water through covers. Testing is being done under carefully controlled conditions in the field in large-scale lysimeters following initial small-scale laboratory tests and modeling of cover performance. Emphasis is being given to managing infiltration with or without subsidence acting on the cover. Other areas of future investigation include (1) evaluating the reliability of existing methods for determining compliance of LLW earthen covers and liners with regulatory requirements, (2) determining erosion protection design criteria for long-term stabilization of covers, (3) determining load deformation responses of components that contribute to cover performance, and (4) determining the long-term performance of intruder barriers.

SITE CHARACTERIZATION AND MONITORING

Site Characterization

As previously stated, the NRC must be able to evaluate assertions made by a LLW disposal facility licence applicant that the intended site will be acceptable under Part-61. In addition, the NRC must be able to ensure that the hydrologic and geochemical properties of the site controlling contaminant transport are measured and understood prior to issuance of a license. This means that both the surface water hydrology of the site and the ground-water hydrology of the site (including both the saturated and unsaturated zones) and the ground-water chemistry must be adequately characterized. With respect to determining surface-water hydrology for a site, unresolved issues remain including (1) estimation of long-return flooding (e.g., 500-year flood) beyond the period of record, (2) estimation of drainage changes due to natural processes or human activities over the long term (100-300 years), and (3) determination of erosion and land-form modifications over the long term.

With respect to evaluating the saturated zone hydrology, additional information is needed in the areas of (1) determining the steady-state and transient water tables for the site, (2) determining the impact of the engineered facility on existing ground-water flow paths, and (3) determining the long-term impact of regional/local ground-water use on an LLW disposal facility.

In the case of characterizing the unsaturated zone hydrology, issues that remain outstanding include (1) determining hydraulic and pneumatic properties of heterogeneous unsaturated sediments, (2) determining ambient moisture content and hydraulic potential of heterogeneous unsaturated sediments, and (3) delineating liquid and vapor pathways in unsaturated sediments because of non-uniform moisture content and pressure heads.

With regard to ground-water chemistry, additional information regarding the complex interaction of leachate with the natural ground water is needed.

Monitoring

An applicant for an LLW disposal license must collect information about the proposed site to determine if the site is suitable. The monitoring information or data collected at the site must provide an accurate description of the site. In general, more information on physical processes and monitoring techniques is available for the saturated zone than the unsaturated zone. The principal uncertainty is in the

validity of measurement techniques for the unsaturated zone.

More specifically, additional information is needed in the areas of (1) determining the effect of spatial variability on monitoring strategies; (2) determining the overall monitoring strategy for each of the pathways; (3) determining the effect of engineered barriers on monitoring strategies; (4) accounting for the extreme variability of the natural ground-water flow system in the unsaturated zone; (5) accounting for the complex interaction among contaminant chemistry, the concrete in the engineered system, and the natural ground-water flow system; (6) determining information needed to predict performance at time of closure; (7) determining post-closure ecologic changes acting on LLW disposal facilities; and (8) determining long-term climatic changes.

The strategy for meeting needs for site characterization and monitoring is to focus on (1) determining what information is needed for predicting contaminant transport to insure that information will be gathered during site characterization and as part of monitoring during operation, and (2) establishing methods for providing early warning of contaminant movement from beyond the boundary of disposal units. The greatest uncertainty is in characterizing and monitoring low-permeability saturated media and unsaturated porous media. Consequently greatest emphasis will be given to these areas.

PERFORMANCE ASSESSMENT

Performance Assessment Pathway Model Evaluation

To help assess the performance of a proposed facility and to evaluate the applicants' assertions regarding the requirements in 10-CFR-Part-61, the NRC intends to use models predicting the interactions of the waste and the site. The principal issue that requires investigation is the validity of the models used. More specifically, it is necessary to (1) determine an overall methodology for assessing the contribution of various pathways (air, water, etc.) for different scenarios; (2) be able to account for engineered barriers in the evaluation of different scenarios; (3) determine the effect of field-scale heterogeneity on the prediction of site behavior; (4) gather relevant, accurate data on surface water drainage and flood assessment into available models and calibrate for the site; and (5) gather relevant, accurate data into available ground-water models on saturated and unsaturated flow and transport and calibrate for the site.

Resolution of performance assessment issues will require technical information and predictive models resulting from research on waste form and waste package performance, failure mechanisms, radionuclide releases, engineered barrier performance, and site characterization. With regard to scenario evaluation, the strategy will be to develop a methodology for assessing (1) the contributions of various scenarios, (2) the effect of field-scale heterogeneity on the prediction of site behavior, and (3) the ability to account for engineered barriers in the evaluation of different scenarios.

Radionuclide Source Term

A major part of performance assessment is determining the radionuclide source term. Calculating the source term requires that the releases of radionuclides and chemicals leached during waste form and waste package degradation be modeled.

With regard to source term model development, issues that must be resolved include (1) accounting for the range of radiological and chemical characteristics of LLW, (2) developing a systematic disposal unit model from inventories of disposal sites, (3) determining the important parameters and processes influencing radionuclide release and transport, and (4) benchmarking a source term model against lysimeter tests and in-situ data.

With regard to the assessment of waste form degradation, the most outstanding issue is determining the corrosion mechanisms and rates, particularly for high-integrity containers.

For the assessments of waste form leaching, areas where the NRC needs additional information include (1) determining mechanisms and rates of leaching, (2) determining release from partially failed containers, and (3) coupling diffusion models with dissolution models.

To resolve uncertainties regarding the source term, NRC plans to use modeling combined with laboratory test data on waste form and package performance to quantify the release of radionuclides and other contaminants, including chelating agents, to the boundary of the disposal unit.

Transport of Radionuclides and Chemicals at LLW Disposal Sites

The last test of the potential performance of an LLW facility will be how far and how fast radionuclides will move through the site and into the environment after a source term becomes available.

In deciding whether or not to license LLW disposal facilities, the NRC will have to be able to understand and quantify radionuclide transport under unsaturated and saturated flow conditions. Uncertainties that must be resolved in this area include (1) the relative importance of mechanisms (e.g., surface complexation, ion exchange model, precipitation/ dissolution, physical and chemical sorption, matrix diffusion) controlling retardation; (2) the relationship of laboratory measurements of retardation to field measurements; (3) the role played by soil composition in

controlling radionuclide movement; (4) the role played by nonradiological waste package components in enhancing radionuclide transport; (5) the role played by biotic processes in enhancing radionuclide movement considering the complexity of organic ligands produced in the rhizosphere of vegetation and the role played by microbes in metal corrosion and in changing the chemistry of ground-water systems; (6) the role of organic complexants and microparticulates in radionuclide migration; (7) the transport behavior of C-14 and H-3, particularly in applying Regulatory Guide 1.109 methodology for determining environmental parameters, especially C-14 transfer coefficients for transport through soil and transpiration to the atmosphere; and (8) validation of radionuclide retardation/transport models to understand the transport of chemicals and radionuclides at LLW disposal sites.

NRC's research strategy is to quantify mechanisms controlling movement and to ascertain the role played by soil composition, biotic processes, organic complexes, and microparticulates. Radionuclide retardation/transport models will be validated against laboratory, large-scale lysimeter data, and field data on radionuclide releases from actual disposal facilities, including DOE facilities and foreign sites. NRC will trace the movement of releases from the boundary of disposal units into the accessible environment, with a goal of developing a complex hydrochemical transport code.

CONCLUSION

The research program described in this paper and set out in NRC's NUREG-1380, "Low-Level Radioactive Waste Research Program Plan," presents the baseline LLW research program for FY-1990 and beyond. It is intended that this baseline plan will be a living document for a stable program with a framework that is sufficiently flexible to permit revisions arising from program changes that may be needed during the course of the research program. The program plan will be revisited annually in the spring in conjunction with the annual updating of the NRC's Five Year Plan.

During FY-1990, in preparation for the first update of this plan, we expect to emphasize interactions with (1) the Department of Energy's LLW program and (2) the appropriate State organizations in order to refine and clarify both the critical LLW disposal issues and the approach NRC is taking to resolving these issues.

In addition, NRC plans to use the research conducted by other agencies like USGS and EPA and other countries as a resource to complement, augment, and enhance the research described in NUREG-1380.