UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON NUCLEAR WASTE
WASHINGTON, DC 20555 - 0001

ACNWR-0234

December 27, 2005

The Honorable Nils J. Diaz
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

SUBJECT: OPPORTUNITIES IN THE AREA OF LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT

Dear Chairman Diaz:

At a briefing of the Commission earlier this year, the Advisory Committee on Nuclear Waste (ACNW) offered to review the history of the U.S. Nuclear Regulatory Commission's (NRC's) low-level radioactive waste (LLW) regulatory framework and identify areas for which the framework might be better risk-informed. The Committee and its staff developed the enclosed white paper. This white paper provides a thorough, though not exhaustive, examination of the history and status of NRC's LLW regulatory program, based on a review of the available literature. The paper includes a summary of past ACNW advice to the Commission in this area.

The Committee believes that current regulations are fully protective of the public health and safety and fully protective of worker health and safety. The Committee also believes that this white paper provides a framework to identify opportunities to better risk-inform and improve the effectiveness of LLW management and regulation. The Committee believes the white paper will contribute to future work with staff and stakeholders. In its FY 2006-2007 Action Plan, the Committee recommends working group meetings to address specific LLW activities. The Committee also believes that where possible the improvements in risk-informing LLW regulations should be accomplished through licensing actions and regulatory guidance.

At its 165th meeting on December 13, 2005, representatives of the Office of Nuclear Materials Safety and Safeguards (NMSS) briefed the Committee on current staff activities in the area of LLW and on their preliminary views on the Committee's white paper. Development of this white paper provided a vehicle for interacting constructively with the NRC staff. The staff provided comments which have helped to improve the technical content and format of the paper. During the last two Committee meetings, LLW stakeholders had an opportunity to recommend information for inclusion in the paper to ensure the completeness of the history of the LLW regulatory program. The white paper also includes a list of stakeholders that have published recent positions on LLW management issues.

The Committee has learned that the staff is initiating a strategic planning effort to identify and prioritize the agency's major LLW activities based on the issues that have emerged over the last few years. The staff plans to select activities that will lead to improvements in the current U.S. LLW disposal system.

Some of the activities being considered include, but are not limited to:

- Reviewing past guidance on LLW storage
- Responding to a 2005 Commission order on the disposal of large quantities of depleted uranium
- Addressing 10 CFR 20.2002 issues

There are other related external efforts and initiatives underway, including the National Academy of Sciences low-activity waste study (Phase II) and a new Government Accountability Office review of best LLW management practices. The Committee is aware of these activities, will continue to follow them, and will consider the findings when they become available.

At this time, the Committee believes that it is prudent to identify a preliminary list of areas where Part 61 might be better risk-informed. The list can be expanded later, depending on the outcomes of the future efforts and reviews. The Committee believes it must communicate with staff to better leverage the Committee's work to support the staff's strategic planning in the LLW area. The Committee also believes it is important to include stakeholder views in identifying opportunities to improve the effectiveness of the regulatory framework. It is also important to identify and evaluate any unintended consequences from recommended changes. Part 61 is referenced in a number of other regulations and laws, and any opportunities for risk-informed improvements need to be carefully assessed for their impacts in these other areas.

The Committee does not intend the following list of opportunities for risk-informing LLW regulation to be exhaustive or to reflect any ranking or priority.

- Part 61 intruder scenarios are not risk-informed. They are based on bounding or extremely conservative assumptions and conditions. Furthermore, there is no guidance on performing an LLW human intrusion calculation. The assumptions used in the intruder scenario have a direct bearing on the Class A, B, and C concentration limits in Section 61.55. Section 61.58 allows for alternative requirements for waste classification and characteristics. This section could serve as a basis for better risk-informing 10 CFR 61.55.

- Part 20 has been updated to incorporate recent recommendations of the International Commission on Radiological Protection (ICRP) Section 61.41 relies on older ICRP dosimetry models that are based on a different system of dose calculation. This inconsistency can cause confusion.

- With one exception, the Subpart D siting criteria are qualitative. A more quantitative and risk-informed or performance-based approach to siting criteria might be helpful in developing new sites.

- The Part 61 institutional controls and financial assurance measures have recently been considered in the proposed revision to decommissioning guidance. The updates may provide insights into the institutional control and financial assurance requirements for LLW sites.

- Collection of environmental monitoring data is required during the operational and institutional control periods. These data could be used to increase confidence in long-term predictions of performance of LLW facilities.

- Credit for engineered barriers for waste form, waste packaging, disposal site design, and cover design were not explicitly included in Part 61. It would be an improvement to consider appropriate credit for the contribution of these engineered features to system performance.

We are forwarding the LLW White Paper as a draft final version, subject to limited peer review. We plan to issue the final version shortly as a NUREG report. Using the white paper as a starting point, the Committee is prepared to interact with the NMSS staff and stakeholders on risk-informing the management of LLW. Because of significant stakeholder interest in LLW activities, the ACNW plans to sponsor a working group meeting with NMSS to solicit stakeholder views on what changes to the regulatory framework for managing LLW should be recommended for Commission consideration.

Sincerely,

/RA/

Michael T. Ryan
Chairman

Enclosure: ACNW White Paper

ACNW WHITE PAPER:
HISTORY AND FRAMEWORK OF COMMERCIAL LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT IN THE U.S.

Submitted by

The Advisory Committee on Nuclear Waste

December 30, 2005

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ABBREVIATIONS

ACNW	Advisory Committee on Nuclear Waste
AEA	Atomic Energy Act of 1954
AEC	Atomic Energy Commission
AIF	assured isolation facility
ALARA	as low as reasonably achievable
ANPR	Advance Notice of Proposed Rulemaking
BEIR	biological effects of ionizing radiation
BRC	below regulatory concern
BWR	boiling water reactor
CAA	Clean Air Act of 1977, as amended
CEQ	Council on Environmental Quality
CFR	*Code of Federal Regulations*
CORAR	Council on Radionuclides and Radiopharmaceuticals
DCFs	disposal concentration guides
DSI	Direction-Setting Initiative
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EMCB	earth-mounded concrete bunker
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FR	*Federal Register*
GAO	U.S. General Accounting Office
GTCC	greater-than-Class C radioactive waste
HAPS	hazardous air pollutants
HIC	high-integrity container
HLW	high-level radioactive wastes
HPDE	high-density polyethylene
ICRP	International Commission on Radiation Protection
ISFSI	independent spent fuel storage installation
LLW	low-level radioactive waste
LLW Forum	Low-Level Radioactive Waste Forum
LLWPA	Low-Level Waste Policy Act of 1980
LLWPAA	Low-Level Waste Policy Amendments Act of 1985
LSV	liquid scintillation vial
LWR	light-water reactor
MAC	maximum average concentration
MCLs	maximum concentration limits
MIMS	Manifest Information Management System (of DOE)
MOU	Memorandum of Understanding
MRS	monitored retrievable storage
NACOA	National Advisory Committee on Oceans and the Atmosphere
NARM	naturally-occurring and accelerator-produced radioactive material
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act of 1970

NESHAPS	National Emission Standards for Hazardous Air Pollutants
NOI	Notice of Inquiry
NORM	naturally occurring radioactive material
NRC	U.S. Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
OTA	Office of Technology Assessment
PAM	performance assessment methodology (for LLW)
PCBs	polychlorinated biphenyls
PRA	probabilistic risk assessment
PRESTO	Protection of Radiation Effects from Shallow Trench Operations (EPA computer code)
PWR	pressurized water reactor
QA	quality assurance
RCRA	Resource Conservation and Recovery Act of 1976
RES	Office of Nuclear Regulatory Research
SA	specific activity
SLB	shallow land burial
SNF	spent nuclear fuel
SNL	Sandia National Laboratory
SRM	Staff Requirements Memorandum
SS	sources and special nuclear material
TEDE	total effective dose equivalent
TENORM	technologically-enhanced naturally occurring radioactive materials
TRU	transuranic radioactive waste
TSCA	Toxic Substances Control Act of 1976
USGS	U.S. Geological Survey
WCS	Waste Control Specialists, LLC (of Texas)

PART I – LOW-LEVEL RADIOACTIVE WASTE PROGRAM HISTORY

1 Early Approaches to the Management of Low-Level Radioactive Waste

Most establishments working with radioactive materials produces radioactive wastes since anything the radioactive material comes into contact with becomes contaminated. In the United States, thousands of establishments, both government and private, are licensed to use radioactive materials. The volume and level of activity in the wastes produced varies in direct proportion to the amount of radioactive material used. Historically, in the United States, the greatest proportion of radioactive waste produced is low-level radioactive waste (or LLW); although LLW only accounts for about 0.1 percent of the total radioactivity being disposed of. See Moeller (1992, p. 118).

The term "low-level radioactive waste" or "LLW" has carried a changing and somewhat imprecise definition over the years. Before the promulgation of the U.S. Nuclear Regulatory Commission's (NRC or the Commission) LLW disposal regulations found at Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the *Code of Federal Regulations* (10 CFR Part 61), the term LLW was exclusionary. It generally meant that portion of the radioactive waste stream that did not fit the prevailing definition of high-level (HLW) or intermediate-level radioactive wastes at the time, and with concentrations of transuranic elements less than 100 nanocurries per gram (ηCi/gm). Some LLW has radioactive material concentrations comparable to that of spent nuclear fuel (SNF) and this waste is considered by the NRC to be greater-than-Class C (GTCC) radioactive waste. Such wastes are the responsibility of the U.S. Department of Energy (DOE) to manage. Some LLW contains chemically hazardous constituents and is referred to as "mixed waste." Some of this type of LLW is subject to regulation under the provisions of the Resource Conservation Recovery Act of 1976 (RCRA).[1]

Commercial sources generate less than 34 percent of LLW by volume. It is generated at commercial nuclear power plants, research laboratories, hospitals, industrial facilities, and universities, most of whom are NRC or Agreement State licensees. Some LLW is generated in facilities that are not regulated under the NRC's authority under the Atomic Energy Act (AEA) but are regulated by the States. LLW typically consists of contaminated protective shoe covers and clothing, wiping rags, mops, filters, reactor water treatment residues, equipments and tools, luminous dials, swabs, injection needles, syringes, and laboratory animal carcasses and tissues. The radioactive material concentration can range from just above background levels found in nature to very high concentrations of radioactive material in certain cases such as parts from inside the reactor vessel in a nuclear power plant. About 97 percent of LLW decays to safe levels within 100 years whereas a small percentage of longer-lived radionuclides persist at potentially hazardous concentrations through 300 to 500 years. LLW is typically stored on-site by licensees, either until it has decayed and can be disposed as ordinary trash, or until

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[1]RCRA is administered by Environmental Protection Agency (EPA) as well as States with comparable RCRA regulations. RCRA defines a hazardous waste as any substance that is flammable, corrosive, reactive, or toxic. RCRA-classified waste must be managed and disposed in compliance with regulations for both chemical and radiological hazards. Due to legislative ambiguity (Parler, 1989), the management of mixed waste is subject to dual regulation by both NRC and the EPA. However, the review of mixed waste issues is beyond the scope of this paper. The management of mixed wastes is discussed at some length in Office of Technology Assessment (OTA – 1989) and the National Academy of Sciences (NAS – 1999).

amounts are large enough for shipment to an approved disposal site. DOE, operating under different rules from the commercial sector, disposes of much of its own LLW.[2] Government-generated LLW includes past nuclear weapons production and research, environmental restoration of federal facilities, and routine operations of the U.S. Navy's nuclear propulsion program. Review of DOE's LLW management program is beyond the scope of this paper but is described in a National Safety Council (2002) report.

1.1 Ocean Disposal

In the early years of the domestic atomic energy industry, the Atomic Energy Commission (AEC)[3] used three methods to dispose of radioactive waste – dilution and dispersion, shallow land burial (SLB), and disposal at sea.

Both commercial and noncommercially-generated LLW was first disposed only by the AEC of 1954. Commercial wastes were typically disposed in the ocean, based on the recommendations of the NAS (1959, 1962) .[4] Because most radionuclides had short half-lives, it was believed that dilution in ocean water plus decay would result in innocuous levels and pose minimal hazards to man. Furthermore, there was the view that the sea was readily available and economic to use (Raubvogel, 1982; pp. 21–23). Disposal at sea was conducted by the U.S. Navy until about 1959. Thereafter, the AEC licensed six companies to dispose of the wastes.

Ocean disposal of LLW occurred in waters greater than 1000 fathoms (about 6000 ft) following the 1954 recommendations of the National Bureau of Standards' (NBS) *National Committee on Radiation Protection* (NBS, 1954; p. 2). The disposal container most often used was a 55-gallon steel drum. The LLW was mixed with cement or concrete to assure sinking and to withstand the deep-sea pressures. Sometimes, prefabricated steel-mesh-concrete boxes of varying sizes were used instead of drums. As in the case of the steel drums, cement or concrete was mixed with the LLW to achieve the negative buoyancy necessary to assure sinking. This general design configuration was not intended to be permanent (U.S. General Accounting Office[5] – GAO, 1981; pp 2-9). It provided an estimated 10 years of radionuclide

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[2]DOE self-regulates all LLW it generates and disposes of those wastes on-site at its facilities. DOE has developed a number of "orders" that address radioactive waste management. See DOE (1998). These orders do not have the legal enforcement mechanism of Federal regulations found in the *Code of the Federal Regulations* (CFR). Instead, DOE Orders are incorporated by reference into individual government contracts for vendors who operator the disposal facilities on behalf of DOE. DOE Order 435.1 (DOE,1999a) covers all HLW, LLW, transuranic (TRU) waste, and the radioactive components of mixed waste. Chapter IV of the implementing manual (DOE, 1999b) for DOE Order 435.1addresses the management of LLW. DOE does not classify LLW using NRC's Part 61 system. See NAS (1999 and 2003) and National Safety Council (2002).

[3]The AEA initially assigned the AEC the functions of both encouraging the use of nuclear power and regulating its safety. The AEC regulatory programs sought to ensure public health and safety from the hazards of nuclear power without imposing excessive requirements that would inhibit the growth of the industry.

[4]The NAS generally recommended that no 300-mile section of the coast line should contain more than three disposal areas and that adjacent disposal areas be separated by at least 75 miles. The NAS also had specific recommendations on the total quantity of activity disposed at any one location monthly as well as annually.

[5]In July 2004, the GAO was renamed the *General Accountability Office.*

containment[6] in the marine environment (NAS, 1959, p. 1).

More than 60 disposal sites were distributed between 5 major disposal locations in the Pacific Ocean, 1 in the Gulf of Mexico, and 11 in the Atlantic Ocean. The LLW was not evenly distributed among the sites; three sites received about 90 percent of the LLW, by volume. The number of LLW containers and the associated activity disposed is summarized in Table 1. Overall, it is estimated that about 95 percent of the containers disposed in the Atlantic and Pacific Oceans, and the Gulf of Mexico were 55-gallon drums (NAS, 1971; p. 36).

In 1970, the AEC ended its practice of disposing of LLW at sea. In the early 1980s, there was renewed interest in ocean dumping. In a report dated April 1984, the National Advisory Committee on Oceans and the Atmosphere (NACOA) recommended (pp. 6-7) that the present policy of excluding the use of the ocean for LLW disposal be reversed.

1.2 Land Disposal

In the 1960s, commercial interest in ocean disposal began to decline and had ended completely by 1970. One of the principal reasons was the adverse public reaction to polluting the ocean. The other motivation was economic. Ocean disposal was reported to cost as much as $48.75 per 55-gallon drum compared to $5.15 per drum for burial on land (Mazuzan and Walker, 1997; p. 367). For the reasons cited above, the AEC decided to endorse a new disposal policy permitting land burial using commercial disposal sites. Under this policy, it was envisioned that the private sector would identify sites with favorable geologic and meteorologic conditions and provide the same disposal service to commercial generators, but at lower cost. The intent was to geographically locate disposal sites in those regions generating the wastes. At the time, the Oak Ridge National Laboratory (ORNL) and the National Reactor Testing Station (now the Idaho National Engineering Laboratory) were the principal LLW handlers of wastes generated by then-AEC licensees. In contrast to ocean disposal, LLW generated there and at other at federal facilities was being disposed at about 16 major and lesser Federally-owned sites (NAS, 1976; p. 18-19).

Because of concerns about long-term institutional controls at potential commercially-operated sites, in January 1960, the AEC proposed that they be located on Government-owned land, regulated and licensed by the Government (Mazuzan and Walker, 1997; p. 366). As an interim measure, until a commercial disposal capability became available, the AEC decided to accept non-government LLW for disposal (*Op cit.*, p. 367). In September 1962, the AEC authorized private firms to dispose of commercial LLW on land. The first privately-operated LLW land-burial service was near Beatty, Nevada, on State-owned land. The site was operated by Nuclear Engineering, Inc., one of the six firms already licensed by the AEC to commercially dispose of LLW at sea. At the time, licensing criteria specific to the disposal of LLW did not exist. The only applicable licensing criteria were the AEC's general regulations at 10 CFR 20.302(a) and (b).

Between 1962 and 1971, the six shallow-burial LLW disposal facilities were licensed and operated to dispose of the Nation's commercial LLW. Most of these facilities were located within the boundaries of or adjacent to a much larger federal reservation operated by the AEC

[6] With the exception of the radionuclides ^{90}Sr, ^{137}Cs, and possibly ^{60}Co.

Table 1. Summary of LLW Ocean Disposal Operations in the United States. Compiled using NAS (1959, p. 5), NAS (1971; p. 37), and NACOA (1984, Appendix C). However, the reader should note that questions have been raised in the past about the accuracy of past record-keeping and the accuracy of these statistics (Raubvogel, 1982, p. 23).

Water Body	Years of Disposal Activity	Number of Individual Disposal Sites	Number of Containers	Estimated Activity at Time of Packaging (Ci)
Atlantic Ocean	1951-1967	+24	34,203 [a]	79,482.9
Pacific Ocean	1946-1970	+34	56,261	14,980.5
Gulf of Mexico	< 1959	2	79	< 25

a. Includes unpackaged and liquid wastes.

(see Table 2). Four of the disposal sites – Beatty, Barnwell, Maxey Flats, and West Valley – were licensed by their respective host states through the Agreement State Program with the AEC (the predecessor to the NRC) under Section 274 of the AEA. The remaining two sites (Richland and Sheffield) were licensed by the AEC as their hosts had not become Agreement States at the time of licensing. Following the licensing of the second LLW disposal site (Maxey Flats), the AEC stopped accepting commercial LLW at its own facilities in May 1963.

The commercially-operated sites adopted the practice of near-surface, shallow-land burial (SLB) disposal technology adhered to at existing AEC facilities at the time. This disposal method relies on relatively simple engineering designs to isolate wastes from infiltrating water. The natural (geologic) characteristics of the site are the principal attenuators of any radioactive material that might be released to the accessible environment. There were no systematic site selection criteria or design requirements that could be used to establish the best mix of features necessary to contain and isolate the wastes. Disposal generally involved clearing and grading the land and excavating shallow unlined trenches (generally less than 50 feet deep) that would be used to receive the waste. At the time, LLW had no specific packaging requirements for disposal.[7] It was packaged in a variety of container types that were randomly dumped or stacked into the trenches. The waste was placed into the trenches generally on a first-come, first-serve basis. Trenches were then backfilled using materials removed during trench excavation, compacted, and graded to create an earthen mound cap necessary to prevent rainwater ponding and to promote runoff. The earthen cap was then re-seeded to grow a short-rooted protective grass cover. To preclude inadvertent intrusion, disposal sites were surrounded by a security fence. The working technical assumption behind this near-surface disposal method was that the nature and rates of natural processes acting on the earthen trench system would be sufficient to slow the movement of radionuclides from the disposal trenches to the accessible environment until they had decayed to acceptable background levels found in nature (EG&G Idaho, 1994; p. 4).

In 1973, the AEC asked the NAS to independently review the shallow-land disposal practices at its facilities. The AEC was particularly interested in identifying "... undesirable existing conditions and disposal practices ..." as well as identifying corrective actions, such as "... changes in current burial practices, changes in conditioning of [LLW] materials for burial, and special treatment of the ground prior to disposal ...." See Pittman (1973). The reason for this request was that routine monitoring at some of their sites had begun to reveal that the disposal trenches were not containing the wastes and radionuclides were being released (NRC, 1977a; p. 17). At the time, the AEC was also particularly concerned about the long-term management of the transuranic constituents of its wastes (NAS, 1976). In 1976, the NAS published its findings and recommendations following the review of solid LLW management practices at AEC facilities (later to become the Energy Research and Development Administration or ERDA[8]). Although the NAS found no serious deficiencies in past federal disposal practices, they did make numerous administrative as well as technical recommendations for it to consider.

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[7]Department of Transportation (DOT) regulations for the transportation of radioactives wastes were first promulgated in 1979 (44 FR 1851).

[8]In 1974, the AEC was reorganized into the NRC and ERDA. See Section 2 of this paper for further details.

Table 2. Past and Current LLW Disposal Facilities. Taken from EG&G Idaho (1994), unless otherwise noted.

Site	Operational Period	Original Licensing Authority (year)	Status	Area (acres)[a]	Disposal Volume (10e6 ft^3)	Waste Form Characteristics			Comments
						By-product material (10e6 Ci)	Source Material (10e6 lbs)	Special Nuclear Material (lbs)	
Beatty, Nevada	1962 – 1992	AEC (1962)	Closed	80 (60)	4.7	0.64	4.0	605	A site adjacent to the now-closed LLW disposal facility is currently operated as a RCRA- and PCB-approved disposal facility. [b]
Maxey Flats, Kentucky	1963 – 1977	State (1962)	Closed	280	4.7	2.4	0.533	950	Designated as a EPA Superfund Site in 1986. Remediation completed in 1991.
West Valley, New York	1963 – 1975	State (1963)	Closed	3345 (22) [c]	2.5	1.3	1	125	LLW operations ceased in 1975 when burial caps leaked contaminated water.
Richland, Washington	1965 – present	AEC (1965)	Open	100 [d]	13.6 [e]	36.1 [e]	13.5 [f]	351 [f]	Co-located within the Hanford nuclear reservation. Disposal site leased from the government. Disposal fees lower than Barnwell but higher than Envirocare.
Barnwell, South Carolina	1969 – present	State (1971)	Open	300	24.8 [e]	12.8 [e]	33.6 [f]	6739 [f]	Originally licensed for above-ground LLW storage. In 1971, LLW burial was approved. Highest disposal fees in the country.
Sheffield, Illinois	1968 – 1978	AEC (1967)	Closed	170 (20)	+3	3	0.06	126	Attempts to expand disposal capacity in 1975 were unsuccessful because of the detection of contaminated leachate, effectively ending site operations. In 1988, the Sheffield operator agreed to a 10-year monitoring plan with the State.
Clive, Utah	1991 – present	State (1991)	Open	540	25.0 [g]	11.3 [g]	NA	NA	Initially licensed to accept naturally-NORM. 1991 amendments permitted the disposal of LLW. Envirocare license has been amended 10 times to allow for the disposal of more types of LLW.

a. Actual disposal area, in parenthesis, smaller than area comprising disposal site.
b. In June 1988, the site operator, U.S. Ecology received a joint State-Federal RCRA permit to dispose of hazardous chemical wastes at a location adjacent to the LLW disposal site (Howekamp, 1996; p. 3). Pre-RCRA classified waste types had been disposed at this site since 1970. In 1978, the company also received EPA approval to operate a polychlorinated biphenyl (PCB) storage and disposal facility at the Beatty site.
c. Site owned by New York State includes multiple radioactive waste management areas.
d. Hanford nuclear reservation encompasses an area of 1000 acres.
e. Data for the period 1995-98 taken from Fuchs (1996, p. 6, 1997, p. 6; 1998, p. 6; and 1999, p. 7). Data for the period 1999 though June 2005 taken from MIMS.
f. Data only through 1994.
g.   Data for period June 1992 through May 2005 taken from MIMS.

1.3 Early Performance Issues

After several years of operation, the West Valley, Maxey Flats, and Sheffield[9] sites began to encounter surface and/or ground water management problems. These problems coupled with other early LLW disposal practices resulted in the unexpected release and transport of radionuclides from the disposal sites. Key failure modes included waste container exhumation due to surface erosion, ground failures (subsidence) caused by inadequate waste container compaction, and the filling and subsequent release of contaminated leachate from disposal trenches resulting from infiltrating ground water (commonly known as the so-called "bath tub effect"). Because the disposal "units" were leaking, decisions were made to suspend operations and close the sites in the 1970s.

The remaining LLW sites had problems of a different type. The Beatty and Richland sites were temporarily closed in 1979 by the Governors of those States as a result of waste packaging violations and transportation safety issues. When the volume of waste shipped to the South Carolina site began to increase because of closures and interruptions at the other sites as well as a large increase in LLW generated following the Three Mile Island incident, there was concern that the facility would bear sole responsibility for the disposal of the Nation's commercial LLW. As a result, in 1979, the Governor of South Carolina ordered that waste acceptance operations be scaled-back by 50 percent over a 2-year period [see EG&G Idaho (1994)].

To address some of the past LLW site performance concerns as well as to develop geohydrologic guidelines that could be used to establish technical criteria for selecting, evaluating, licensing, and operating new LLW disposal sites, the U.S. Geological Survey (USGS) received direct LLW appropriations for the first time in 1975 (Schneider and others, 1982; p. 57) leading to the preparation of various reports. [See summaries in Trask and Stevens (1991), for example.] To reduce the potential for the environmental transport of radionuclides at disposal sites, the NAS (1976, pp. 67-68) independently recommended that arid sites in the west be considered based on the view that the geohydrologic settings there would be less complex and hence the view that performance could be more reliably predicted. Incidentally, the USGS reached this same opinion as early as 1974 recommending 17 types of earth-science information needed to predict the rate and direction of radionuclide transport. See Papadopulos and Winograd (1974). Other recommendations were made that some form of engineered barrier, working in concert with the natural system (geosphere), be integrated into future LLW facility designs (Battelle Memorial Institute, 1976; pp. 24, 48).

Technical issues notwithstanding, there still was the practical matter facing LLW generators that there had been a reduction in existing disposal access because of site closures and operational interruptions. Also, there was a mismatch in the geographic location of the remaining disposal facilities (mostly in the west) whereas most of the waste generation was in the east. The three remaining States with operating sites made it clear that they would not continue to accept all of the Nation's LLW (GAO, 1983; p. 7).

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[9]Actually, contaminant transport was not discovered at the Sheffield site until after operators of the closed site attempted to re-open with expanded disposal capacity (EG&G Idaho, 1994; pp. 37-38).

2 CONGRESSIONAL ACTIONS

Congress abolished the AEC in the Energy Reorganization Act of 1974 (Public Law 93-438). The act placed the AEC's regulatory functions into the newly created NRC and placed the atomic energy promotional functions within ERDA, which were later absorbed into DOE following its creation in 1977.

2.1 The U.S. Nuclear Regulatory Commission and 10 CFR Part 61

The NRC began operations on January 19, 1975. The NRC (like the AEC before it) focused its attention on several broad issues that were essential to protecting public health and safety. Initially, NRC (and the AEC) regulated LLW using a collection of generic regulations specified in 10 CFR Parts 30 ("Rules of General Applicability to Domestic Licensing of Byproduct Material"), 40 ("Domestic Licensing of Source Material"), and 70 ("Domestic Licensing of Special Nuclear Material"). However, in response to the needs and requests expressed by the public, the States, Congress, industry and others, one of the earliest rulemaking efforts the Commission was to undertake was the development of a set of comprehensive requirements for licensing the land disposal of LLW.

In 1976, the GAO published a report that reviewed existing private and federal LLW disposal practices in light of the reported operational and performance irregularities identified at some disposal sites. Among other things, that review identified the need for studies and criteria to judge the suitability of LLW disposal sites as well as the need for standards to determine when releases from disposal sites reached unacceptable levels and corrective actions needed (GAO, 1976; pp. 19–21). In parallel to the GAO review, the NRC had formed a task force to examine its programs as well as those of the existing Agreement States that regulated commercial LLW disposal. Among the recommendations of that task force (NRC, 1977a; p. ii), was the need for NRC to "accelerate" the development of its LLW regulatory program. Shortly thereafter, the NRC (1977b) published a program plan that described the elements and schedules for implementing an integrated LLW program. This program plan included plans for the development of an environmental impact statement (EIS) and a yet-to-be-defined LLW regulation.

NRC began development of its LLW regulation in 1978 by relying on an extensive National Environmental Policy Act (NEPA) scoping process.[10] Early in that process, the Commission determined that comprehensive standards, technical criteria, and licensing procedures were needed to ensure public safety and long-term environmental protection in the licensing of new sites as well as the operation and closure of existing ones. The staff determined that the most viable approach to the regulation would be an "umbrella" regulation applicable to land disposal

[10]The National Environmental Policy Act of 1970 (Public Law 91-190) initially requires federal agencies to integrate environmental values into their decision-making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. NEPA also requires that all Federal agencies prepare an EIS "for major actions significantly affecting the quality of the human environment." To meet this basic requirement, Federal and State governments, at all levels, now routinely prepare detailed EIS. In deciding to develop a LLW regulation, the NRC determined that the promulgation of Part 61 qualified as a major federal action.

The Council on Environmental Quality (CEQ) is responsible for developing regulations that implement NEPA. CEQ defines the scoping of an EIS at 40 CFR 1501.7 as "... an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to the proposed action...."

of most types of LLW. The challenge was that the regulation had to apply to a broad range of geologic/geomorphic conditions within the United States as well as apply to disparate waste streams. The other challenge was that early in the scoping process, the NRC staff determined that inadvertent re-entry into a LLW disposal area could not be precluded (NRC, 1980; 45 FR 13105). Consequently, the staff explored ways of classifying LLW for use in standardized exposure scenarios as a way of predicting potential doses to receptors. See Rogers (1979) and Rogers and others (1979). The staff also considered both generic and specific disposal methods in the context of an EIS that considered the costs, benefits, and impacts of a base-case disposal concept as well as alternative concepts. From those analyses and studies, performance objectives and technical criteria were proposed by the Commission in a draft regulation designated 10 CFR Part 61 (NRC, 1981; 46 FR 38081).

Following several years of development, the Commission issued a final Part 61 rule in December 1982. The regulation covered all phases of shallow, near-surface LLW disposal from site selection through facility design, licensing, operations, closure, post-closure stabilization, to the period when active institutional controls end. The regulation also established the procedures, criteria, terms, and conditions on which the Commission would issue and renew licenses for the shallow-land burial of commercially-generated LLW (see Section 5 of this report). Among other things, Part 61 at §61.55, introduced a three-tier waste classification system for LLW based on the concentrations of the longer-lived radionuclides. These classes are designated Classes-A, -B, and -C in ascending order of potential radiological hazard, and the regulation had specific design standards applicable to each class.

2.2 The Low-level Radioactive Waste Policy Act of 1980

At the same time the NRC established a LLW regulatory framework, Congress passed the Low-Level Waste Policy Act of 1980 (LLWPA – Public Law 96-573). This act set forth a Federal policy that LLW disposal was best handled on a regional basis. The Act made States responsible for disposing of their own LLW generated within their borders,[11] and encouraged the States to form interstate compacts and establish regional disposal sites rather than establishing 50 separate disposal sites. The act was passed in response to policy recommendations from several states[12] and state-supported organizations, including the National Governors' Association and the National Conference of State Legislatures, intended to address past and present LLW management issues. The other key provision of LLWPA was that compacts were allowed to exclude LLW generated outside their borders.

Following passage of the act, the States began to enter into negotiations to form the required compacts. The States were generally committed to the compact arrangement. Shortly following its passage, 40 States had entered into agreements or were negotiating to form seven required compacts (GAO, 1983, p. 16). However, in its review of the compact-forming agreement process, GAO observed that the agreement process was "slow and drawn-out" despite having been devised by Congress (see Table 3). The GAO also observed that only

[11] By January 1, 1986, except for LLW generated by the Federal Government.

[12] Washington State, in conjunction with Nevada and South Carolina, sought passage of LLWPA because of the imbalance between the volumes of LLW those states were generating and the wastes they were receiving for disposal from outside their respective states. See Washington State Department of Health (2004, p. 43).

Table 3. Administrative Process for Establishing LLW Compacts. Taken from GAO (1983, p. 10). Compacts formed through this process are described later in Table 6 of this paper.

Step	Description of Activity
1	States negotiate among themselves to form regional Interstate Compacts of two or more states.[a]
2	Once formed, proposed Interstate Compacts draft Interstate Compact Agreements.
3	Drafted Interstate Compact Agreements are approved by the state legislatures and signed by the Governors in each state participating in the Interstate Compact.
4	Ratified (approved) Interstate Compact Agreements are to be approved by a majority of both Houses of Congress.
5	Following Congressional approval, each Interstate Compact is to form a Commission to administer the compact agreement.[b, c]

a. Alternatively, if a State chooses not to participate in the Interstate Compact process, it must indicate its intent not to do so. States deciding to act alone to meet their own LLW disposal needs still need to undertake the process steps outlined in Footnote b.
b. Once formed, the Interstate Compact Commission is responsible for ensuring that its member states (i) screen the region defined by the Interstate Compact to identify candidate disposal sites, (ii) select a preferred site and perform the required environmental assessment, (iii) prepare a LLW license application, and (iv) construct and operate the disposal facility, once the license application is approved.
c. Compacts can choose to defer the site selection/license application development process to a private entity.

three of the tentative compact regions had operating disposal sites, and those sites had been in existence before the passage at the act. GAO estimated that once a compact agreement had been entered into, it would take an additional 5 years before the disposal site was ready to receive LLW (*Op cit.*, pp. 20-21). Nevertheless, despite the progress being made GAO (*Op cit.*, p. 15) concluded that no new disposal sites would be operating until sometime after 1988, 2 years after the Congressionally mandated dated 1986.

When it became apparent that the deadline for operating new disposal sites would not be met, decision-makers recognized that adjustments to the existing LLW act were needed. Moreover, the three States with operating disposal sites made it clear that they would not continue to accept all of the nation's LLW. But before Congress could amend the 1980 act, an "understanding" was necessary between Nevada, South Carolina, and Washington – the States with operating disposal facilities – and the 47 unsited States. Following negotiations, these three states agreed to continue to receive out-of-State wastes for an additional 7 years, subject to certain conditions which where later reflected in the 1985 amendments to the act (NRC, 1989c p. 13).

2.3 The Low-level Radioactive Waste Policy Amendments Act of 1985

On January 15, 1986 Congress passed the Low-level Radioactive Waste Policy Amendments Act of 1985 or LLWPAA (Public Law 99-240). LLWPAA extended the original January 1, 1986, deadline to develop new disposal facilities by 7 years to January 1, 1993. Because new LLW disposal facilities were expected to be operational by the 1993 date, the existing States with operating LLW disposal facilities had the right, at that time, to decline receiving LLW from outside of their respective compacts. In exchange, the unsited States and regions were required to meet newly-established milestones and deadlines (see Table 4).[13] If States failed to comply with the specific LLWPAA milestones, the three States operating disposal facilities were authorized to deny disposal access those states in violation of the milestones. LLWPAA also included the following provisions:

- the establishment of financial penalties on waste disposed of at existing disposal facilities if certain milestones were not met.
- making the Federal Government responsible for disposing of commercial LLW exceeding Part 61 Class-C concentration limits.
- specifying which categories of LLW were exempt from LLW disposal facilities.

In passing the act, Federal agencies were given expanded responsibilities in the area of LLW (see Table 5). Specific new responsibilities were also assigned to DOE and the NRC. DOE was now required to do the following:

- dispose of GTCC-designated wastes,

[13]In a 1992 decision (New York vs. United States et al. – 505 U.S. 144) , the U.S. Supreme Court struck down the "take title" provision requiring that States must take title to their LLW if a disposal facility were not available by 1996.

Table 4. Milestones and Deadlines Defined by the LLWPAA.

Milestone Date	LLWPA Requirement
By July 1, 1986 ...	Each State shall join a regional compact by ratifying compact legislation or, by the enactment of legislation or the certification of the Governor, indicate its intent to develop its own LLW disposal facility.
By January 1, 1988 ...	Each compact region or the host State in which its LLW disposal facility is to be located shall develop a siting plan for such a facility providing detailed procedures and a schedule for establishing a facility location and preparing a facility license application and shall identify a developer to implement such plan.
	Each non-sited compact region shall identify the State in which its LLW disposal facility is to be located, or shall have selected the developer for such facility and the site to be developed, and shall identify a developer to implement such plan.
By January 1, 1990...	Each State (or the designated disposal facility developer) shall have submitted a complete application (as determined by the NRC or the appropriate agency of an agreement State) for a license to operate an LLW disposal facility or, in lieu of the license application, the Governor's written certification to the NRC, that such State will be capable of providing for, and will provide for, the storage, disposal, or management of any LLW generated within such State and requiring disposal after December 31, 1992, and include a description of the actions that will be taken to ensure that such capacity exists.
By January 1, l992...	A complete application (as determined by the NRC or the appropriate agency of an Agreement State) shall be filed for a license to operate an LLW disposal facility within each non-sited compact region or within each non-member State.
By January 1, 1993...	Each State (or its compact region, where applicable) is expected to have provided a disposal facility for all the LLW it generates, and disposal rights at the three existing disposal facilities (Barnwell, Beatty, and Richland) will end.
	If a State (or, where applicable, a compact region) is unable to provide a disposal facility for its LLW, those States in the compact region shall, upon the request of the LLW generator or owner, be obligated to take title to and possession of the waste, or assume financial liability for costs associated with its storage and maintenance.
	If a State (or, where applicable, a compact region) is unable to provide a disposal facility for its LLW, the State (or States) will have to forfeit rights to rebates of previous surcharge payments made by LLW generators (or owners) because of the State's failure to meet earlier LLWPAA milestones.
By January 1, 1996...*	If a State (or, where applicable, a compact region) is unable to provide a disposal facility for its LLW, those States in the compact region shall, upon the request of the LLW generator or owner, be obligated to take title to and possession of the waste.

* In 1996, the US Supreme Court found that this provision of the 1985 Act was unconstitutional.

Table 5. Federal Responsibilities for the Management and Disposal of Commercial LLW. As defined by various Federal statutes.

Agency	Responsibility
Department of Energy	Overall lead agency for national planning of commercial LLW management and disposal. Assist in the forming of Interstate Compacts and establishing site selection procedures. Also undertake (or sponsor) research and development in the area of LLW disposal technology, and transfer that technology to the private sector.
Department of Transportation	Regulating waste containers, transportation vehicles, and other interstate aspects of LLW transport. [a]
Environmental Protection Agency	Establishing overall federal radiation protection guidance and environmental standards. [b]
Geological Survey	No basic responsibility for the management of LLW. Conduct basic research in the geological sciences and develop basic data for application in the development of disposal criteria. Also provide technical advice in the assessment of specific disposal sites.
Nuclear Regulatory Commission	Regulating and licensing the commercial and non-defense governmental use of source, by-product, and special nuclear material, including the licensing of commercial LLW disposal facilities.

a. Through a Memorandum of Understanding, the NRC and DOT have delineated their respective responsibilities for the transportation of radioactive wastes. The NRC regulates packaging for wastes containing high amounts of radioactive materials to assure safety and safeguards during transportation. DOT regulates all other aspects of radioactive waste transportation.
b. See Section 6.4.1 of this paper for more information.

- manage the collection of and disbursal of LLWPAA-levied surcharges[14],
- provide financial and technical assistance to the States and compacts, and
- generate certain status reports on the management of national LLW inventories.

For its part, the NRC was now required to the following:

- review LLW disposal facility license applications,
- develop standards and procedures for exempting certain LLW from disposal in licensed facilities,
- provide regulatory and technical assistance to Agreement States[15], and
- determine procedures for granting emergency access to LLW facilities for wastes generated in other regions[16].

Section 10 of LLWPAA also required that NRC establish standards for determining when radionuclides are present in waste streams in sufficiently low concentrations or quantities as to be "below regulatory concern" or BRC, and therefore not subject to NRC regulation. As early as February 1980, the staff indicated it intent to establish a *de minimis level* [17] for commonly-used, short-lived radioisotopes. In August 1986, the Commission published its proposed policy statement outlining its plans to establish certain new BRC rules and procedures (NRC, 1986a; 51 FR 30839). The Commission proposed that if radioactive materials did not expose individuals to more than 1 millirem per year (mrem/yr) or a population group to more than 1000 person-rem per year, they could be eligible for an exemption from full-scale regulatory control. However, this exemption would not be granted automatically; the NRC would consider requests from licensees that met the dose criteria through its rulemaking or licensing processes. The Commission intended that its BRC policy would apply to consumer products containing small amounts of nuclear materials and other sources of very low levels of radiation such that those types of wastes could safely be disposed in sanitary land-fills. The policy was also to provide a framework for making future exemption decisions and reviewing previous exemptions by which small quantities of low-level radioactive materials could be largely exempted from existing

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[14]"Surcharges" were financial penalties imposed by DOE on waste generators if certain LLWPAA milestones were not met. These penalties were in addition to the basic disposal charges imposed by the disposal facility operator.

[15]Under Section 274 of the AEA, the NRC can relinquish portions of its regulatory authority to license and regulate byproduct materials (radioisotopes), source materials (uranium and thorium), and certain quantities of special nuclear materials to the States. The mechanism for the transfer of NRC's authority is an agreement signed by the Governor of the State and the Chairman of the Commission, in accordance with Section 274b of the act. "Agreement States" therefore are those States whose Governors have entered into such limited agreements with the Commission. At present, there are 33 NRC Agreement States.

[16]Promulgated as 10 CFR Part 62 (NRC, 1989a; 54 FR 5409).

[17]A *de minimus level* is one in which the radioactivity in the waste is sufficiently low that the waste can be disposed as ordinary, non-radioactive trash (NRC, 1980; 45 FR 13106).

regulatory controls (NRC, 1986b; p. 1). The Advisory Committee on Nuclear Waste (the ACNW or the Committee) provided two sets of comments to the Commission on the proposed BRC Policy in 1988. The NRC's proposed BRC policy was received unfavorably by both Congress and the public. As a result, it was officially withdrawn by the Commission in June 1993 (Walker, 2000; p. 120).

3 EFFORTS TO SITE NEW LLW DISPOSAL FACILITIES

The objectives of the LLWPA and LLWPAA were to provide for more LLW disposal capacity on a regional basis and distribute the responsibility for the management of LLW equitably among the States. In response to these two acts, by 1998, 44 states entered into 10 Interstate compact agreements. Compact membership varied from two to eight States per compact. As part of the compact agreement process, host States for the future disposal facilities were agreed-to and site-screening commenced. For those who already had not done so, designated host States entered into Agreement State programs with the NRC, and subsequently developed the regulatory and technical capabilities necessary to administer their respective programs. By definition, this would have included developing a regulatory framework compatible with the requirements of Part 61 and other NRC guidance (see Section 5 of this report).[17] In most cases, host states assigned the responsibility for implementing their respective programs to existing State agencies or created new or quasi-State authorities. Two regional compacts (Nebraska and California) delegated the disposal facility development responsibilities to private sector firms while retaining the regulatory functions.

As a result of these efforts, 7 out of 10 of the regional compacts were able to meet the first three milestones of the 1985 act leading to the submission of license applications. Regulatory authorities in four states (California, Illinois, Nebraska, and Texas) received license applications requesting authorization to construct new disposal facilities. California, however, the host State for the Southwestern Interstate Compact, was the only state able to proceed sufficiently in the licensing process to authorize the issuance of a construction authorization (see Table 6).

Despite these overall efforts, none of the States or compacts have been able to successfully develop new LLW disposal facilities. In their 1989 review, OTA found that some States enacted bans to legally restrict SLB disposal even though Federal regulations found that particular disposal method technically sound. Other issues cited by OTA included the rising costs of LLW disposal (at the time of the study, it had trebled in 20 years), and the management of mixed wastes. In California a contingent construction authorization for a new facility (Ward Valley) was granted by the State but the land transfer from the federal to the State government was never completed, effectively ending the facility's start up. LLW generators continue to rely on the existing disposal sites. Only one new disposal facility has actually been licensed – the Envirocare LLW disposal facility in Clive, Utah – was achieved outside of the LLWPAA framework.[18] Citing industry sources, the GAO (2004, p. 9) reports that national expenditures on various disposal facility development efforts since the passage of the LLWPAA may have reached approximately $1 billion. In its 1999 review of the national LLW program, GAO (p. 5)

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[17] The Envirocare facility is located in Clive Utah and was initially licensed by the Utah Department of Environmental Quality to accept naturally-occurring radioactive waste or NORM (i.e., uranium mill tailings) for disposal. In 1991, the Envirocare license was amended by the State to permit the disposal of Class-A LLW, including mixed wastes, from all states except those in the Northwest Interstate Compact. On November 1, 1999, the operators of the Envirocare facility submitted a license amendment to the State to allow it to receive and dispose of containerized Classes-A, -B, and -C LLW.

[18] Current Commission regulations regarding NRC's relationship with the Agreement States are contained in 10 CFR Part 150 ("Exemptions and Continued Regulatory Authority in Agreement States and in Offshore Waters Under Section 274").

Table 6. **LLW Compacts and LLWPA Milestone Status.** Host state for the disposal facility is designated in bold type. "C" means completed disposal facility development milestones. Compiled using GAO (1992, 1999, and 2004).

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
APPALACHIAN	Delaware Maryland **Pennsylvania** West Virginia	1985C	*see Comments*	----	----	----	Voluntary siting process suspended in 1991 because no municipality volunteered to host the disposal site.
CENTRAL	Arkansas Kansas Louisiana **Nebraska** Oklahoma	1982C	1989C	1990C	*see Comments*	----	A 1998 Nebraska denial of an application to construct was overturned in April 1999 by a US district court. In May 1999, Nebraska legislature voted to withdraw from Central Interstate compact. In 2004, a Federal appellate court ruling affirmed an earlier Federal district court decision that Nebraska, as a designated host State, is liable for $151 million in damages for reneging on its obligations to the Central Interstate compact to build a disposal facility by denying a license application for reasons not related to the merits of the initial application.
CENTRAL MIDWEST	**Illinois** Kentucky	1984C	1991C	1991C *see Comments*	----	----	In 1992, the Illinois legislature rejected conclusions of an earlier siting decision, effectively ending the license application review process. Since then, a new siting review process has been established as well as a cost-benefit analysis to determine whether a disposal facility should be built based on current LLW volumes.
MIDWEST	Indiana Iowa **Michigan** [a] Minnesota Missouri **Ohio** Wisconsin	1982C	*see Comments*	----	----	----	In 1997, the Midwest Interstate Compact Commission decided to suspend siting process noting that certain waste management action had taken place reducing the volumes of LLW being generated within the compact.

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
NORTHEAST (later renamed **ATLANTIC**)	Connecticut [b]	1985/2001C	*see Comments*	----	----	----	State legislature terminated siting efforts in 1992 citing the availability of out-of-state disposal capacity.
	New Jersey [b]		*see Comments*	----	----	----	State siting board terminated siting efforts in 1992 also citing the availability of out-of-state disposal capacity.
	South Carolina		C	C	C	1969 C	In 2001, South Carolina legislation restricted the use of the Barnwell disposal facility to generators in the three-member Atlantic Interstate compact after mid-2008.
NORTHWEST	Alaska Hawaii Idaho Oregon Montana Utah **Washington** Wyoming	1985C	C	C	C	1965 C	The compact's regional disposal facility is the existing Richland (Washington) facility.
ROCKY MOUNTAIN	Colorado **Nevada** New Mexico	1985C	C	C	C	1965 C [c]	Since the closure of the Beatty site, the compact has contracted with the Northwest Interstate compact to dispose of LLW at the existing Richland facility.
SOUTHEAST [d]	Alabama Florida Georgia Mississippi **North Carolina** Tennessee Virginia	1985C	*see Comments*	----	----	----	South Carolina withdrew from compact in 1995. State siting board terminated operations in 1997 because insufficient funding. In 1999, North Carolina withdrew from the compact (GAO, 1999; p. 72). In 2000, North Carolina joined the re-named Atlantic Compact (GAO, 2004; p. 28).

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
SOUTHWESTERN	Arizona **California** North Dakota South Dakota	1985C	1988C	1989C	1993C	*see Comments*	From 1993-96, the Secretary of the Interior deferred making a land-transfer decision necessary to construct and operate the State-approved Ward Valley site while a number of technical review and administrative activities were underway by the government and the NAS. See GAO (1977). In a 1999 court decision brought on by California, it was found that the Federal government was not required by Federal law to transfer (sell) the land. Since that decision, there have been no additional siting activities by the State.
TEXAS	Maine **Texas** Vermont	1998C	1992C	1992C *see Comments*	----	----	In 2003, the Texas legislature designated a geographic area in the State as acceptable for a new disposal facility, and the host state's regulator developed a license application process for this facility.
UNAFFILIATED	District of Columbia New Hampshire Rhode Island Puerto Rico	These States do not intend to build LLW disposal facilities. They will seek storage and disposal arrangements with other States.					
	Massachusetts	n/a	*see Comments*	----	----	----	In 1995, the state hired a contractor to conduct a state-wide screening process. In 1996, the process was terminated because of renewed access to the Barnwell disposal facility (GAO, 1999; p. 76).

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
	New York	n/a	*see Comments*	----	----	----	In 1988, the state's independent siting commission conducted a multi-step screening process to identify candidate sites for evaluation as LLW disposal sites. In its independent review of the site selection process, GAO (1992) found that the state did not adhere to its administrative procedures for selecting candidate sites. The Governor later suspended the siting process. In 1995, the state legislature declined to fund the siting commission (GAO, 1999; p. 76).

a. Michigan expelled from compact in 1991 for not acting in good faith to locate an acceptable disposal site. Ohio is the alternate host State.
b. Originally intended as dual host states in 1985 as part of the Northeast Interstate compact region. In 2001, the two States, along with South Carolina, formed the Atlantic Interstate compact region.
c. The Beatty facility provided disposal service to the Rocky Mountain Interstate Compact until 1992.
d. The Barnwell site in South Carolina provided the Southeast Interstate Compact region with disposal service until 1995, at which time it withdrew from the compact.

identified some common reasons for the lack of success in providing new disposal facilities. The reasons included the following:

- the controversial nature of nuclear waste disposal and public opposition to the siting of new LLW disposal facilities.
- the declining volumes of LLW being generated as a result of waste minimization and processing into safer forms.
- the high costs associated with the siting, licensing, constructing, and operating of new disposal facilities.
- the continued availability of existing disposal capacity.
- the consideration of alternatives to disposal – e.g., assured isolation.

4 CURRENT PROGRAM STATUS

In the mid-1990's, the NRC significantly scaled-back its LLW program for budgetary reasons. At the time, the actions were justified as the NRC already had a regulatory framework in-place sufficient to review a Part 61 license application,[19] and the Commission had relinquished its licensing authorities to those host states with a lead role in developing new LLW disposal facilities. Another factor cited was the lack of national progress in siting new disposal facilities.

To keep abreast of national LLW developments under the current reduced program, the staff has done several things. For example, the staff regularly monitors developments within the national program by attending regular meetings of the *Low-Level Radioactive Waste Forum*.[20] The staff has also performed several specific tasks, as directed by the Commission. They include efforts to improve the transparency of NRC decision-making as it relates to Section 20.2002 requests[21] and determine whether depleted uranium needs to be added to the Part 61 waste classification system.[22]

Consistent with earlier Congressional direction, DOE established a *National Low-Level Radioactive Waste Management Program* to develop and make available useful information concerning LLW management. Under contract to DOE, the operating contractor for the Idaho National Engineering and Environmental Laboratory prepared technical reports covering many LLW areas – e.g., SLB corrective measures (EG&G, 1984), LLW laws and administration (EG&G, 1985), and environmental monitoring (EG&G, 1989).[23] From 1979 to 2000, annual State-by-State assessment reports were also prepared that provided information on the types and quantities of LLW (e.g., Fuchs, 1999). In 1986, DOE developed a computerized *Manifest Information Management System* (or MIMS[24]) to monitor the management of commercial LLW. This system later subsumed the annual State-by-State assessment reports series. In 2000,

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[19]This framework is discussed in more detail in Sections 6.4.4 and 7.1 of this paper.

[20]Until 1985, representatives of the Governors worked to achieve the goals of the LLWPA through a committee of the National Governors' Association. After passage of the 1985 amendments, representatives of compacts and States established a separate organization, known as the *Low-Level Radioactive Waste Forum* (LLW Forum), to promote the objectives of the new Federal law and the compacts. In 2001, the LLW Forum became an independent nonprofit organization.

[21]From time to time, the Commission receives requests to permit the disposal of small quantities of low-activity radioactive materials, on site, at existing NRC-licensed facilities. Disposal exemptions to Part 61 are allowed under NRC's regulation at §20.2002 ("Method for obtaining approval of proposed disposal procedures") to Part 20 ("Standards for Protection Against Radiation"). Staff guidance regarding the on-site disposal of small qualitites of radioactive waste can be found in Goode and others (1986), Neuder (1986), Neuder and Kennedy (1987). The Commission can grant other types of disposal exemptions under §§ 20.2003 (sanitary sewer releases), 20.2004 (incinerator releases), and 20.2005 (biomedical waste releases).

[22]In a decision dated October 19, 2005, the Commission directed the staff to determine whether depleted uranium produced by uranium enrichment facilities warrants consideration under §61.55(a) of NRC's waste classification tables. See Diaz and others (2005).

[23]Time limitations in the development of this paper did not permit a review on the DOE-sponsored literature.

[24]The MIMS webs site can be found at *http://mims.apps.em.doe.gov/*.

Congress stopped appropriating money for the DOE's national LLW program with the exception of the funds necessary to maintain MIMS. In its 2004 evaluation of the National program, GAO (pp. 14–16) found shortfalls in the quality of the MIMS data and recommended that the NRC take responsibility for generating the required reports. The GAO was particularly concerned that the unreliability of the data would make it difficult to forecast future disposal needs for all classes of LLW.

In its 1994 and 2000 reports described earlier, the GAO assessed three management options to address concerns about limited or no disposal access for LLW generators. The three options suggested were:

- retain the existing compact approach and allow it to adopt to the changing LLW situation;

- repeal the existing LLW legislation and allow market forces to respond to the changing LLW situation; or

- use existing DOE facilities for the disposal of commercial LLW.

Most recently, in November 2005, the GAO was directed by congress to report on approaches to improve the management of LLW within the United States. This examination is expected to include a review of best practices internationally (GAO, 2005).

4.1 Recent Disposal Facility Developments[25]

The Beatty LLW disposal site was permanently closed in 1992 by order of the State's Governor. The site is currently operated as a RCRA and PCB waste disposal facility. The nation's only remaining disposal facilities are at Barnwell, Richland, and Envirocare. Only the Envirocare facility receives mixed LLW. The Barnwell facility presently receives Classes-A, -B, and -C LLW. In 2000, the South Carolina Legislature restricted disposal access to the facility to only members of the Atlantic Interstate Compact after mid-2008. In 2001, a license amendment was approved by the state regulatory authority in Utah to allow the Envirocare facility to dispose of Classes-B and -C LLW. Under state law, approval of the legislature and governor are now required before Classes-B and -C waste can be received (GAO, 1994; p. 33). In late 2005, the governor voiced his opposition and placed a moratorium on the acceptance of these wastes.

Attempts are also underway to site a LLW disposal facility in Andrews County, Texas, by Waste Control Specialists (WCS), LLC. The WCS facility is located on 14,400 acres. More than 1340 acres is currently permitted to treat and dispose of RCRA waste and Toxic Substances Control

[25] Taken primarily from GAO (2004).

Act (TSCA) materials. The Andrews WSC site is also permitted for GTCC LLW storage, PCB-contaminated waste treatment, storage and land disposal, AEC Section 11e.(2) waste storage, and NRC exempt and exempt-mixed waste land disposal, including selected NORM waste. In 2003, the Texas Legislature passed legislation that allows a private entity to make an application for an NRC Part 61 LLW disposal site (Lauer, 2003; p. 13). In August 4, 2004, WSC submitted a license application to the Texas Commission on Environmental Quality to construct a near-surface LLW disposal facility. That license application is currently under review. The State regulatory agency has found the license application to be complete and expects to publish the draft license and hearing notice in mid-2006.

4.2 Assured Isolation

As an alternative to permanent (geologic) disposal, the concept of *assured isolation* has been proposed by Newberry and others (1995). Unlike the prevailing Part 61 disposal concept, assured isolation was considered to be a more publicly-acceptable alternative for it calls for caretaker oversight to allow for the indefinite storage of LLW in an engineered facility until such time that the waste no longer poses a radiological hazard. Conceptually, assured isolation is envisioned to be simpler from a technical standpoint in that structures, systems, and components (SSCs) of the *assured isolation facility* (or AIF) do not have to be designed to maintain their intended safety functions after the facility is closed, as would be the case with permanent disposal. AIF is envisioned to effectively function as a monitored storage system, with the capability for regular inspections and maintenance of SSCs to ensure that the wastes are being contained and, if necessary, retrieved. Unlike a Part 61 disposal facility, which has several performance objectives, applying to both the pre- and post-closure operational phases, the AIF would only have to meet the Part 20 worker safety standards so long as the wastes remained hazardous,. Because the site (geosphere) is no longer a consideration in the performance of the system, the need for detailed site characterization, complex performance assessment analyses, and the development of a long-lived waste package is obviated. Also see Newberry and others (1996).

In a September 2002 SRM, the Commission directed the NRC staff to explore interest in the assured isolation concept and develop a rulemaking plan that could be used to provide a foundation for a Commission decision on whether to develop such a rule. The need for a rulemaking plan was prompted by the development of a draft AIF regulation by the State of Ohio, and the State's subsequent request for NRC to review and comment on that draft regulation. At the time, at least 5 other states were contemplating similar regulations. The Ohio rule is now the only AIF regulation currently in effect. For its part, the NRC has no regulations or criteria for the design and operation of an AIF. To ensure consistency with any future state regulations, the staff has previously recommended the development of an AIF rule. However, before proceeding to develop such a rule, the staff surveyed the States, Interstate Compacts, and industry representatives to determine how widespread the support was for an NRC regulation in this area; responses to that survey suggested only limited interest. See SECY-03-0223 (NRC, 2003). Should NRC promulgate an AIF regulation, Ohio and any other states with similar regulations would be required to modify those regulations to be consistent with NRC's, based on the Commission's AEC authorities. In a January 2004 SRM, the

Commission has directed the staff to defer action on the development of an AIF rule and annually review the need for further action in this area.

The literature does not indicate if there has been a detailed comparison between the AIF and the prevailing Part 61-based disposal concepts. In a 2005 review of DOE's LLW management programs, the GAO (2005) recommended the use of life-cycle cost analyses to evaluate competing LLW management alternatives.

4.3 Stakeholder Views

In addition to the National program reviews by the GAO and OTA, some LLW stakeholder organizations and entities have prepared position papers expressing their views on various matters related to the management of commercial LLW. Some of these position papers also call for regulatory changes to NRC's LLW regulatory framework. A Internet search summarized in Table 7 indicates that there are several published position papers. These position papers provide different perspectives and sometimes conflicting positions on stakeholder views. No attempt has been made to summarize the opinions expressed. The reader is referred to the individual papers to better understand the respective views of the organizations who have prepared these papers.

Table 7. Availability of Stakeholder Position Papers on LLW.

Organization/Entity	Internet Homepage	LLW Policy Statement	
		Title	Date
INTERSTATE LLW COMPACTS			
Southeast	http://www.secompact.org/	"Management of Low-Level Radioactive Waste"	November 30, 2005
STAKEHOLDER ORGANIZATIONS			
American Nuclear Society	http://www.ans.org/	Disposal of Low-Level Radioactive Waste – Position Statement No. 11	November 2004
California Radioactive Materials Management Forum (Cal Rad Forum)	http://www.calradforum.org/	"A National Solution for a National Problem"	2003
Council on Radionuclides and Radiopharmaceuticals (CORAR)	http://www.corar.org/	"Council on Radionuclides and Radiopharmaceuticals Position Paper on Low-level Radioactive Waste Disposal"	April 6, 2001
Health Physics Society	http://www.hps.org/	"Low-level Radioactive Waste Management Needs a Complete and Coordinated Overhaul"	September 2005 (revision)
League of Women Voters	http://www.lwv.org//AM/Template.cfm?Section=Home	"Environmental Protection and Pollution Control" [general subject of LLW management]	July 5, 2005
LLW Forum	http://www.llwforum.org/	"Management of Commercial Low-Level Radioactive Waste"	September 22, 2005
National Governor's Association	http://www.nga.org/portal/site/nga	NR-19 Policy Position: "Low-Level Radioactive Waste Disposal Policy"	February 26, 2004
National Mining Association	http://www.nma.org/	"The National Mining Association's and the Fuel Cycle Facilities Forum's White Paper on Direct Disposal of Non-11e.(2) Byproduct Materials in Uranium Mill Tailings Impoundments" [includes a discussion of LLW]	No date

PART II: NRC's LLW REGULATORY FRAMEWORK

5 INTRODUCTION

Without exception, all past case studies of LLW disposal pointed to the need to improve its management to ensure that the wastes, once disposed, would not create a public health hazard. Applied to the disposal of LLW, this meant not only protecting workers and the public during the operational phase of waste disposal but also assuring that once a facility was closed, the disposal "system" contained the waste for a period of time sufficient to ensure that it no longer posed a hazard.

In response to the needs and requests of the public, the States, industry and others, the Commission promulgated specific requirements for licensing the near-surface land disposal of commercial LLW[26] at Part 61. These requirements were developed during the 5-year period from 1978 to1982 following the 1977 recommendations of an internal NRC task force (NRC, 1977b). NRC's final commercial LLW disposal regulation was published in the *Federal Register* on December 27, 1982 (47 FR 57446). The rule applies to any near-surface LLW land disposal technology. This includes SLB, engineered land-disposal methods such as below-ground vaults (BGVs), earth-mounded concrete bunkers (EMCBs), and augered holes. The regulation emphasizes an integrated-systems approach to LLW disposal, including consideration of site selection, site design and operation, waste form, and disposal facility closure. To lessen the burden on society over the long periods of time contemplated for the control of radioactive material, Part 61 emphasizes passive rather than active systems to minimize and retard releases to the environment. Various subparts of the rule cover general provisions and procedural licensing aspects, as well as those subparts covering the performance objectives, financial assurances, State and Tribal participation, and records, reports, tests and inspections. Existing LLW disposal sites were not required to conform to the Part 61 requirements, although many of the features of the regulation were incorporated as license conditions for existing facilities.

Since 1983, the NRC staff has developed several documents intended to aid in the implementation of Part 61. Foremost among these are NUREG-1300 – "Environmental Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility (Environmental Report)" (NRC, 1987); NUREG-1199 – "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility" (NRC, 1991a); and NUREG-1200 – "Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility" (NRC, 1994). NUREG-1199 details the necessary components and information needed in a license application for an LLW disposal facility required under Part 61. NUREG-1200 provides guidance on the process that the staff would use to review a Part 61 license application. Consistent with the requirement in the LLWPA to review a Part 61 license application within 15 months of its receipt, NUREG-1274 (Pittiglio, 1987) was prepared that describes the staff's approach to reviewing any potential license application. In issuing an Part 61 LLW disposal facility license, the NRC would be required to prepare and issue an EIS. NRC Regulatory Guide 4.18 (NRC, 1983b) and NUREG-

[26]LLW waste is defined in Part 61 the same way as it is defined in the LWPAA and the Nuclear Waste Policy Act of 1982, as amended [i.e., radioactive waste that is not classified as HLW, TRU waste, SNF, or byproduct material as defined in Section 11e.(2) of the AEA (i.e., uranium or thorium tailings and waste).]

1300 (NRC, 1987) provide guidance to the staff on what should be included in the EIS. Because of the key role quality assurance (QA) has played in the nuclear program, the NRC staff has also developed specific QA guidance for the LLW regulatory arena. NUREG-1293 (Pittiglio and Hedges, 1991) provides specific guidance on how to meet the Part 61 requirements.[21] NUREG-1383 (Pittiglio and others, 1990) provides QA guidance related to site characterization activities. Additional QA guidance for potential Part 61 applicants is provided in Chapter 9 of both NUREG-1199 and NUREG-1200.[22]

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[21]The criteria described in NUREG-1293 are similar to the criteria contained in Appendix B of 10 CFR Part 50. Although Appendix B to Part 50 is not applicable to NRC's LLW disposal regulation, the criteria it contains are basic to any nuclear regulatory QA program.

[22]Section 8 of the LLWPAA also directed the NRC to identify and publish technical information for disposal methods other than SLB. NRC complied with this provision by publishing NUREG-1241 (Higginbotaham and others, 1986) and NUREG/CR-3774 [Bennett and others (1984), Bennett (1985), Bennett and Warriner (1985), Miller and Bennett (1985), and Warriner and Bennett (1985)]. In addition, the NRC revised NUREG-1199 and NUREG-1200 to address BGVs and EMCBs, in addition to SLB.

6 APPROACH TO DEVELOPING PART 61[23]

Before the promulgation of Part 61, there were no standards nationally or internationally defining what level of safety was necessary to protect the public from disposed LLW. The only comparable regulations in place that defined "safety" were the AEC generic criteria relating to occupationally-exposed workers during the operation of licensed nuclear facilities found at Part 20. These criteria define the maximum permissible levels of radiation in unrestricted areas. Although Part 20 does not contain technical criteria or standards specific to the disposal of licensed materials such as LLW, it was nevertheless used to license early LLW disposal facilities because the regulation was generally intended to protect both workers and members of the public.

Consistent with the staff's 1977 plan, the Commission published an *Advance Notice of Proposed Rulemaking* (or ANPR), in October 1978 (43 FR 49811), inviting advice, recommendations, and comments on the scope of the EIS the staff was developing in support of the new Part 61 regulation. The EIS proposed was not intended to be a generic EIS on LLW disposal vis-a-vis the NEPA process. Rather, it was intended to serve as the document that would provide the bases and record for Commission decisions on the requirements to be set out in the forthcoming regulation. To ensure that no viable LLW disposal alternatives would be overlooked, as part of the scoping process, the NRC sponsored a technical study (Macbeth and others, 1978) that was included as part of the 1978 ANPR. Also see Denham (1988).

The comments received by the Commission during the ANPR were used to scope and form the content of the draft EIS, designated as NUREG-0782 (NRC, 1981) as well as the preliminary draft regulation which was made available for public comment on February 28, 1980 (45 FR 13104). The draft regulation identified the licensing procedures, performance objectives, and technical requirements necessary for the licensing of LLW disposal facilities. The proposed regulation also reflected NRC's long-standing ALARA or "as low as reasonably achievable" regulatory principles. During the summer and fall of 1980, the Commission also sponsored four regional workshops to provide stakeholders with an opportunity to discuss the issues addressed in the proposed Part 61 rulemaking. The Commission received 36 comments from the public on the ANPR. The respondents strongly supported the Commission's development of specific standards and criteria for the disposal of LLW (NRC, 1981; 46 FR 38082). Among the comments received were specific recommendations that a system was needed for classifying or segregating the waste based on (radiological) hazard (46 FR 38082). After consideration of the information received, the Commission published its proposed Part 61 LLW regulation on July 24, 1981 (46 FR 38081). The NRC staff and one of its technical assistance contractors, ORNL, conducted a series of three symposia between 1981 and 1983 intended to examine technical issues related to the siting, design, and/or performance of LLW disposal facilities as well as the proposed draft Part 61 regulation. See Yalcintas and Jacobs (1982a) and Yalcintas (1982b and 1983).

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[23]The purpose of this section is to provide some general background on the approach used to develop Part 61 and in doing so, highlight a few key issues considered important at the time. This summary is not intended to be exhaustive. NUREG-0782 and NUREG-0945 provide a more detailed account of this development process as well as the staff's and Commission's disposition of key issues related to that development.

The Commission received comments from 107 individuals, organizations, and entities on the proposed regulation. The general response to the proposed rule was considered favorable by the Commission (NRC, 1982b; 47 FR 57447). For the most part, the commenters were evenly split, either declaring explicit support of the rule and the Commission's proposed overall regulatory approach or, offering constructive comments on specific aspects of the proposed rule without taking a general position on the rule itself or offering to support, with reservations. No State group or existing LLW disposal site operator expressed opposition to the proposed rule. Only 15 commenters expressed outright opposition to the rule or some significant portion of it. As a result of the generally favorable comments received, the Commission finalized Part 61 in 1982 (47 FR 57446). To support publication of the final rule the staff also issued a final EIS – designated NUREG-0945 (NRC, 1982a), which contained a detailed analysis of the comments received on the draft EIS as well the decision bases and staff positions in support of the final regulation.

6.1 Elements of the LLW Regulation

The Part 61 regulation applies to any land disposal technology for commercial LLW. The regulation covers all phases of LLW disposal from site selection through facility design, licensing, operations, closure, and post-closure stabilization, to the period when active institutional controls end. The regulation also establishes the procedures, criteria, terms, and conditions on which the Commission would issue and renew existing licenses. The requirements emphasizes an integrated-systems approach to shallow land disposal, including consideration of site selection, site design and operation, waste form, and disposal facility closure. Because of the long periods of time contemplated for the control of radioactive material, Part 61 also emphasizes passive rather than active systems to minimize and retard releases to the environment. To provide flexibility in siting and designing disposal facilities, a LLW waste classification system was devised based on half-lives and concentrations of radioactive materials that are expected to be in the wastes. All commercial LLW classes are subject to minimum waste form characteristics.

The Part 61 regulation is organized into several subparts. Various subparts cover general provisions and procedural licensing aspects, as well as those subparts covering the performance objectives, financial assurances, State and Tribal participation, and records, reports, tests and inspections. In addition, the regulation specifies requirements that must be met by the waste generator, including requirements for waste form and content, waste classification, and waste manifests. See Appendix A for more details on major subject areas in the regulation.

As noted previously, the focus of the Part 61 regulation is on the long-term disposal of LLW, which was unique concept at the time. The Commission employed a top-down, integrated systems approach to developing it. It proposed performance goals (objectives) that accounted for both the short-term as well as long-term radiological exposures. The regulation was oriented towards overall performance goals defined in Subpart C that define the objectives (regulatory policies) to be achieved in waste disposal. The performance goals are supported by a narrow (minimum) set of prescriptive technical standards in Subpart D based on past operating experience judged to be important to meeting the overall performance goals. The intent of this regulatory approach was to allow some flexibility to LLW disposal facility developers, consistent with a particular geologic and/or geographic setting, in choosing advantageous siting and design features and operating practices necessary to achieve the performance goals (NRC,1981; 46 FR 38083). The Commission chose not to include too much specificity in setting the technical standards as that would require considerable amount of detailed knowledge about the spectrum of designs, techniques, and procedures for disposing of LLW. Alternatively, the Commission chose to provide prospective applicants flexibility in deciding how the performance objectives would be met.

Through the earlier scoping process, the site (geosphere) is considered to be part of the containment system which, in concert with specific design features (e.g., clay liners, engineered barriers), would slow the expected release of LLW to acceptably small quantities of radioactive material over time. The technical requirements apply to site suitability, specific features of the facility design, operations and closure, waste classification, waste form and certain institutional assurance measures. Requirements for environmental monitoring are also established in the post-closure phase to assess the overall system's performance. These minimum technical requirements were collectively deemed important to achieving successful waste disposal by the Commission based on past reviews and experience. By relying on multiple barriers, reliance is not placed on any one component of the LLW disposal system to ensure that the performance objectives are met. Rather, all components of the system, acting in concert, are intended to contain and isolate the wastes. This concept of multiple barriers is consistent with the Commission's traditional views regarding *defense-in-depth*[24] and aids in the decision-making for issuing a Part 61 license using the standard of *reasonable assurance*.[25]

6.2 Who Should be Protected and What Should the Level of Protection Be?

As noted earlier, the Commission's intent in promulgating Part 61 was to develop an umbrella regulation that addressed all phases of the LLW disposal cycle. This meant that the regulation had to be sufficient to cover disposal operations and closure as well as the long-term period of waste isolation.

The performance objectives defined in Subpart C were developed expressly for commercial LLW.[26] They define the overall level of safety to be achieved by disposal. Although the Commission's requirements at Part 20 were considered appropriate to existing types of nuclear facility operations, they were not considered appropriate for the long-term disposal of LLW (NRC, 1989; p. 7). The Part 61 performance objectives are intended to provide protection from normal disposal facility operations as well as longer-term protection from the release of radioactive materials after facility closure, including accidental exposures caused by inadvertent

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[24]"Defense-in-depth" is more of an NRC design principle and operational philosophy rather than a regulatory requirement per se. One of the essential properties of the principle is the concept of employing successive physical barriers that provide redundancy to what is in this case a disposal system containing LLW. This principle applied to NRC's regulatory programs is discussed in more detail in NRC (1995, 60 FR 42622), NRC (1998b), and Powers (1999).

[25]Section 61.23 defines thee standards the Commission will use to determine if it can issue a Part 61 license application to operate a LLW disposal facility. In issuing any license, the Commission would apply the standard of *reasonable assurance*. Historically, the concept has been used by the Commission to describe the acceptability of information submitted in a license application that wold demonstrate that the licensed facility would perform as intended and in doing so, protect public health and safety. See Schweitzer and Sastre (1987, pp. 4–5).

[26]In the absence of applicable environmental radiation standards promulgated by EPA, the NRC developed the four performance objectives through rulemaking. See Section 6.4.2 of this paper for further information.

intrusion and waste exhumation, in which the intruder is unaware of the presence of the waste. The technical requirements in Subpart D are considered minimum requirements intended to help ensure compliance with the performance objectives.

The Commission was also concerned about the potential for inadvertent intrusion once institutional control of the site had ended and knowledge of the hazard ceased. In relying on near-surface disposal, there is the possibility for exposures to ionizing radiation resulting from man's efforts to reclaim a disposal site for productive use such as farming, housing, or natural resource development. Archeological activities and scavenging could also lead to waste exhumation. The staff recognized early in the EIS scoping process that because there was no basis for predicting these types of behavior, there was no way to guarantee that inadvertant human intrusion at the site would not occur in the future (NRC, 1981; 46 FR 38083). Consequently, the staff determined that future generations, in effect, should be afforded the same level of protection as the general population today. Although widely used today in the evaluation radioactive waste disposal systems,[27] the human intruder scenario was a unique concept at the time it was first proposed by the Commission.

In another type of inter-generational equity concern, the Commission also took the position that future generations should not bear the responsibility for managing wastes produced by past generations. To address this issue, the Commission took the position that the disposal facility, its components, and even certain types of LLW should be robust and recognizable for some minimum period of time into the future while the radiological hazard still exists so as to preclude the potential for releases into the environment (NRC, 1982; 47 FR 57457, 57459).

As a result of these considerations, during the rulemaking scoping process, the following performance goals found in Subpart C were proposed:

- Protect members of the public and occupationally-exposed workers during facility operation (at §§61.41 and 61.43).

- Protect inadvertent human intruders entering the facility once disposal operations ceased and the facility decommissioned (at §61.42).

- Assure the long-term physical stability of the disposal facility to obviate the need for long-term maintenance after decommissioning of the facility (at §61.44).

These performance goals effectively defined Commission's policy on who would be protected (and when) as the result of the operation of a reference LLW disposal facility. The first performance goal applied to short-term exposures associated with the pre-closure phase of facility operations. As noted earlier, the intent of this requirement was to ensure that LLW disposal facilities would be operated in conformance with the same standards for radiation protection that the Commission already applied to existing materials licensees. As a

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[27]The deterministic modeling of human intrusion is now a widely-employed analytical technique that is used to evaluate the robustness of radioactive waste disposal concepts to the disruptive consequences of borehole drilling. See, for example, Charles and McEwen (1991), Nuclear Energy Agency (1991), Berglund (1992), and Wescott (2001).

consequence, this performance goal required compliance with existing Part 20 criteria for radiation exposure to workers.

With the update of Part 20 (NRC, 1991c) there are now two different bases for doses in §§61.41 and 61.43. The whole body and organ dose limits specified in §61.41 are based on the older system of dose calculation based on the methods documented in the *International Commission on Radiological Protection* (ICRP) *Publication 2* (ICRP, 1960). This system is based on the principles of maximum organ burdens and intakes so annual doses are limited to the maximums allowed for critical organs. Now Part 20 is based on ICRP *Publications 26* and *30*. See ICRP (1977 and 1979-88,[28] respectively). The principles in these reports are based on estimating doses for 50 years for intakes that occur in a year of practice and limiting exposures so that the assigned dose for intakes in that year do not exceed limits.

The practical result is that under the new system long lived radionuclides are more restricted that under the old system. In short a dose expressed in mrem/yr whole body using the concepts in §61.41 is not necessarily equivalent to 25 mrem total effective dose equivalent (TEDE) assigned to a year of practice using the concepts in Part 20 and therefore by greater if more long lived radionuclides are involved in internal exposures. The difference is greater if more long lived radionuclides are involved in internal exposures.

Although appropriate for the pre-closure phase of operations, Part 20 was not considered adequate for the post-closure phase as the manner, the timing, and the nature of potential radioactive releases for specific types of LLW would be more difficult to predict under any scenario – natural or otherwise – for any particular repository design. To determine what specific technical requirements might be needed to achieve safety during the post-closure phase, a more definitive assessment of the potential radiological hazard was needed. To conduct this assessment, two logical exposure scenarios came to mind: (a) an event in which radioactive material is transported off-site (i.e., ground water migration) as a result of the natural evolution of the disposal system and its environs – what is now commonly referred to as undisturbed or “base case” scenario”; or (b) a potential event similar to the one already described above in which individuals come into unintentional, direct contact with the buried waste – what is now commonly referred to as a disturbed or “human intrusion” scenario.

The remaining three performance goals were intended to address potential long-term exposures that might be encountered during the post-closure phase (period) of the disposal facility life-cycle. In proposing these performance standards (and the supporting technical requirements), the Commission recognized that the period of greatest reliance on the disposal system would be well-after the facility had been closed as some LLW could still remain hazardous for up to 500 years. Because of the potential for humans to egress into a disposal facility and come into contact with radioactive waste, albeit inadvertently, it was quickly recognized that the intruder scenario would likely be the key scenario driving decisions on what combination of siting and design technical requirements were necessary to provide a level of

[28] *ICRP Publication 30* was issued in four parts between 1979 and 1988. See ICRP (1979, 1980, 1981, and 1988). Including indexes and supplements, there are 8 volumes associated with the *Publication 30* series.

protection sufficient to ensure safety of the public and the environment taking into account the hazard posed by certain types of LLW over the long time-frames of concern.[29]

6.3 10 CFR Part 61 Scoping Activities

Based on the review of the past performance of some LLW disposal sites, it was recognized that certain LLW management practices (i.e., siting and design decisions, preferred waste forms, packaging techniques) had already produced favorable disposal outcomes. For some sites, LLW had been contained in disposal cells and no releases of radioactive material to the accessible environment had occurred. The challenge in developing the new regulation was to understand what combination(s) of practices and/or standards could be relied on to produce the same favorable outcomes at future disposal sites. Understanding the answers to theses questions would help address the question as to what level of protection was necessary for a LLW disposal facility.

6.3.1 NUREG-0456: A Proposed LLW Dose Assessment Model

In developing the technical criteria and standards for SLB, it was recognized that it would be necessary to define the concentrations and quantities of waste acceptable for disposal under a LLW regulation. This meant developing an analytical methodology that allowed the interfaces between key components of a LLW disposal system – i.e, specific siting and design features, performance goals, and source terms – to be defined quantitatively. More specifically, for certain key radionuclides and waste forms, the staff needed to understand what existing LLW management practices and/or disposal methods worked best in containing wastes and limiting doses.

One of the early analyses the staff conducted as part of the draft EIS scoping process was the development of a generic LLW dose assessment methodology. For certain key radionuclides and waste forms, the staff sought to identify (and quantify) an optimal set of model parameters (e.g., disposal practices) that could be used to control doses. Using a consistent set of relatively simple exposure pathways, a deterministic dose assessment methodology was proposed in NUREG-0456 (Adam and Rogers, 1978). It was applied to two reference disposal methods (sites) and a preliminary three-tier LLW classification system. Estimated dose impacts could be compared to dose guidelines developed for the study[30] to determine maximum allowable concentrations (limits) of radionuclides appropriate for each of the proposed waste classification tiers through “what-if” types of analyses.

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[29] If there were complete assurance that a commercial LLW disposal site would not be subject to human intrusion, then the Part 61 rulemaking effort would have been reduced to determining what technical criteria where necessary to ensure that the disposed wastes would remain within the confines of the disposal facility until such time that the LLW had decayed to natural background levels. However, because complete assurance was not possible, the rulemaking effort needed to account for the eventuality that there would be human egress into a disposal site and exhumation of or contact with the wastes, specific design precautions and/or waste form specifications might be necessary to protect against the more hazardous, longer-lived LLW forms, specifically Classes-B and -C wastes (NRC, 1982; 47 FR 57451).

[30] By law, EPA had the responsibility for the development of radiation exposure standards and criteria to be applied to LLW. However, at the time of the staff’s scoping analyses, such criteria were not available. Consequently, the NRC staff postulated a reasonable set of guidelines to provide protection from the effects of ionizing radiation, based on a review of the recommendations of national and international standard-setting organizations, consistent with *ICRP Publication 26* (ICRP, 1977). See Adam and Rogers (1978, pp. 6–10). Also see discussion in Section 6.4.1 of this paper for more information.

The dose methodology developed was the traditional release-transport-exposure-consequence model. The methodology consisted of a basic dose model, dose guidelines, exposure scenarios, and calculational basis. Two mechanisms or exposure scenarios were considered in which individuals come into contact with the waste. They were the “on-site reclaimer” scenario and “off-site transporter” scenario. The on-site reclaimer scenario considered six potential exposure pathways versus four for the on-site transporter scenario (see Table 8). These exposure scenarios were considered to be reasonably conservative. All features of the NUREG-0456 dose methodology were deterministic. The intruder scenario was assumed to occur with a probability of one, 150 years after the end of administrative controls at the disposal site, when most of the short-lived radionuclides have already decayed. The off-site transporter scenarios were also calculated deterministically and were assumed to occur immediately after the waste was disposed. In this latter scenario, there is essentially no credit for radionuclide decay and the releases therefore could be considered instantaneous exposures.

Once developed, the overall methodology was benchmarked against existing analog sites to validate the computational features of the analysis. The analog locations selected were the Maxey Flats LLW disposal site, in Kentucky, and the Latty Avenue uranium mill tailings site, in Missouri. In addition, based on the study’s dose limit guidelines limits, the methodology was also able to provide preliminary estimates the maximum concentrations or inventories of radioactive material in LLW that were permissible to ensure that dose exposures did not exceed the assumed safety goals for maximum individual and total population dose. Before publication, all features of the NUREG-0456 methodology and results were peer-reviewed to provide a critical, independent assessment of the work.

6.3.2 NUREG/CR-1005: A Proposed Radioactive Waste Classification System

Having defined a generic methodology for understanding the sensitivity (coupling) between key disposal system interfaces, the next phase of the EIS scoping analysis was to propose a waste classification system that would allow a correlation between the hazard posed by the waste, the safety goal to be achieved by disposal, and some prescriptive regulatory requirements necessary to achieve the safety goals. In considering any disposal solution, radiotoxicity coupled with environmental mobility are recognized as key parameters in defining the magnitude of exposure hazards to the public.

For example, analyses from NUREG-0456 already indicated that certain disposal practices such as increasing the time frame when the first exposure occurs through the use of institutional (administrative) controls could limit the magnitude of those exposures or obviate the significance of certain exposure scenarios all together. Alternatively, burying wastes at greater depths can achieve similar dose outcomes by eliminating the potential for certain types of intruder scenarios as well as providing some shielding of the wastes. Hence, by focusing on the length of institutional controls and limiting the physical accessibility of the wastes, it was possible to formulate disposal categories that indicated how specific types of waste should be treated as well as recommend radionuclide concentration limits for each disposal category.

Thus, in considering the importance of half-life (decay) and environmental mobility to potential dose outcomes, King and Cohen (1977) suggested that any one of the following three disposal actions could occur:

- The radioactive waste did not pose significant radiological health-risk to the public, and the waste could be disposed as part of the municipal waste stream.

Table 8. Exposure Scenarios Considered in NUREG-0456. Taken from Adam and Rogers (1978, pp. 15–17).

Scenario	Event	Pathway	Comments
On-Site Reclaimer	Inhalation	Worker	Inhalation of contaminated dust.
		Resident	
	Ingestion	Well Water Consumption	Ingestion of contaminated ground water and/or consumption of food grown in soil irrigated with contaminated ground water
		Food Consumption	
	Direct Exposure	Worker	Direct exposure to gamma radiation.
		Resident	
Off-Site Transport	Inhalation	Continuous Operational Release	Atmospheric transport.
		Accidental Release	
	Ingestion	Groundwater to River	Ingestion from contaminated ground water resource.
		Surface Erosion	

- The radioactive waste did pose some level of radiological health-risk to the public, and the waste needed to be confined in some controlled manner to allow limited releases to the environment at predictably low rates, consistent with levels of natural background of radiation found in nature.

- The radioactive waste posed a significant radiological health-risk to the public, over an extended period of time, and the waste needed to be isolated so that biologically significant releases of radioactive material to the environment (or inadvertent human intrusion) were unlikely.

Thus, for the purposes of scoping the Part 61 regulation, a "what type of radioactive waste goes where" type of disposal classification system was proposed in NUREG/CR-1005 (Rogers, 1979). Five types of disposal solutions were proposed applicable to all types radioactive waste. The principal considerations in defining the proposed disposal categories were the duration of institutional controls and reclaimer accessibility (Op cit., p. 24). As previously noted, it was believed that governmental institutions could restrict access to disposal sites and thus the potential for coming into contact with hazardous wastes if an institutional control time of sufficient duration was specified. If this time were sufficiently long, then the exposure (hazard) would be reduced by virtue of the natural decay of the waste. Similarly, if wastes were buried deeply enough, the same benefit could be achieved by virtue of the isolation of the wastes at depths greater than those reached by routine excavation. Both considerations were key to NRC's Part 61 umbrella regulation concept.

Building upon the earlier work of NUREG-0456, deterministic *disposal concentration guides* (DCGs)[31] applicable to each disposal class were proposed consistent once again with some specified safety goal. DCGs were the front-end parameters of the dose assessment model. They represent the activity of the waste available for consideration in the assessment at the time of disposal. DCGs were derived by starting with a specified dose limit and working backwards through the dose model, pathway-by-pathway, to the initiation point of the analysis. Another important interface value was the *maximum average concentration* (MAC). It represents the back-end of the dose assessment model. It corresponds to the radionuclide contaminant concentration found in a particular exposure pathway. Both concentration parameters are expressed in units of microcuries per cubic centimeter ($\mu Ci/cm^3$). By using a revised dose assessment model (Rogers and others, 1979[32]), it was demonstrated that DCGs and MACs could be used to derive a five-tier system of disposal recommendations taking into account duration of institutional control and reclaimer exposure pathways[33] (see Table 9). In general, the NUREG/CR-1005 analysis indicated that for higher calculated DCGs (see Table 10), additional administrative and isolation measures were needed to ensure the safe disposal of the waste. The analysis also showed that for some exposure scenarios, the MAC can be the limiting factor in the specification of a radionuclide-specific DCG. The analysis also showed

[31]Because it is not practical to perform a radioisotopic survey for every type of LLW configuration, DCFs for individual isotopes were developed for NUREG/CR-1005.

[32]Similar to or derived from the NUREG-0456 dose model.

[33]For the purposes of NUREG/CR-1005, only four dose pathways were considered: reclaimer dust inhalation, food ingestion from reclaimed soil, well water consumption, and direct gamma radiation. It is believed that these pathways are the most restrictive in limiting doses to receptors.

Table 9. Waste Disposal Classification Categories Proposed in NUREG/CR-1005. Taken from Rogers (1979, p. 25).

Disposal Class	Administrative Control	Accessibility	Comments
A	None	No reclaimer access	Default class. No upper-limit for DCGs. Understood to be deep geologic isolation.
B	150 years	No reclaimer access except well water after 150 years	Ready access to reclaimer is unlikely. Understood to represent intermediate-depth land burial (about 30 ft). Off-site-transport, well-water ingestion is controlling exposure scenario after 150 years. DCGs are from Class C and adjusted using a 150-year decay factor.
C	20 years	No reclaimer access except well water after 20 years	Ready access to reclaimer is unlikely. Understood to represent intermediate-depth land burial. Off-site-transport, well-water ingestion is controlling exposure scenario after 20 years.
D	150 years	Reclaimer access following administrative control	Understood to represent shallow land burial (about 10 ft).
E	None	Worker/reclaimer access	Understood to correspond to a municipal sanitary landfill.

Table 10. DCGs for Waste Classes Proposed in NUREG/CR-1005. Waste classes are defined in Table 9. Taken from Rogers (1979, p. xiv).

Radionuclide	Waste Class DCGs (in µCi / cm³)				
	A*	B	C	D	E
^{3}H	2.9e9	4.3e5	94	94	0.05
^{14}C	7.1e6	140	140	2.4e-3	1.2e-3
^{55}Fe	1.9e10	SA	SA	SA	12
^{66}Co	9.7e9	SA	SA	2.1e6	2.5e-4
^{90}Sr	3.6e8	38	2.4	0.02	2.3e-4
^{99}Tc	1e4	64	64	0.1	0.05
^{129}I	850	0.3	0.3	0.3	0.024
^{135}Cs	2.4e3	20	20	0.2	0.10
^{137}Cs	1.7e8	SA	SA	0.9	4.2e-3
^{235}U	41	11	11	0.03	0.015
^{238}U	6.4	SA	SA	0.03	0.015
^{237}Np	1.3e4	0.3	0.3	0.02	5.4e-4
^{238}Pu	3.4e8	SA	SA	0.4	3.4e-4
^{239}Pu	1.2e6	90	90	0.1	3.0e-4
^{240}Pu	4.7e6	810	810	0.1	3.0e-4
^{241}Pu	2.2e9	SA	SA	5.9e3	0.015
^{242}Pu	7.6e4	13	13	0.1	3.1e-4
^{241}Am	6.4e7	SA	SA	0.4	9.2e-4
^{243}Am	3.6e6	SA	600	0.3	9.2e-4
^{242}Cm	2.6e10	SA	SA	SA	0.024
^{244}Cm	6.2e8	SA	SA	130	1.5e-3

* Specific activity (SA) of the isotope.

that by comparing potential doses with study guidelines, the waste concentrations, waste volumes, or disposal methods could be modified to provide adequate protection to the public – another important EIS scoping consideration.

6.3.3 NUREG-0782: The Draft EIS[34]

The last step in the rulemaking process was to prepare an EIS consistent with NEPA. As noted earlier, the purpose of the draft EIS was to fulfill NRC's NEPA responsibility as well as demonstrate the decision-making process applied to the development of Part 61. Using the EIS process, the NRC staff was able to evaluate the potential health impacts of LLW disposal, possible means for limiting the impacts, and considering these measures, what potential reduction (benefit) could be achieved. The EIS contained an exhaustive and detailed analysis of alternatives such as disposal facility environments, waste characteristics, disposal facility designs, and operating practices. Determinstically-derived doses were presented for whole body and six organs (bone, liver, thyroid, kidney, lung and gastro-intestinal tract. NRC's draft EIS for the proposed Part 61 rulemaking was published as NUREG-0782 (NRC, 1981b). It was a four-volume report prepared following both CEQ regulations for preparing an EIS as well as NRC's NEPA-implementing regulations set out in 10 CFR Part 51 ("Licensing and Regulatory Policy and Procedures for Environmental Protection"). The deterministic analyses in NUREG-0456 and NUREG/CP-1005 provided a generic methodology for evaluating the risks of different types of radioactive wastes and proposing disposal solutions commensurate with the radiological hazard. NUREG-0782 relied on those methodologies and integrated them into the NEPA-EIS framework necessary to support the proposed rulemaking. However, unlike the earlier analyses, NUREG-0782 considered data (information) viewed to be more representative of the types and kinds of LLW being managed at the time as well as pervasive LLW management practices. The NEPA-required analyses were mostly described in Volume 2 of NUREG-0782; Volume I was a "summary" report. Volumes 3 and 4 of the draft EIS contained the technical analyses and other supporting information that addressed the required elements of an EIS.[35]

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[34]In conducting the draft EIS scoping calculations, the staff assumed a reference disposal facility representative of existing LLW disposal facility designs and operating and management practices throughout the United States. To summarize, it was decided that the draft EIS reference design would be a SLB facility located in a humid environment characteristic of the eastern United States. The reference facility covered an area of 148 acres with a capacity of one million ft^3. This general location was selected because that part of the country was determined to be generating most of the LLW and thus most likely to have the largest number of disposal facilities in the future. The site had four distinct climate seasons although the winters were considered short and mild with an average annual precipitation of about 46 inches. The disposal facility was assumed to have a 20- to 40-year operational life cycle with a disposal capacity of 1 million cubic meters. At the end of operations, the disposal site would be stabilized using existing conservation practices, and the site closed and decommissioned. Following decommissioning, the NRC operating license would then be terminated, and title of the site would be transferred to a governmental agency that would provide active institutional controls (surveillance, monitoring, and custodial maintenance) for a period of about 100 years. During this 100-year caretaker period, there would be no incidents involving inadvertent human intrusion.

The reference facility and other applicable parameters are described in more detail in Appendix E ("Description of a Reference Disposal Facility") of Volume 2 of NUREG-0782.

[35] Specifically, the purposes, scope, and need for the rulemaking action, description of the affected environment, discussion of a preferred action as well as consideration of alternatives, costs, and impacts.

Two key features of the analytical framework used to evaluate the performance of a hypothetical LLW disposal facility in the draft EIS are discussed below. They are *the LLW streams* and *the exposure pathways considered*.

6.3.3.1 The LLW Waste Streams Considered[36]

At the time the regulation was being developed, there were an estimated 20,000 NRC materials licensees producing LLW in a wide variety of waste types, forms, and amounts. LLW was not a uniform physical quantity. It contained both short-lived and long-lived radionuclides. LLW also ranged from trash that was only suspected of being contaminated to highly radioactive material such as activated structural components from nuclear power reactors. It could be in solid, liquid, or gaseous forms.

For the purposes of the draft EIS scoping process and analyses, existing commercial LLW was separated into 36 distinct waste streams (see Table 11). Each waste stream represented a separate type of LLW generated by a particular type of waste source, and had distinct physical, chemical, radiological, and other characteristics unique to that waste stream. The isotopic content of various waste streams was also analyzed. The most important radionuclides present in each commercial waste stream were then identified (see Table 12) for consideration in the draft EIS analysis. To allow for the required consideration of disposal impacts and alternative management options, the volumes of each waste stream were also considered. In developing the regulation, the Commission noted that a key concern was the mobility of certain long-lived radioisotopes (^{129}I, ^{99}Tc, ^{14}C, and tritium) in the environment, especially in ground water. By defining radionuclide concentration limits for each disposal site, the Commission sought to ensure that the proposed Part 61 performance objectives related to ground water would be me (NRC, 1982b; 47 FR 57455).

As noted earlier, another of the Commission objectives in developing the LLW regulation was to identify existing as well as new LLW management practices and designs that could contribute to meeting the overall performance goals. Consequently, it was decided to also consider waste form and processing options as part of the draft EIS scoping analysis. This was achieved by categorizing existing commercial LLW into four waste "spectra" representing generic processing options to be considered (see Table 13).

6.3.3.2 The Exposure Pathways Considered

Based on a review of exposure pathways considered in earlier staff investigations, the NRC selected a limited number of exposure pathways for the draft EIS. There were concentration-limited exposure events and activity-limited exposure events. As noted earlier, all of the intruder scenarios described were assumed to occur with a probability of 1. For each of the scenarios studied, the staff addressed the following four potential mitigation actions in the context of the draft EIS:

- controlling the concentrations of the radionuclides in the specific waste streams being disposed;

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[36]The waste stream definition process described above is explained in more detail in Appendix D ("Low-Level Waste Sources and Processing Options") of Volume 2 of NUREG-0782.

Table 11. Waste Steams Considered in Part 61 EIS Scoping Analyses. Taken from Volume 2 of NRC (1981b, p. 3-11).

Waste Stream Group	Group Description
Group I: LWR Process Wastes	PWR Ion Exchange Resins PWR Concentrated Liquids PWR Filter Sludges PWR Filer Cartridges BWR Icon Exchange Resins BWR Concentrated Liquids BWR Filter Sludge
Group II: Trash	PWR Compactible Trash PWR Noncompactible Trash BWR Compactible Trash BWR Noncompactible Trash Fuel Fabrication Compactible Trash Fuel Fabrication Noncompactible Trash Institutional Trash (large facilities) Institutional Trash (small facilities) Industrial SS Trash (large facilities) Industrial SS Trash (small facilities) Industrial Low Trash (large facilities) Industrial Low Trash (small facilities)
Group III: Low Specific Activity Wastes	Fuel Fabrication Process Wastes UF_6 Process Wastes Institutional LSV Waste (large facilities) Institutional LSV Waste (small facilities) Institutional Liquid Waste (large facilities) Institutional Liquid Waste (small facilities) Institutional Biowaste (large facilities) Institutional Biowaste (small facilities) Institutional SS Waste Institutional Low-Activity Waste
Group IV: Special Wastes	LWR Nonfuel Reactor Components LWR Decontamination Resins Waste from Isotope Production Facilities Tritium Production Waste Accelerator Targets Sealed Sources Industrial High-Activity Waste

Abbreviations:
- LWR light-water reactor
- PWR pressurized water reactor
- BWR boiling water reactor
- SS sources and special nuclear material
- LSV liquid scintillation vial

Table 12. Radionulides Considered in Part 61 EIS Scoping Analyses. Taken from Volume 2 of NRC (1981b, p. 3-12).

Radionuclide	Half Life (years)	Radiation Emitted	Principal Means of Production
^{3}H	12.3	β	Fission; ^{6}Li (n, α)
^{14}C	5730	β	^{14}Ni (n, p)
^{55}Fe	2.60	γ	^{54}Fe (n, γ)
^{66}Co	5.26	β, γ	^{59}Co (n, γ)
^{59}Ni	80,000	γ	^{58}Ni (n, γ)
^{63}Ni	92	β	^{62}Ni (n, γ)
^{90}Sr	28.1	β	Fission
^{94}Nb	20,000	β, γ	^{93}Nb (n, γ)
^{99}Tc	2.12×10^{5}	β	Fission; ^{98}Mo (n,γ), ^{99}Mo (β^{-})
^{129}I	1.17×10^{7}	β, γ	Fission
^{135}Cs	3.0×10^{6}	β	Fission; daughter ^{135}Xe
^{137}Cs	30.0	β, γ	Fission
^{235}U	7.1×10^{8}	α, γ	Natural
^{238}U	4.51×10^{9}	α, γ	Natural
^{237}Np	2.14×10^{6}	α, γ	^{238}U (n, 2n), ^{237}U (β^{-})
^{239}Pu	86.4	α, γ	^{237}Np (n, γ), ^{238}Np β^{-}); daughter ^{242}Cm
^{239}Pu	24,400	α, γ	^{238}U (n, γ), ^{238}U (β^{-}), ^{239}Np (β^{-})
^{240}Pu	6580	α, γ	Multiple n-capture
^{241}Pu	13.2	β, γ	Multiple n-capture
^{242}Pu	2.79×10^{5}	α	Multiple n-capture; daughter ^{242}Am
^{241}Am	458	α, γ	Daughter ^{241}Pu
^{243}Am	7950	α, γ	Multiple n-capture
^{242}Cm	32	α, γ	Multiple n-capture
^{244}Cm	17.6	α, γ	Multiple n-capture

Table 13. Waste Spectra Considered in Part 61 EIS Scoping Analyses. Each waste spectrum represents a cross section of all waste streams that might be generated and disposed of in a LLW disposal facility. Adopted from Volume 2 of NRC (1981b, p. 3-21).

Waste Spectrum	Description
1	This spectrum assumes a continuation of existing and some past waste management practices. Some of the LWR wastes are solidified. However, no processing done on organics, combustible wastes, or streams containing chelating agents. LWR resins and filter sludges are assumed to be disposal sites in a dewatered form. LWR concentrated liquids are assumed to be concentrated in accordance with current practices, and are solidified with various media designated as solidification scenario A. No special effort is made to compact trash. Institutional waste streams are shipped to disposal sites after they are packaged with currently utilized absorbent materials. Resins from LWR decontamination operations are solidified in a medium with highly improved characteristics.
2	This spectrum assumes that LWR process wastes are solidified using improved solidification techniques. LWR concentrated liquids are additionally reduced in volume through an evaporator/crystallized. All LWR concentrated liquids are evaporated in 50 weight percent solids, and all LWR process wastes are solidified. In the case of cartridge filters, the solidification agent fills voids in the packaged waste but does not increase the volume. Liquid scintillation vials are crushed at large facilities and packed in absorbent material. All compactible trash streams are compacted; some streams are compacted at the source of generation; and some waste streams are compacted at the disposal facility. Liquids from medical isotope production are solidified.
3	In this spectrum, LWR process wastes are solidified assuming that further improved waste solidification agents are used. LWR concentrated liquids are first evaporated to 50 percent weight solids. All possible incineration of combustible material (except LWR process wastes) is performed; some incineration is done at the source of generation (fuel cycle trash, LWR decontamination resins, institutional wastes from large facilities and industrial trash from large facilities) and some at the disposal site (institutional and industrial trash from small facilities). All incineration ash is solidified.
4	This spectrum assumes extreme volume reduction. All wastes amenable to evaporation or incineration with fluidized bed technology are calcined and solidified; LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Spectrum 3. All noncompactible wastes are reduced in volume at the disposal site or at a central processing facility using a large hydraulic press. This spectrum represents the maximum volume reduction that can be practically achieved.

- considering alternative waste form and/or waste packaging configurations;
- evaluating the effectiveness of the duration of institutional controls; and
- examining the effects of engineered and/or natural barriers to intrusion.

Consistent with the draft EIS scoping process and rulemaking objectives, the intent was to understand what effect, if any, potential mitigation actions would have on predicted dose outcomes based on the likely waste streams expected. If effective, the potential mitigation actions might make reasonable regulatory recommendations to advance for the purposes of the Part 61 rulemaking. These recommendations would be decided on by identifying which exposure scenarios were the most restrictive (i.e., producing the highest doses) and then evaluating the effectiveness of the potential mitigation actions listed above in reducing the estimated doses.

Concentration-limited exposure events.[37] There were three potential exposure scenarios identified depending on the time duration (length) of the exposure scenario. The first was a intruder-construction scenario." It assumed that the intruder is unaware of the radiological hazard and constructs of a house directly over a LLW disposal cell. The second scenario was a "intruder-discovery scenario" in which an intruder exhumes a portion of the disposal cell as part of building a house and comes into direct contact with the waste. Realizing that something is amiss, the intruder then terminates construction activities and egresses from the disposal facility but not before receiving a minimal exposure to the ionizing radiation. The third scenario was a "intruder-agriculture scenario" in which intruders grow and consume food on contaminated soil at the site. This was a type of resident farmer scenario. This scenario also assumes the intruder is unaware of the radiological hazard. In all cases, the overriding assumption is that any one of the intrusion scenarios takes place after the end of the governmental 100-year caretaker period, when institutional controls end and knowledge about the LLW facility ceases. In all cases, it was also assumed that the probability of intrusion at year100-post closure was one and that the probability of intruding into Class-C waste was one. Further in all cases the conditions of intrusion, lack of recognition and routes exposure to the intruder can be best characterized as extreme bounding conditions.

Activity-limited exposure events.[38] This scenario occurs when an intruder drills a water-supply well at or in the vicinity of the disposal site, unaware of the presence of LLW, and consumes contaminated water. Four receptor-well locations (scenarios) were considered, as noted below:

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[37]The EIS' treatment of these three exposure scenarios is discussed in more detail in Chapter 4 ("Presentation and Analysis of Alternatives – Intruder") of Volume 2 of NUREG-0782.

[38]Analysis of these four scenarios is discussed in more detail in Chapter 5 ("Long-Term Environmental Protection – Presentation and Analysis of Alternatives") of Volume 2 of NUREG-0782.

The water supply well...	*The exposure scenario involves ...*
... penetrates disposal facility cell	*...only a single intruder. Would be considered a subsistence well today.*
... is located at the edge of the disposal site boundary	*... locating a production well for a few individuals in the path of the contaminant plume.*
... is located 500 meters down-gradient from the disposal facility	*... locating a production well for a small population of individuals (about 100) in the path of the contaminant plume.*
... is located 1 km down-gradient from the disposal facility	*... locating a production well for a small population of individuals (about 300) in the path of the contaminant plume.*

Again, as was the case with the concentration-limited exposure events, there was no knowledge of the radiological hazard posed by the drinking water from the presence of the LLW disposal facility because the scenario takes place after the end of the caretaker period and all institutional knowledge of the facility had been lost.

6.4 Assumed Definition of Safety

As noted earlier, EPA was responsible for developing and issuing environmental standards, guidelines, and criteria to ensure that the public and the environment were adequately protected from potential radiation impacts. President Richard M. Nixon announced the creation of EPA with the publication of *Reorganization Plan No. 3 of 1970*. The intent of this plan was to consolidate Federal research, monitoring, standard-setting and enforcement activities into one agency to ensure environmental protection. This plan also granted EPA its standard setting authority to establish "... generally applicable environmental standards for the protection of the general environment from radioactive material .... (The White House, 35 FR 15624) "

6.4.1 EPA Efforts to Promulgate LLW Standards

In 1972, the EPA Office of Radiation Programs began a program with the Conference of Radiation Control Program Director's to examine the practice of shallow-land disposal of commercial LLW (EPA, 1988; p. 1-3). From 1977–78, EPA conducted a series of public workshops to examine the policy and technical issues associated with the development of radiation standards (e.g., EPA, 1978a). As a precursor to the required standards, and about the same time the NRC was developing a LLW regulatory framework, EPA proposed *Federal Guidance* for the storage and disposal of all forms of radioactive waste (EPA, 1978c; 43 FR 53262). In 1980, Meyer (p. 10) described the sources EPA was consulting in the development of its proposed standards. They included the NEPA statutes, the Biological Effects of Ionizing Radiation (BEIR) II recommendations (NAS, 1977a), *ICRP Publication 26* (ICRP, 1977), and two other reports (NAS, 1977b; and EPA, 1978a). However, the agency later withdrew its proposed guidance criteria noting that the many types of radioactive wastes and different methods necessary to manage and dispose of them made the issuance of generic disposal guidance too complex and that radiation standards based on waste type would be the best approach (EPA, 1981; 46 FR 17567). Alternatively, EPA decided to promulgate regulations specific to the management and disposal of LLW.

In December 1982, the Commission issued the final Part 61 regulation. Following its release, and depending on its final content, the staff noted its intent to amend Part 61 (and potentially other NRC regulations) once the EPA LLW standards were issued if the regulations did not comply with the standards (NRC, 1989c; p. 11). In August 1983, EPA published an ANPR announcing its plans for establishing general environmental radiation protection standards for LLW (NRC, 1983b; 48 FR 39563). In connection with the development of these standards, tentatively designated as 40 CFR Part 193, EPA developed the PRESTO-EPA[39] computer code (EPA, 1983a). Similar to NRC's earlier dose-modeling efforts in this regard, the purpose of the EPA-sponsored code was also to model radionuclide transport through major environmental pathways to humans. EPA also requested that the Agency's Science Advisory Board review a PRESTO-EPA-derived risk assessment prepared as part of the LLW standards development (EPA, 1985b). As a result of these efforts, EPA transmitted a proposed regulation to the Office of Management and Budget (OMB) in 1987. This was followed by the publication of a draft EIS in 1988.

In describing the proposed LLW standards, Gruhlke and others (1989; p. 273) notes that EPA proposed the following definition of commercial LLW:[40]

> "... radioactive waste that was not (1) spent fuel, high-level radioactive waste, or transuranic waste, as previously defined in 40 CFR Part 191, (2) or uranium or thorium mill tailings subject to 40 CFR Part 192, or (3) or NARM as defined in 40 CFR Part 764 ...."

EPA's proposed LLW regulation never cleared the OMB review process. The rule encountered significant interagency opposition during the review because of concerns over the ground-water provisions of the proposed standard (EPA, 2000a; p. 21). Consistent with other regulatory authorities, EPA did successfully promulgate regulations in other nuclear waste management areas – uranium and mill tailings (EPA, 1983c) and HLW (EPA, 1985a). EPA also promulgated standards related to the maximum concentration limits (MCLs) of radioactive material in its *National Primary Drinking Water Standard* found at 40 CFR Part 141 (EPA, 1976)[41] as well as radiation emission standards associated with the Clean Air Act of 1977 (CAA), as amended.[42]

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[39]PRESTO is an acronym for Protection of Radiation Effects from Shallow Trench Operations. The computer code was a simple one-dimensional ground-water transport model (EPA, 1988; p. 8-2) and although it could be used to estimate intruder exposures, EPA expressed the view in its draft EIS that the intruder pathway was probabilistic in nature and that safeguards against it should be considered on a site-specific basis. For this reason, EPA did not consider the human intrusion scenario it its draft EIS.

[40]A more detailed discussion of the history and evolution of the LLW definition can be found in Appendix C of this paper.

[41]EPA first promulgated interim regulations in 1976 that established MCLs for radium-226 and radium-228 of 5 pCi/L. The most recent MCLs can be found in EPA (2000b, 65 FR 76708), which also includes an MCL of 30 µg/L for uranium.

[42]CAA provided EPA the specific authority to limit radionuclide emissions to the air. Section 122 of the act directed EPA to review all relevant information and determine whether emissions of radioactive pollutants will cause or contribute to air pollution that may reasonably by anticipated to endanger public health.

In 1979, EPA added radionuclides to the list of hazardous air pollutants (HAPS) under the CAA (EPA, 1979). Among

6.4.2 The NRC Selection of a Default LLW Standard

As noted above, EPA's LLW standards and criteria were not available at the time NRC was developing its LLW regulatory framework. Rather than delay the development of its disposal regulations, the NRC staff decided to postulate a reasonable set of "study guidelines" that could be used as surrogates for the forthcoming EPA standard. At the time, there was no nationally accepted set of safety guidelines defining what level of safety (protection) disposal facilities should provide the public from the ionizing effects of radiation. Consequently, the staff decided to review the literature[43] and consider the recommendations of national and international standard-setting organizations to identify surrogate dose guidelines for the scoping analyses and later, the proposed and final rule. See Table 14.

Then, as now, the ICRP was considered to be the authoritative body on the subject of health physics. In proposing limits on radiation risks, the ICRP observed that radiation risks where a very minor fraction of the total number of environmental hazards to which members of the public where generally exposed. Consequently, in considering what the acceptable magnitude of radiation risk might be, the ICRP suggested that such risks be considered in light of the public acceptance of other risks encountered in everyday life – generally in the range of 10^{-6} to 10^{-5} per year. In its *Publication 26* (ICRP, 1977; p. 23), the ICRP recommended a whole body-dose equivalent of 500 mrem/yr for individual members of a critical group (i.e., tens of individuals) provided that the average annual dose equivalent to individual members of the public (i.e., hundreds of individuals) did not exceed 100 mrem/yr (Op cit.).

To conduct the hypothetical series of dose analyses described in NUREG-0456 and NUREG/CP-1005, the ICRP 1977 recommendations were used as dose guidelines (e.g., surrogate standards). See Adam and Rogers (1978, p. 7) and Rogers (1979, p. 9), respectively. Estimated exposures to workers and the (hypothetical) inadvertent intruder were not given separate treatments in these analyses.

In developing the Part 61 draft EIS (NUREG-0782 – NRC, 1981b), the staff decided to rely on existing EPA standards in allied areas of radiation management and selected a range of public exposure limits from those standards which were expected to bound EPA's forthcoming rule. One mrem/yr was selected as a lower dose bound since at the time it was less than the 4

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the radionuclides included were those defined by the AEA as source material, special nuclear material, and by-product materials as well as TENORM. EPA determined that radionuclides are a known cause of human cancer and genetic damage, and that radionuclides cause of contribute to air pollution within the meaning of Section 122(a) of the CAA. Once listed, Section 112(b)(1)(B) of the CAA requires EPA to establish "National Emission Standards for Hazardous Air Pollutants" (NESHAPS) at a level which provides an ample margin of safety. In 1989, EPA published NESHAPs for eight radionuclide source categories, covering an estimated 6300 sources at 40 CFR Part 61 (EPA, 1989). Eleven parties, primarily representing the regulated community, subsequently sued EPA during the development of the radionuclide NESHAPs.

Between 1992 and 1996, EPA evaluated the ALARA programs at many NRC-licensed facilities. Based on this evaluation, EPA concluded that radionuclide emissions from NRC- and Agreement State-licensees did not exceed the 10 mrem/yr NESHAP-established standard. NRC subsequently issued a "constraint rule" under Part 20 of its regulations that required licensees to maintain emissions below the 10 mrem/yr standard. EPA found that NRC's regulatory program protects the public health to a safe level with an ample margin of safety and the NESHAP regulating air emissions from NRC-licensees was rescinded in 1996 (EPA, 1996).

[43] See Appendix N ("Analysis of Existing Recommendations, Regulations, and Guides") in Volume 4 of NUREG-0782.

Table 14. Dose Guideline Options Considered by the NRC in Developing 10 CFR Part 61. Taken from the references cited.

Receptor	**NUREG-0456 (Adam and Rogers, 1978)**	**NUREG/CP-1005 (Rogers, 1979)**	**NUREG-0782 (NRC, 1981)**	**Draft Part 61 (NRC, 1981)**	**Final Part 61 (NRC, 1982b)**
Public (General Population)	Individual exposures to a few individuals (~10s) – 500 mrem/yr [a]	Individual exposures to a few individuals (~10s) – 500 mrem/yr [a]	25 mrem/yr whole-body exposure to an individual at the disposal site boundary [c]	25 mrem/yr whole-body exposure to an individual at the disposal site boundary	25 mrem/yr whole-body exposure to an individual at the disposal site boundary
	Individual exposures to many individuals (~100s) – 100 mrem/yr [a]	Individual exposures to many individuals (~100s) – 100 mrem/yr [a]		Meet EPA requirements of 40 CFR Part 141 for the nearest drinking water supply [e]	
Worker			10 CFR Part 20 [b]	10 CFR Part 20 [b]	10 CFR Part 20 [b]
Intruder			500 mrem/yr [d]	500 mrem/yr [d]	Not specified but implied [f]

a. NUREG-0456 dose guidelines based on recommendations of the ICRP (1977).
b. Includes consideration of ALARA principles.
c. Based on view that releases would not be higher than standards already established for fuel cycle facilities found at Part 190 (EPA, 1977). Commission considered a range of 1 mrem/yr to 25 mrem/yr.
d. Considered to be an unusual event. Dose guidelines in NUREG-0782 and Draft Part 61 based on recommendations of the ICRP (1977).
e. Specifically, maximum radiation concentration limits of 10pCi/l above background levels (or 4mrem/yr whole body exposure). See EPA's *National Primary Drinking Water Standards* (EPA, 1976).
f. Tied to Table 1 concentration limits in draft Part 61 regulation but 500 mrem/yr retained as a basis for limits specified in the tables in the final regulation.
g. Note the technical bases for dose limits under § 61.41; the basis for the concentration limits in the intruder scenario; and the current Part 20 are different. For short lived radionuclides the difference is negligible; for long lived radionuclides the difference may be significant.

mrem/yr limit found in the EPA 1976 drinking water standards (EPA, 2000; 65 FR 76710). Bearing in mind that NRC's goal was to propose a LLW regulation based on currently available technology, the staff believed that 1 mrem/yr would provide a limit against which the effectiveness of current technology could be analyzed. At the upper end, 25 mrem/yr was selected as an upper bound since it was already in use as an existing radiation standard at 40 CFR Part 190 – "Environmental Radiation Protection Standards for Nuclear Power Operations" (EPA, 1977) – applied to routine operating releases from nuclear fuel cycle facilities. In proposing this range, the Commission concluded that the forthcoming EPA LLW standards would not be higher than those already set out in Part 190 (NRC, 1981c; 46 FR 38063). The specified performance objective in Part 20 was applied to worker safety because the standard was already being applied to other NRC-licensed facilities and therefore was still considered appropriate to apply to an operating commercial LLW disposal facility. Because the human intruder scenario was considered to be an unusual (rare) event, likely to involve only one or two individuals, the Commission believed that whole body-dose equivalent of 500 mrem/yr (assuming a 100-year period of institutional controls) was considered acceptable and protective, consistent with the earlier recommendations of the ICRP (Op cit.).

From the draft EIS scoping analyses, the staff was able to conclude that a limit in the range of existing EPA drinking water regulations (4 mremyr) could be achieved at the nearest public drinking water supply given some modest increased costs and changes to the reference disposal facility design. The staff also concluded that meeting the EPA drinking water standards at the nearest public drinking water supply would result in annual potential exposures of less than 25 mrem whole body, 75 mrem thyroid, and 25 mrem to any other organ to an individual who might consume water from a well located at the site boundary. An annual exposure limit of 25 mrem whole body, 75 mrem thyroid and 25 mrem to any other organ to the maximally exposed individual at the site boundary coupled with an annual population limit of 4 mrem at the nearest public drinking water supply was, therefore, selected as the preferred performance objective when the regulation was published for public comment (NRC, 1981; 46 FR 38063).

Following a review of the public comments received on its proposed regulation, the NRC made two changes to the final rule as it related to the Subpart C performance objectives. The first was in response to a comment from EPA, which expressed the view that it was inappropriate to apply the agency's drinking water standard in the manner first proposed in §61.41 (NRC, 1982b; 47 FR 57448). The Commission deleted that provision from its final rule. The second comment concerned the proposed 500 mrem whole body dose to the human intruder. Many commenters suggested that the intruder performance objective was too restrictive. It was also argued that a licensee would not be able to monitor or demonstrate compliance with a specific dose limit to an event that might occur sometime in the future several hundred years from now (47 FR 57449). The Commission deleted this provision from the Subpart C performance objectives as well but retained the 500 mrem as a basis for the waste classification limits.

6.4.3 The NRC Proposed LLW Classification System

As a means of relating waste characteristics to the Subpart C performance objectives, a simple waste classification scheme was devised and incorporated into the proposed regulation. This three-tier classification system was based on the earlier thesis demonstrated during the rulemaking scoping process that waste characteristics provide some level of assurance that the performance objectives will be met. Key decision parameters in the waste classification system were the physical stability of the waste form[44] and its isotopic concentration. These parameters were viewed as important for they provide the minimum information necessary for basic decisions on the safe handling and disposal of wastes.

Three classes of LLW were defined in §61.55 as acceptable for disposal in near-surface facilities. They were designated *Class A*, *Class B*, and *Class C*, with the highest being Class C. Class designations were tied to certain minimum requirements and stability requirements,[45] and specifications for maximum allowable concentrations of certain radionuclides in each class. By controlling isotope concentrations in each waste class (and to a lesser degree, the site inventory), inadvertant intruder exposures are controlled (47 FR 57455). *Class-A waste* includes primarily lightly-contaminated paper, cloth, and plastics. These wastes must be segregated from other LLW during disposal because of their potential for degrading over time and causing subsidence in disposal cells. The isotope concentrations in this class of wastes are not to exceed the values listed in the regulation. *Class-B waste* by definition meets more rigorous physical stability requirements than Class-A wastes. This waste class is also permitted higher isotope concentrations. The physical form and characteristics of Class-B waste must also the meet the *minimum* and *stability* requirements of the regulation. *Class-C waste* was generally considered intruder waste. This higher-activity, longer-lived LLW is generally suitable for SLB and requires special measures to protect against human intrusion after institutional controls lapse. The regulation required that any Class-C waste with concentrations of radionuclides that would cause exposures greater than 500 mrem need to be protected from intrusion by deeper burial and/or through the use of some type of engineered intruder barrier.[46] Wastes exceeding the Class-C concentration limits are, by regulation at §61.55(a)(2)(iv), were "generally not acceptable" for SLB.

As noted in the preceding sections of this paper, the Part 61 regulation is deliberately structured around the three-tier LLW classification system defined by the concentration of radionuclides in the waste form as well as the physical characteristics of the waste form. This classification system is integrated with the stylized human intrusion scenarios that form the basis for the

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[44]In the *Statements of Consideration* for the final rule (47 FR 57457) , the Commission noted that "...waste that is stable for a long period helps to ensure the long-term stability of the site, eliminating the need for active maintenance after the site is closed. This stability helps to assure against water infiltration caused by failure of the disposal covers and, with the improved leaching properties implicit in a stable waste form, minimizes the potential for radionuclide migration in ground water. Stability also plays an important role in protecting an inadvertent intruder, since the stable waste form is recognizable for a long period of time and minimizes any effects from dispersion of the waste upon intrusion...." The Commission also noted its belief that ".... to the extent practicable, waste forms or containers should be designed to maintain gross physical properties and identity over 300 years, approximately the time required for Class B waste to decay to innocuous levels...." (Op cit.)

[45]The minimum requirements that all waste forms must meet, to be acceptable for near-surface disposal, are given in §61.56(a). In addition to these minimum requirements, certain wastes (i.e., Classes-B and -C wastes, and Class-A waste that is to be co-disposed with Classes-B and -C waste) must be stabilized (structurally) and meet the requirements of §61.56(b). Stability is defined in terms of the ability to keep dimensions and form under disposal conditions. Stability can be provided by the waste form (e.g., activated metals); by processing the waste to an acceptable form (e.g., cement solidification); placing the waste in a high-integrity container (HIC); or by the disposal unit itself (e.g., vault disposal).

[46]The calculation performed to establish the Class-C limits was based on a postulated SLB disposal method. These limits are considered conservative by the Commission since there may be other near-surface disposal methods (and costs) than SLB (NRC, 1987; 52 FR 5999).

Subpart C performance objectives. Despite this rigor, the Commission decided to allow for the consideration of alternative requirements for the classification of LLW at §61.58 on a specific basis so long as it can be demonstrated that the Subpart C performance objectives can be met.

Section 61.58 acknowledges the need to allow for the disposal of different types, physical forms, and quantities of LLW not necessarily recognized at the time the regulation was being developed.

6.4.4 Summary: Final 10 CFR Part 61

The Commission's final LLW disposal regulation at Part 61 was developed with the intent to address some of the past LLW site performance concerns as well as to develop guidelines that could be used to establish technical criteria for selecting, evaluating, licensing, and operating new commercial disposal sites. The regulation covers all phases of shallow, near-surface LLW disposal from site selection through facility design, licensing, operations, closure, post-closure stabilization, to the period when active institutional controls end. Key provisions of the regulation include:

- Specifying minimum geologic/geomorphic characteristics of an acceptable LLW disposal site using the site suitability requirements at §61.50.

- Defining a three-tier waste classification system for commercial LLW disposal based on the concentrations of the longer-lived radionuclides at §61.55.

- Specifying the minimum requirements that all commercial LLW forms must meet at 61.56(a) to be acceptable for near-surface disposal. In addition to these minimum requirements, certain LLW classes[47] must be structurally stabilized and meet the requirements at §61.56(b).

- Introducing requirements for caretaker oversight of LLW disposal sites for a period of 100 years following facility closure at §61.59.

The regulation also establishes procedures, criteria, terms, and conditions on which the Commission would issue and renew licenses for the shallow-land burial of commercially-generated LLW.

In issuing its final regulation, the NRC staff prepared a final EIS, in response to public comments received on the draft EIS and the proposed rule. The final EIS, designated NUREG-0945 (NRC, 1982a), presents the final decision bases and conclusions (costs and impacts) regarding NRC's LLW regulation. In addition, the document refined the deterministic EIS impact analysis methodology and grouped the disposal alternatives into four cases: past LLW disposal practices, existing LLW disposal practices, disposal practices based on proposed final Part 61 regulatory requirements (47 FR 57446), and an upper bound exposure example.

Although the Commission left several of the proposed Part 61 regulations substantially unchanged following the public comment period, the final EIS provided a number of clarifications for specific rule provisions, including the following:

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[47] Classes B and C, and Class A waste that is to be co-disposed of with Classes B and C waste.

- Doses were generally presented only for the whole body, thyroid, and bone.

- Waste classification represented a combination of waste form, radionuclide characteristics, radionuclide concentration, method of emplacement, and to some extent site characteristics.

- The limits for Class-A and Class-C waste disposal were re-evaluated.

- The Class-C limits were raised by a factor of 10 for all radionuclides.[48]

- A fourth class of LLW – GTCC LLW – was considered generally unacceptable for near-surface, shallow-depth disposal.[49]

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[48]It should be noted that the concentration limits were established based on the staff's understanding at the time of the characteristics and volumes of LLW that would be reasonably expected to the year 2000, as well as potential disposal methods (52 FR 5999).

[49]In 1986, the NRC staff updated the impacts analysis methodology used in the EIS scoping and rulemaking process to allow for improved consideration of the costs and impacts of treating and disposing of LLW that was close to or exceeding the Class-C concentration limits. See Oztunali and Roles (1986) and Oztunali and others (1986). The updates included the use of the more recent health physics guidance found in *ICRP Publication 30*.

7 The Management of GTCC LLW

Quantities of LLW whose radionuclides concentrations exceeded certain values were defined in §61.55(a)(4)(iv). Such classified wastes are designated as GTCC. They are produced in small volumes primarily as a result of the operation of commercial nuclear power reactors and other fuel cycle facilities. Examples include activated metal hardware (e.g., nuclear power reactor control rods), some spent fuel disassembly hardware (Stellite balls), some ion exchange resins, filters, evaporator residues, some sealed sources that are used in medical and industrial applications, and moisture and density gauges. The radionuclides that are frequently contribute to wastes being classified as GTCC waste include those found in §61.55, Table 2. By law, DOE is responsible for disposing of GTCC wastes.

7.1 NRC Activities

In an 1987 ANPR, the Commission proposed to redefine the existing definition of high-level radioactive waste (HLW) in a manner that would apply the term “high-level radioactive waste” to materials in amounts and concentrations exceeding numerical values that would be stated explicitly in the form of the table (52 FR 5992). The Commission proposed to classify wastes as HLW or non-HLW wastes. Wastes that could not be disposed of safely in a hypothetical “intermediate” disposal facility would be classified as HLW (NRC,1987; 52 FR 5996). The technical basis supporting this proposal was published in Kocher and Croff (1987).

Following a review of public comments on the ANPR, the Commission adopted an alternative strategy. In 1988 (53 FR 17709), the NRC published its proposed amendments to Part 61 recommending, in the first instance, disposal in a separate facility licensed under Part 60 (“Disposal of High-Level Radioactive Waste Geologic Repositories”) – the generic regulations for the disposal of HLW (NRC, 1983a). The Commission expressed the view that given the quantities of waste of concern[50] and the likely costs of disposal, a separate disposal facility unique to GTCC LLW was not justified. That same year, the Congressional OTA (1988) published an independent report with its recommendations on the issue that generally supported the Commission’s 1988 proposed rulemaking position. Both OTA and the Commission took the position that if, following a review, it was determined that the impact of GTCC LLW disposal on any HLW repository was unacceptable, then DOE should develop an alternative disposal concept. Amendments to Part 61 were proposed that would require the deep geologic disposal of GTCC LLW unless an alternative means of disposal elsewhere was approved by the Commission. This action was proposed to obviate the need for amending the existing classifications of LLW and HLW, thereby insuring that GTCC LLW would be disposed of in a manner consistent with the protection of public health and safety. Following a review of public comments, in 1989, Part 61 was amended at §61.55(b)(2)(iv) to permit the disposal of GTCC LLW in a HLW geologic repository licensed under Part 60 or some other type of disposal facility design approved by the Commission (NRC, 1989a; 54 FR 22578).

On November 2, 1995, the Commission received a petition from the Portland General Electric Company (the utility licensed by the NRC to operate the Trojan Nuclear Power Plant) requesting that NRC’s regulations at 10 CFR Part 72 (“Licensing Requirements for the

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[50]Expected to be in the range of 2000 to 4800 cubic meters through 2030, citing DOE estimates (54 FR 22580). This volume corresponds approximately to a single emplacement drift in a HLW repository.

Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste" – at the time) be amended to specifically provide for storage of GTCC waste at an independent spent fuel storage installation (ISFSI) or a monitored retrievable storage (MRS) facility pending its transfer to a permanent disposal facility. See NRC (1996a). Because interim storage of the GTCC waste would be accomplished in a manner similar to that used to store spent fuel at an ISFSI, the petitioner believed public health and safety and environmental protection would be ensured. The NRC staff evaluated the petition and the six comments received during a public comment process,[51] which all supported the petition, and concluded that the petitioner's concept had merit because there are currently no routine disposal options for GTCC waste. The Commission subsequently amended Part 72 to allow licensing for the interim storage of GTCC waste in a manner that is consistent with current licensing for the interim storage of SNF. See NRC (2001). The amendments only applied to GTCC LLW wastes generated at commercial nuclear power plants.

7.2 DOE Activities

The 1988 OTA assessment (p. 31) expressed the view that it would be 15 to 20 years before disposal access for GTCC LLW would be available to generators. As an interim measure, OTA recommended extended on-site storage for those producers who had capacity to do so. For those who had no capacity, OTA recommended storage at an NRC-licensed DOE disposal facility (Op cit.). In 1989, when the issue of the need for the potential for Federal interim storage of nuclear waste was examined, there was no reference to the management of GTCC LLW. See Monitored Retrievable Storage Review Commission (1989).

Section (3)(b)(1)(D) of the LLWPAA directed the Secretary of Energy to issue a report recommending safe disposal options for GTCC LLW. Such a report was issued by the Secretary in 1987. The report (DOE, 1987) also described the types and quantities of GTCC LLW being generated at the time. Hulse (1991) and Lockheed Idaho Technologies Company (1994a and 1994b[52]) have provided updates that later revised earlier information about estimates of current and future volumes of GTCC LLW from the original 1987 census.

DOE published a *Notice of Inquiry* (NOI) in 1995 soliciting public and stakeholder input to the development of a strategy for the management and disposal of GTCC LLW (DOE, 1995; 60 FR 13424). In its *Federal Register Notice*, DOE proposed to prepare a preliminary EIS that indicated its intent to begin the scoping process for developing GTCC LLW disposal options. The scoping process included three public meetings with stakeholders. Five strategy options were proposed in the 1995 NOI. It was noted that the decision-making regarding the

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[51]The NRC published a notice of receipt of the petition in the *Federal Register* on February 1, 1996 (NRC, 1996a; 61 FR 3619), allowing a 75-day comment period. The NRC received six comment letters, all supporting the petition. The NRC staff evaluated the petition and the comments and concluded that the petitioner's concept had merit. The requirements at Part 72 only provide for licensing storage of spent fuel at an ISFSI and storage of SNF and solid HLW at an MRS. Nonetheless, a reactor licensee could elect to store GTCC LLW at an ISFSI site under licenses issued under other NRC regulations, namely, Part 30 and Part 70. However, the Part 30 and Part 70 regulations at the time did not provide specific licensing criteria for storage of GTCC LLW at an ISFSI, and thus may not have been known to the petitioner or to the commenters that GTCC waste can be stored under a Part 30 or a Part 70 license.

[52]This study concerned sealed sources, the number of which in the United States was estimated to be about 250,000.

Department's preferred management option would be addressed in supplemental NEPA documentation (60 FR 13425). Following the conduct of three public meetings, no additional action was taken by the Department to develop the preliminary EIS. Alternatively, in 2005, the Department published a advance NOI prepare a EIS for GTCC LLW. See DOE (2005, 70 FR 24775).[53] As part of the EIS development process, DOE proposed that the NRC staff participate as a cooperating agency (NRC, 2005). After review, the Commission rejected this proposal and in a 2005 SRM, directed the NRC to comment on the GTCC EIS.

[53]It should be noted that in a review of potential waste streams for a HLW repository, another DOE program office has reviewed the characteristics of GTCC wastes. See ORNL (1992). In the final EIS for the Yucca Mountain geologic repository, DOE accounted for GTCC LLW disposal in a bounding analysis that estimates the environmental impacts of repository disposal activities (DOE, 2002; pp. A-57 – A-61). However, there are no published plans at this time suggesting that DOE will place GTCC waste in the proposed HLW repository.

8 OTHER NRC LLW PROGRAM DEVELOPMENTS

Section 5 of this paper describes the regulatory products the staff prepared to help potential licensees develop complete and high-quality license applications based on Part 61 requirements. These products also provide instructions to the staff on how to review those license applications.

In addition to the development of guidance products, the NRC staff has undertaken a number of initiatives intended to aid in the implementation of NRC's LLW regulatory framework. These initiatives are described in Section 7.1 of this paper and took place at various times over the years in relation to the development of the Part 61 regulatory and guidance framework previously described. As part of an agency-wide planning initiative in the early 1990s, the NRC staff undertook a broad reassessment of its LLW program. This reassessment is described in Section 7.2 of this paper.

8.1 LLW Regulatory Guidance and Policy

The NRC staff has historically relied on the use of guidance documents such as technical positions as a means of interpreting the Commission's regulatory requirements. In addition, the Commission periodically issues *Policy Statements* as a means of communicating to licensees and stakeholders Commission views bearing on some particular issue. These "communications" were not intended as substitutes for the regulations and compliance with them is not required. They generally represent the staff's recommendations on preferred approaches to addressing the requirements[54] or the Commission's views on issues bearing on its regulatory activities. Table 15 summarizes the subject areas for which the Commission has issued policy statements or the staff have provided additional regulatory guidance to potential LLW licensees.

The NRC also sponsored numerous technical assistance projects intended to provide predictive models and analytical tools necessary to evaluate the performance of LLW disposal facility systems and components. Areas of interest included waste package container performance, evaluation of leaching phenomena, hydrogeological and hydrochemical characterization and modeling, and cover performance. Most of this work focused on SLB disposal facilities. The use of predictive models to evaluate the performance of a disposal system or its components is generally referred to as "performance assessment" and has gained increased use in NRC's waste management programs (Eisenberg and others, 1999). As early as 1987, the staff recognized that some type of assessment methodology would need to be acquired" or "developed" for estimating the performance of Part 61 LLW disposal facilities (NRC, 1987; 52 FR 5996). To provide focus and integration of the overall LLW program, a LLW performance assessment strategy was also developed (Starmer and others, 1988). A proposed LLW performance assessment methodology (PAM) based on this strategy was subsequently developed by the Sandia National Laboratories (SNL).

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[54]In general, the staff has believed that methods and solutions differing from those set out in guidance documents should be acceptable if they provide a sufficient basis for the findings requisite to the issuance of a permit or license by the Commission.

Table 15. Additional NRC Technical Guidance and Policy Direction in the Area of LLW.

Title	Scope	Reference
Commission Policy/Position Statements		
"Policy Statement on Low-Level Waste Volume Reduction" [a]	Licensees are encouraged to establish programs to result in good volume reduction practices in order to: (1) extend the operational life of existing commercial LLW disposal sites; (2) alleviate concerns regarding existing LLW disposal capacity should there be delays in establishing regional disposal facilities; and (3) reduce the number of LLW shipments.	NRC (1981c)
"Regulatory Issues in Low-Level Radioactive Waste Performance Assessment" (SECY-96-103) [b]	The Commission expressed its views on: (1) consideration of future site conditions, processes, and events; (2) performance of engineered barriers; (3) specification of a time frame for a LLW performance assessment; (4) treatment of sensitivity and uncertainty in LLW performance assessments; and (5) the role of performance assessment during the operational and closure periods.	NRC (1996)
Technical Positions/Recommendations		
Branch Technical Position on "LLW Burial Ground Site Closure and Stabilization" NUREG-0782)	In closing and stabilizing a LLW disposal facility, the overall objective is to leave the site in a condition such that the need for active ongoing maintenance is eliminated, and only passive surveillance and monitoring are required to the point when the NRC license is terminated.	NRC (1979)
Branch Technical Position on "Site Suitability, Selection, and Characterization" (NUREG-0902)	Provides the staff's interpretation of: (1) the site suitability requirements proposed in §61.55; (2) the site selection process as related to the consideration of alternatives, as required by the NEPA process; and (3) the scope of site characterization activities necessary to develop site-specific data necessary for a Part 61 license application and environmental report.	Siefken and others (1982)
Technical Position on "Waste Form"	Provides guidance on acceptable methods for demonstrating compliance with the waste form structural stability requirements found at §61.56.	NRC (1991b)
Branch Technical Position on "Concentration Averaging and Encapsulation"	Defines a subset of concentration averaging and encapsulation practices that the staff would find acceptable in determining the concentrations of §61.55 tabulated radionuclides	NRC (1995a)

Title	Scope	Reference
"A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities – Recommendations of NRC's Performance Assessment Working Group" (NUREG-1573) [c]	Describes (1) an acceptable approach for systematically integrating site characterization, facility design, and performance modeling into a single performance assessment process; (2) five principal regulatory issues related to the interpretation and implementation of the Part 61 performance objectives and technical requirements, all of which are integral to an LLW performance assessment; and (3) how to implement the NRC's PAM.	NRC (2000)

a. The *Policy Statement* acknowledged but did not specifically identify LLW volume reduction technologies under review at the time. See Trigilio (1981). In a report prepared for the ACNW, Long (1990) examines the use of incineration as a potential volume reduction method.
b. Commission's positions were later restated in NUREG-1573.
c. See Appendix D.

In terms of measuring disposal facility designs and performance against the Part 61 performance objectives, the guidance provided by NUREG-1199, NUREG-1200, and NUREG-1300 was general, and many specific implementation issues and acceptable approaches for resolving them were not addressed. Moreover, the relationships between the overall Part 61 data and design requirements, and the specific LLW performance assessment needs, were not explicitly addressed by the existing guidance documents. Previously, site characterization, facility design, and performance modeling were activities that heretofore were considered separate. To clarify these issues and other issues, the staff developed detailed information and recommendations, for potential applicants, as they relate to the performance objective concerned with the radiological protection of the general public (at §61.41) in NUREG-1573 (NRC, 2000). See Appendix D of this paper for additional information.

8.2 LLW Research

Once NRC's regulatory framework was established, the staff focused its attention to conducting technical analyses intended to provide an improved understanding of the behavior of a LLW disposal facility and its components based on lessons-learned at commercial and DOE-operated LLW disposal sites. Many of the NRC products and activities described elsewhere in this paper where conducted by or on behalf of NRC's Office of Nuclear Materials Safety and Safeguards (NMSS). Another NRC program office, the Office of Nuclear Regulatory Research (RES) also sponsored a significant amount of LLW technical work, or more specifically "research." In 1989, RES staff published a LLW research program plan which presented RES' strategy for pursuing the LLW research studies. See O'Donnell and Lambert (1989). Many of the RES-sponsored research projects completed through 2000 in the area of LLW were cited in NUREG-1573. Appendix E of this report contains a selected bibliography of technical reports and papers sponsored by RES in the LLW area since NUREG-1573 was published.

As noted earlier in this paper, the USGS was given certain basic and applied research responsibilities in the area of LLW. In April 1992, the USGS cooperated with RES on basic research applied to LLW siting, monitoring and modeling issues through an Interagency MOU. A major accomplishment of the joint MOU was the convening of a "Joint USGS–USNRC Workshop on Research Related to Low-Level Radioactive Waste Disposal, May 4–6, 1993, National Center, Reston, Virginia." The workshop covered five topics: (a) surface- and ground-water pathway analysis; (b) ground-water chemistry; (c) infiltration and drainage; (d) vapor-phase transport and volatile radionuclides; and (e) ground-water flow and transport field studies. The workshop and its subsequent proceedings (Stevens and Nicholson, 1996) reported on the current state-of-the-art and practice in research related to LLW disposal hydrogeologic, hydrologic, geochemical and performance assessment issues at commercial and military-related facilities. Presenters and participants were from academia, DOE national laboratories, consulting companies, Federal and State agencies, and international research centers.

Other related workshops on modeling and monitoring and their published proceedings include: (a) NUREG/CP-0163, “Proceedings of the Workshop on Review of Dose Modeling Methods for Demonstration of Compliance with the Radiological Criteria for License Termination” (Nicholson and Parrott (1998); (b) NUREG/CP-0177, "Proceedings of the Environmental Software Systems Compatibility and Linkage Workshop" (Whelan and Nicholson, 2002), which helped to initiate the MOU on multimedia environmental modeling signed by 9 Federal agencies;[55] and (c) NUREG/CP-0187,“Proceedings of the International Workshop on Uncertainty, Sensitivity, and Parameter Estimation for Multimedia Environmental Modeling” (Nicholson and others, 2004). These workshop proceedings highlight the advancements in environmental modeling and performance assessments since the 1993 USGS–NRC LLW workshop which are applicable to LLW issues.

Numerous technical reports and technology transfer workshops have been issued and sponsored by RES. Of particular significance to LLW are NUREG/CR-6805, “A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites” (Neuman and Wierenga, 2003) and NUREG/CR-6843, “Combined Estimation of Hydrogeologic Conceptual Model and Parameter Uncertainty” (Meyer and others, 2004) which discuss guidance and tools for modeling hydrogeologic systems and radionuclide transport relevant to LLW.

8.3 Strategic Planning

In addition to the guidance development activities described above, in the early 1990s, the staff undertook a broad reassessment of its LLW program taking into account factors outside the control of the NRC. This assessment took place at the time other reviews of the national program were taking place (e.g., GAO, 1992a).

As part of the NRC’s first assessment, the staff categorized strategies and options for the Commission to consider to advance the goals and objectives of the LLWPAA. These included: expanding technical assistance, revising the existing Part 61 regulatory framework, seeking greater public involvement in the current LLW program, and passing additional Federal LLW legislation (Taylor, 1993). Focusing on the option to revise Part 61, the staff identified specific areas in the regulation that would make potential candidates for revision with the goal of enhancing public health and safety through the establishment of more precise regulations and addressing the State’s experiences in applying the existing Part 61 regulatory framework.

[55] See *http://www.ISCMEM.org*.

Candidate areas identified in the current regulation proposed for revision are listed in Table 16 and include so-called “active” disposal concepts.[56]

At the time these candidate areas were proposed, the staff took the position that there was no evidence that the current regulatory framework represented an impediment to the development of new LLW disposal facilities (Taylor, 1993; p. 6). In fact, it was the staff’s view as well as that of several of the Agreement States that major revisions to Part 61, along with the requirement for conforming revisions by the Agreement States, could create instability in current LLW licensing efforts (Op cit., pp. 6–7).

As an alternative to revising specific sections of the regulation, the staff proposed to revise Part 61 by removing its existing specificity, and making it more performance-oriented by placing greater emphasis on the overall performance objectives. This proposal was introduced before the Commission published its *Probabilistic Risk Assessment (PRA) Policy Statement* (See Appendix B of this paper). Under such an approach, the staff would develop guidance documents to address siting, design, construction, operation, closure, and waste form issues.[57] There is no information to suggest that the Commission responded to the staff’s 1993 analysis. That analysis was first overtaken in 1995 by the issuance of a Commission Paper – SECY-95-201, entitled “Alternatives to Terminating the NRC's Low-Level Radioactive Waste Disposal Program " (NRC, 1995c) – that described three options regarding the future of NRC’s LLW program.[58] In that SECY paper, the staff recommended reducing NRC’s LLW program by eliminating or reducing various parts of the program taking into account current developments in the national LLW program as well as reduced budget allocations at the NRC. The ACNW provided it views regarding the staff’s recommendations in SECY-95-201 in a letter dated December 29, 1995. See Section 8.3.1 of this paper.

Later, in 1995, SECY-95-201 was overtaken by the Commission’s *Strategic Assessment and Rebaselining Imitative*. This was a four-phase strategic planning exercise, the goal of which was to assess and rebaseline NRC’s regulatory activities in order to provide a sound foundation for future agency direction and decision-making. The principal focus of the initiative was the identification of key strategic issues associated with NRC’s primary responsibility to protect public health and safety and the environment. These key issues were called *Direction-Setting Issues* or DSIs. For each of the 16 DSIs, background papers were developed containing the

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[56]The staff generally defined active disposal concepts to include retrievablility, active maintenance and monitoring, and a longer period of custodial oversight (Op cit., p. 7).

[57]At the time, the staff estimated that it would take 2 to 3 years to complete a performance-based rulemaking and an additional 3 years for the Agreement States to adopt it.

[58] These options can be briefly described as: (a) continue the program as currently in place; (b) reduce the program by eliminating or reducing various parts; and (c) terminate all parts of the LLW program.

Table 16. Potential Candidate Areas in 10 CFR Part 61 Identified for Amendment by the NRC Staff in 1993. Taken from Attachment B to NRC (1993).

10 CFR Part 61			1983 NRC Staff Recommendation (Attachment B)
Requirement	**Subpart**	**Subject Area**	
§61.29	B	Active Maintenance	In conjunction with a longer time period of institutional control, include provisions in the regulation for more inspections and preventive maintenance of the disposal facility following closure to assure that the facility is performing as intended.
§61.41	C	Performance Objectives	Establish more stringent dose requirements for protection of the general population lower than the current 25 mrem/yr.
§61.50	D	Technical Requirements for Land Disposal Facilities	Develop specific technical criteria to cover disposal in above ground vaults (AVGs), which are not currently addressed in the regulations.
§61.50(a)	D	Site Suitability Requirements	Current requirements considered to be "minimum" basic requirements. Past experience indicates more specific siting and design requirements are needed. More credit also needed for performance of engineered barriers to compensate for site deficiencies.
§61.53	D	Environmental Monitoring	In conjunction with a longer time period of institutional control, include provisions in the regulation for a period of environmental monitoring after the 100-year caretaker period.
§61.59(a)	D	Land Ownership	Consideration should be given to assigning a responsible third party to the caretaker role other than the government.
§61.59(b)	D	Institutional Control Period	Extend governmental care taker period for more than 100 years.
§§61.55 and 61.56	D	Waste Classification and Characterization	Specific concentration-averaging requirements are not specified in the regulations
n/a	n/a	Retrievability Option	Currently, there is no provision in the regulation to require that the wastes be recoverable should the disposal facility fail to perform as intended.
n/a	n/a	Ground-Water Protection Requirements	The regulation could be made more explicit on how the ground-water resource would be protected. ACNW has previously recommended specific regulatory action in this area.

Commission's preliminary views on policy options in each of the DSI topical areas. The goal in developing these papers was to identify and classify issues that effected each of the NRC programs and, ultimately, the means by which the agency gets its work done. The 16 DSIs were assembled in the *Strategic Planning Framework* (NRC, 1996), which was made available for public comment on September 13, 1996.

"DSI 5" applied to NRC's LLW program. The position paper superceded the staff's earlier 1993 program analysis by recommending six options for managing NRC's LLW programs. The six options proposed are as follows:

Option 1: *The NRC assumes a greater leadership role in the National LLW program.*

Option 2: *The NRC assumes a stronger regulatory role in the in the National LLW program.*

Option 3: *The NRC retains the current LLW program.*

Option 4: The *NRC recognizes progress in the National LLW program and reduces the size of its current program.*

Option 5: *The NRC recommends to Congress that its LLW responsibilities be transferred to the EPA.*

Option 6: *The NRC encourages the long-term storage of LLW under the concept of "assured storage."*

In a Staff Requirements Memorandum (SRM) dated March 7, 1997, the NRC Executive Director of Operations informed the staff of the Commission's preference for Option 3, to maintain the current LLW program. The ACNW provided it's views regarding DSI 5 and other cross-cutting issues outlined in the *Strategic Planning Framework* in a letter dated January 30, 1997. See Section 8.3.2 of this paper.

PART III: PAST ACNW ADVICE AND RECOMMENDATIONS

9 PREVIOUS ACNW REVIEWS

The ACNW was not in existence at the time NRC's LLW regulatory framework at Part 61 was created. Nevertheless, the Committee has commented on the implementation of that framework in more than 20 letter reports. The purpose of this section is to summarize past ACNW advice in the LLW area.

9.1 Background

The ACNW was established by the NRC in June 1988 as a Federal Advisory Committee to provide independent technical advice on agency activities, programs, and key technical issues associated with regulation, management, and safe disposal of certain types of radioactive waste. The Committee is independent of the NRC staff and reports directly to the Commission, which appoints its members. Consistent with NRC's regulatory mission, the ACNW undertakes independent studies and reviews related to the transportation, storage, and disposal of HLW and LLW, including the interim storage of SNF; materials safety; and facility decommissioning. The ACNW also independently evaluates staff efforts to develop and apply a risk-informed and performance-based regulatory framework to these programs (see Appendix B), consistent with Commission direction. This would include reviews of and comments on proposed rules, regulatory guidance, licensing documents, staff positions, and other issues, as requested by the Commission.

The operational practices of the ACNW are governed by the provisions of the Federal Advisory Committee Act (FACA – Public Law 92-463). FACA requires that, with very few exceptions, advisory committee meetings will be open the public.[59] The results of the ACNW's reviews, consisting of both comments and recommendations, are documented in letter reports. For the period 1988-2005, the ACNW has issued about 200 letter reports. Each year, ACNW letter reports are complied and published as updates to NUREG-1423 (ACNW, 1990–2005).

9.2 Discussion

Since its establishment, the ACNW has closely followed public health and safety issues associated with the management of LLW. Past ACNW letters may be generally classified as having been written in response to requests from the Commission, the Executive Director for Operations or NRC Program Office staffs although others have been prepared in response to a

[59] FACA requires that Committee memberships be fairly balanced in terms of the points of view represented and the agency functions being performed. As a result, members of specific advisory Committees tend to possess skills that parallel the program responsibilities of their sponsoring agencies.

perceived need which may have been identified by the staff, the public, licensees, or other agencies. In addition, the Committee had also closely followed international LLW practices and developments, as well as considerations arising from proposed or actual activities by the Agreement States. The Committee has held individual sessions, as well as Working Group meetings, dedicated to the actual licensing activities at proposed, as well as operating, LLW sites and their associated hearings.

Coupled with the broad experience represented by its membership and supporting staff, the ACNW's letters have covered a wide band of selected issues – groundwater monitoring, mixed LLW, onsite storage, performance assessment, and site characterization – in addition to specific technical topics such as the LLW source term and the suitability of certain types of LLW disposal containers. Also included in the Committee's deliberations have been broad topics concerned with the regulation of LLW and the associated NRC programs.

A list of past ACNW letters in the area of LLW can be found in Table 17. The Committee's first letter related to a LLW issue was written in August 1988. A brief summary of past recommendations from those letters is presented below.

9.3 Summary of ACNW Observations/Conclusions

The principal observations presented in Committee letters can be generally classified into six areas:

- General LLW Issues.
- Groundwater Monitoring Issues.
- Mixed LLW Issues.
- Onsite Storage Issues.
- Performance Assessment Issues.
- Comments on Waste Packages and Waste Form Issues.

9.3.1 General LLW Issues

Below Regulatory Concern Policy Statement. As noted earlier, LLWPAA required that NRC establish standards for determining when radionuclides are present in waste streams in sufficiently low concentrations or quantities as to be BRC, and therefore not subject to NRC regulation. As noted earlier, the Commission published its proposed policy statement outlining its plans to establish certain new BRC rules and procedures in August 1986 (51 FR 30839).

Table 17. ACNW Letter Reports Related to LLW Management. Listed chronologically. Electronic copies of these letter reports can be examined by going to the ACNW web site at *http://www.internal.nrc.gov/ACRS/rrs1/Trans_Let/index_top/ACNW_letters/ghindex.html*.

Letter Report Title	Date
ACNW Comments on Proposed Branch Technical Position Concerning Environmental Monitoring for Low-Level Waste Disposal Facilities	August 9, 1988
ACNW Comments on Proposed Commission Policy Statement on Regulatory Control Exemptions for Practices Whose Public Health and Safety Impacts are Below Regulatory Concern	August 9, 1988
Proposed Policy Statement on Below Regulatory Concern	September 15, 1988
Suitability of High Density Polyethylene Hing Integrity Containers	September 16, 1988
Final Rulemaking on 10 CFR Part 61 Relative to the Disposal of Greater-than-Class C Low-Level Radioactive Waste	February 24, 1989
Management of Mixed Hazardous and Low-Level Waste (Mixed Wastes)	May 3, 1989
Reporting Incidents involving the Management and Disposal of Low-Level Radioactive Waste	July 5, 1989
Comments on Technical Position Paper on Environmental Monitoring of Low-Level Radioactive Waste Disposal Facilities	September 19, 1989
Low-Level Waste Performance Assessment Methodology	October 18, 1989
NRC Program on of Low-Level Radioactive Waste	January 30, 1990
Regulation of Mixed Wastes	February 28, 1991
Comments Regarding 10 CFR Part 61 Proposed Revisions Related to Groundwater Protection	June 27, 1991
NRC Capabilities in Computer Modeling and Performance Assessment of Low-Level Waste Disposal Facilities	December 2, 1991
Proposed Expedited Rulemaking: Procedures and Criteria for On-site Storage of Low-Level Radioactive Waste	April 30, 1992
Source Term and Other Low-Level Waste Considerations	March 31, 1993
Review of Low-Level Radioactive Waste Performance Assessment Program	June 3, 1994
Private Ownership of Low-Level Waste Sites	February 6, 1995
Regulatory Issues in Low-Level Radioactive Waste Disposal Performance Assessments	June 28, 1995
Lessons-Learned from the Ward Valley, California, Low-Level Waste Disposal Facility Siting Process	August 10, 1995
Comments on SECY-95-201 and the NRC Activities Regarding Low-Level Radioactive Waste	December 29, 1995
Elements of an Adequate NRC Low-Level Radioactive Waste Program	July 24, 1996
Comments on Selected Direction-Setting Issues Identified in NRC's Strategic Assessment of Regulatory Activities	January 30, 1997
Time of Compliance for Low-Level Radioactive Waste Disposal Facilities	February 11, 1997
NRC Staff Research on Generic Posit-Disposal Criticality at Low-Level Radioactive Waste	July 30, 1998

Letter Report Title	Date
Branch Technical Position on Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities	August 2, 2000

The ACNW provided two sets of comments to the Commission on the proposed policy in letters dated August 9, 1988, and September 15, 1988. See Table 17. In 1993, the Commission withdrew its proposed policy.

Final Rulemaking on 10 CFR 61 Relative to the Disposal of Greater-than-Class-C Low-Level Radioactive Waste *(February 24, 1989).* In 1988, the Commission proposed amendments to Part 61 that would require the deep geologic disposal of GTCC wastes unless an alternative means of disposal elsewhere was approved by the Commission. At its 7th meeting, in 1989, the Committee was briefed on the final proposed rule. Discussion's at the ACNW's meeting centered around the public comments received on the Commission's proposed rule (NRC, 1988; 53 FR 17709) and the staff's review and disposition of those comments. Following public comment, Part 61 was amended at §61.55(b)(2)(iv) to permit the disposal of GTCC waste in a HLW geologic repository licensed under Part 60 or some other type of disposal facility design approved by the Commission (NRC, 1989b; 54 FR 22578). Subject to certain recommendations, the Committee agreed with the final rule, as proposed by the staff. (Also see Section 6.5.1 of this paper.)

Reporting Incidents Involving the Management and Disposal of Low-Level Radioactive Wastes *(July 5, 1989).* Previously, it had been observed that certain LLW form types had performed poorly in disposal facilities (e.g., NAS, 1976). To address this issue, recommendations were considered to characterize the various LLW streams to allow for the identification and treatment (stabilization) of problematic waste form compositions. The issue was addressed partially by the development of a staff technical position on LLW forms (NRC, 1991b). However, the Committee also believed that there should be a system for reporting performance incidents involving problematic LLW forms and it should be developed in a timely manner. The Committee was concerned that the limitations in staff resources at the time should be promptly addressed in development of such a system as a delay would be highly undesirable.

NRC Program on Low-Level Waste *(January 30, 1990).* Earlier sections of this paper noted that by the early 1990s, the Commission's Part 61 regulatory framework was in-place supported by a considerable amount of staff guidance on how to implement that framework. For its part, consistent with direction from LLWPAA, DOE and EPA had also undertaken the development of additional technical information germane to the management of commercial LLW.

At its 16th meeting, the ACNW was briefed on the status of current LLW activities. As a result of that briefing, the Committee produced a letter with several recommendations. They first recommended that more attention should be given to the generator side of the LLW program with a focus processes effecting the types of LLW in the waste stream. The intent was to identify potential efficiencies in waste stream generation as a means of improving the management of LLW. The Committee believed that a "systems" approach to the management and disposal of LLW was necessary and could yield considerable dividends. (For NRC's part, they observed the need for closer coordination between the cognizant program offices with the agency.) They Committee also recommend the need for greater integration of all pertinent technical information from all cognizant agencies. They believed that a "road map", providing comprehensive guidance to licensees should be provided. Such guidance would be referenced, annotated, and contain key regulatory guides, technical positions, NUREGs as well as other technical information developed by other cognizant agencies. The Committee also recommended the preparation of a report that includes insights of current operating experience at existing LLW facilities with a view on how to improve NRC's regulatory responsibilities. Lastly, the Committee recommended that the Commission increase its efforts to accelerate the process for developing new disposal facilities.

Private Ownership of Low-Level Waste Sites *(February 6, 1995).* In 1994, the Commission issued a ANPR (59 FR 39485) that indicated that it was considering to allow private ownership of LLW sites as an alternative to the current requirement at §61.59(a) that permits only Federal or State ownership. The Committee concluded that there are no fundamental reasons why private ownership of LLW disposal sites should be prohibited but found several related issues, in its view, that required deliberate and cautious action.

The first major issue identified by the ACNW concerned the need for assurance of the protection of the health and safety of the public and the environment. During then-recent Commission policy discussions on adequacy and compatibility, the topic of provisions for private ownership of waste disposal sites was not included. The Committee expressed the view that the NRC needed to include explicit statements for pertinent requirements under the heading of adequacy and compatibility if the Commission proceeds with generic approval of private ownership. The Committee believed that NRC should require effective and timely transfer of ownership to another responsible and capable entity, such as the State, when any changes in the private ownership provision for waste sites, including dissolution of the corporate entity, are effected. The measure of adequacy and compatibility of Agreement and State operations should include effective and frequent monitoring and evaluation of private entities that are responsible for waste sites.

The Committee noted that §61.7(a) of the regulation presents 500 years as the target reference for siting and intruder barrier considerations. However, disposed LLW may pose a significant hazard for periods that, under some conditions, may well exceed 500 years. The Committee expressed the view that the Commission should expand the criteria to ensure that the State [or some governmental entity] maintain an active interest in the protection function of the disposal site for as along as the waste poses a hazard in the regulatory sense.

The second major issue concerned the administrative procedures that lead to privatization. The openness procedures used by the NRC to conduct its regulatory affairs provide ample opportunity for all interested parties to have their views considered. The Committee observed that given the potential importance of transferring LLW management accountability to a private corporate entity, with a likely modest life expectancy, compared to the period of time the waste possess a hazard, requires administrative (licensing) procedures comparable to those already used by the Commission. The Committee noted thus far it had not obtained information that this was the case when the State of Utah first acted.[60]

In summary, although the Committee believed that private entities were potentially capable of meeting the long-term protection function requirements of LLW management, final accountability for the long-term performance of a LLW disposal facility should continue to be through some type of governmental oversight entity. Furthermore, the Committee believed that the privatization decision-making process should be an open process not unlike the current administrative decision-making process already used by the NRC.

Following review, the Commission decided to not to amend §61.59(a).

Comments on SECY-95-201 and the NRC Activities Regarding Low-Level Radioactive Waste *(December 29, 1995).* In a September 14, 1995, SRM, the Commission requested the ACNW to provide comments on SECY-95-201 (NRC, 1995c), including practicable alternatives to the proposed options and the ACNW views on the significant consequences on the alternatives available to the Commission. See Section 7.2 of this paper.

SECY-95-201 identified three options regarding the future of the NRC LLW program. Briefly described, these options were:

- Continue the program as currently in place – *Option 1*.
- Reduce the program by eliminating or reducing various parts – *Option 2*.
- Terminate all parts of the LLW program – *Option 3*.

SECY-95-201 concluded that, based on statutory requirements and budget restrictions, Option 2 was the only practicable alternative. The Committee was unable to evaluate in detail the program as outlined in Option 2 because of the lack of specificity in resource allocations for various activities. The ACNW had a number of concerns with the conclusions of SECY-95-201. While current budgetary constraints were recognized, the Committee concluded that it is in the

[60] Acting in its capacity as an NRC-approved Agreement State, the State of Utah issued an exemption to governmental land ownership requirement in its LLW regulations to Envirocare of Utah in March 1991 when the State issued a license to that private corporation to allow it to operate a LLW disposal facility on privately-owned land.

national interest to have a centralized LLW program within the NRC and it strongly recommended that the Commissioners prioritize the LLW program in relation to all activities within the agency. Further, the Committee noted that the use of terms such as "limited" and "essential" to describe the resources and activities under Option 2 in SECY 95-201 was considered ambiguous. The Committee felt that the most important shortcoming of the SECY paper was its failure to address the fundamental question of what type of LLW program would be necesssary and sufficient to satisfy NRC's public health and safety mission.

Later in 1995, SECY-95-201 was overtaken by the Commission's *Strategic Assessment and Rebaselining Imitative* described in Section 7.2 of this paper.

Elements of an Adequate NRC Low-Level Radioactive Waste Program *(July 24, 1996).* The Committee prepared this letter report in response to a request from then-Chairman Jackson as to the Committee's review of what would constitute an adequate LLW program. This topic was previously discussed in connection with the Committee's earlier review of SECY-95-201.

In its July 1996 letter, the Committee expressed the view that an adequate NRC LLW program was one that would ensure that the processing, storage, and disposal of LLW, as defined in Part 61, would be carried out in accord with other NRC regulations (e.g., Part 20) and that the current and future impact of such activities would not represent an excessive risk to the affected population or the environment. Further, the Committee observed it would also be desirable to include in such a program attention to GTCC LLW waste as defined in Part 61 and to "mixed waste." Under such an expanded scope, other wastes that would be included are: naturally occurring and accelerator produced radioactive material (NARM) and NORM, wastes from uranium recovery and processing, wastes that are formed by the inadvertent concentration of contaminants (e.g., sewage, bag house dust), and wastes derived from decontamination and decommissioning activity.

Comments on Selected Direction-Setting Issues Identified in NRC's Strategic Assessment of Regulatory Activities *(January 30, 1997).* As noted earlier in this paper, the Commission under took a four-phase strategic planning exercise in 1995 known as the *Strategic Assessment and Rebaselining Imitative.* The principal focus of the initiative were the identification of key strategic issues associated with NRC's primary responsibility to protecting public health and safety and the environment. These key issues were called DSIs and DSI 5 applied to NRC's LLW program. The ACNW provided it views regarding DSI 5 and other cross-cutting waste management issues outlined in the *Strategic Planning Document* in a letter dated January 30, 1997 (Pomeroy, 1997).

In its letter, the ACNW recommended that the Commission adopt Option 2 – "Assume a strong regulatory role in national LLW program." The Committee had other recommendations, including:

- A number of waste types were missing from the discussion. In its general introductory comments, the Committee noted its concern about the omission of DSI cross-cutting issues such as the management of mixed wastes and GTCC LLW. The Committee believed these issues need to be adequately addressed in the strategic planning of the agency.

- NRC's acceptance of long-term storage of LLW, although attractive as a practical solution to a current problem, may not be acceptable to the Nation. The current national policy is to provide final disposal by the present generation in a manner that does not jeopardize public health and safety now and in the future. The DSI paper did not adequately address the requirements for implementing long-term storage of commercial LLW. The Committee was also concerned about the rather favorable light placed on interim storage in the DSI paper presumably because to date no incident has been reported as a result of storage on the originating site. However, no evidence exists that onsite storage can be effective over the expected life of the waste and the proliferation of storage sites enhances the risk.

- The Committee suggested that caution be exercised in using "rules of thumb" to define waste types in terms of the length of time over which they may be hazardous. In view of the absence of a *de minimis* position regarding radioactivity and the broad application of the no threshold-linear view of the health effects of radiation, the Committee suggested rules of thumb are a significant oversimplification.

- Finally, the Committee questioned the acceptance of DOE waste sites as potential disposal sites for civilian wastes. Existing DOE sites were not selected on the basis of criteria used in siting and licensing civilian disposal facilities, and evidence is lacking that these sites could meet the standards and regulations in effect.

In conclusion, the Committee recommend Option 2 of this DSI paper but encourage additions to (a) develop a more comprehensive definition of LLW and (b) evaluate the potential implementation and impact of assured storage with adequate protection and termination procedures.

9.3.2 Groundwater Monitoring Issues

ACNW Comments on Proposed Branch Technical Position Concerning Environmental Monitoring for Low-Level Waste Disposal Facilities *(August 5,1988).* In November 1987 (52 FR 42486), the NRC staff made a Branch Technical Position (BTP) available for public comment. The BTP addressed the Part 61 Subpart D requirements at §61.53(c) for environmental monitoring of LLW disposal facilities. Following the request for comments, work on the BTP was interrupted because of resource limitations. In its comments to the Commission, the ACNW recommended that work on the BTP should be completed and that the guidance be issued in final form. However, in making its recommendation, the Committee also recommended that the overall purpose of the staff's technical position in this area needs to be clarified, specifically to indicate whether it is prepared to provide guidance on monitoring policy or to prescribe detailed monitoring requirements.

Comments on Technical Position Paper on Environmental Monitoring of Low-Level Radioactive Waste Disposal Facilities *(September 19, 1989)*. After a brief interruption, staff work on the development of a BTP on environmental monitoring of LLW disposal facilities continued, but under the new title of a *Technical Position Paper*. Following a second review, the Committee believed that the renamed paper was acceptable for publication. However, the guidance document was never finalized but was later identified as a candidate area by the staff for rulemaking. See Table 16. As noted earlier (Section 8.2 of this paper), in recent years, RES has sponsored many research projects and public workshops related to the subject of environmental monitoring and modeling.

Comments Regarding 10 CFR Part 61 Proposed Revisions Related to Groundwater Protection *(June 27, 1991)*. In a September 6, 1990, letter, the ACNW recommended that the revised NRC technical position on waste form (NRC, 1991b) be published in final form. Along with the recommendation, though, the Committee expressed several concerns, including the need to revise Part 61 to show more direct emphasis on the resistance of LLW forms to leaching by percolating groundwater. In a December 31, 1990, SRM, the Commission requested that the Committee justify its position by evaluating the efficacy of the existing Part 61 in meeting its concerns.

In a subsequent meeting with staff, the history and performance experiences of earlier NRC-licensed LLW disposal facilities (Table 2) was reviewed, particularly as it related to the migration of radioactive materials. It was noted that the staff considered this past experience in scoping the Part 61 EIS and developing rule subsequent LLW regulation. The Committee also were apprised of the staff efforts at the time to undertake detailed studies of contaminant flow and transport phenomena as part of a broader LLW performance assessment effort (later to be documented in NUREG-1573 (NRC,2000). (See Appendix D of this paper for a more detailed discussion of this NUREG.) Based on this emerging work, the Committee was assured that it would provide additional insights into groundwater protection issues. Lastly, the Committee held a "brainstorming session" with NRC staff and their technical assistance contractors at the time which explored options that might improve radionuclide retention in, or to retard radionuclide migration from LLW forms.

On the basis of these interactions, the Committee set aside its suggestion that Part 61 be revised to explicitly include a requirement for LLW waste performance as a means of enhancing ground water protection.

9.3.3 Mixed LLW Issues

Management of Mixed Hazardous and Low-Level Radioactive Wastes (Mixed Wastes) *(May 3, 1989).* Although not addressed in this paper, chemically-hazardous LLW is subject to dual regulation under EPA's RCRA regulation. Following meetings with the NRC staff and representatives from the Nuclear Management and Resources Council (NUMARC), the ACNW offered several recommendations to the Commission. The Committee believed that additional resources should be assigned to study this issue, that its resolution was primarily institutional, and that the problems caused by dual jurisdiction are solvable (although at the time it seemed to be recognized by most knowledgeable institutions that any facility meeting NRC regulatory requirements is capable of meeting EPA criteria for the disposal of hazardous [nonradioactive wastes]).

The Committee also observed that the management of chemically hazardous GTCC LLW, NARM, and NORM is an area that had been overlooked and recommended attention by the staff.

Regulation of Mixed Wastes *(February 28, 1991).* Following the ACNW's May 1989 letter, OTA (1989) published a comprehensive report on the status of the national LLW program. That report also included an examination of mixed LLW issues and in doing so noted that the lack of mixed waste treatment options, access to mixed waste disposal facilities, and conflicting (and inconsistent) EPA and NRC regulations. At the request of then-Commissioner Curtis, the ACNW reviewed the comparability of protection afforded by NRC and EPA regulations when applied to the disposal of mixed wastes. The Committee responded to the request by conducting a Working Group Meeting devoted to the subject in December 1990 as well as dedicating addition time to the matter at subsequent Committee meetings.

Following on to the previous may 1989 ACNW letter on mixed LLW, the Committee reported that an industry-sponsored study (NUMARC, 1990) seemed to indicate that a facility built in conformance with Part 61 was slightly superior to a facility built in conformance with EPA's RCRA regulations at 40 CFR Part 264. However, the NRC staff stated that certain features of the disposal facility designed to those regulations, such as the requirement for a double liner and the leachate collection and retention provisions, "...appear to offer enhanced protection of groundwater, at least temporarily...." The Committee also noted that the then proposed EPA LLW standard (Part 193) included a "... subsystem requirement that groundwater contamination be limited so that no offsite person will receive an effective dose rate greater than 0.04 mSv (4 mrem) per year, may be a potential important attribute of the EPA regulations that is important...." Several other considerations were discussed in the ACNW's 1991 letter. It was noted that most of the mixed wastes generated in the United States were by DOE and its contractors. The Committee suggested, therefore, that a reasonable solution might be to have commercially-mixed wastes assigned to DOE (similar to the responsibility already given to DOE for GTCC LLW).

The Committee's February 1990 letter also contained some specific recommendations including:

- An action to establish a category of mixed wastes that was below BRC. Such wastes could be reclassified as hazardous wastes and regulated only by EPA. The Committee understood at the time that more than 90 percent of biomedical wastes would fall into this category.

- Concurrently, EPA should be encouraged to modify its regulations to develop and implement *de minimis* criteria for hazardous and mixed wastes. EPA should also be encouraged to modify its regulations to permit interim storage of mixed wastes awaiting disposal and to develop standards for the treatment of such wastes.[61]

- The Committee also believed that a combination bunker disposal for Classes-B and -C LLW, along with a leachate collection system in place for at least as long as would be required by EPA regulations can meet the combination of disposal requirements for mixed wastes specified by NRC and EPA.

In conclusion, the Committee felt strongly that adopting its proposal would significantly reduce the volume of "mixed" LLW produced. By virtue of lower production volumes, the Committee believed that there would be a net savings to waste generators. This cost reduction combined, with some level of regulatory simplification, would in the Committee's view reverse "...the debilitating trends by scientists to avoid the use of radioactive and hazardous materials in important research...."

9.3.4 Onsite Storage Issues

Proposed Expedited Rulemaking: Procedures and Criteria for On-site Storage of Low-Level Radioactive Waste *(April 30, 1992).* At its 42nd meeting in April 1992, the Committee was briefed on a rulemaking plan that would lead to the development of a rule that would allow for the long-term storage of LLW by existing NRC licensees. The Committee endorsed the rulemaking plan and its objectives. However, although the rulemaking plan addressed the wastes generated in the post-1996 time frame, the ACNW was concerned about the wastes

[61] In 2003, EPA published a ANPR discussing alternatives for the disposal of chemical wastes containing low concentrations of radioactive material (68 FR 65119). One of the alternatives cited in the ANPR would be the use of RCRA-C disposal technology for such wastes.

generated in the more immediate post-1992 time frame, stating that there were indications that the acceptance of radioactive waste at all existing LLW disposal sites, except Hanford, may be terminated by the end of 1992. The Committee concluded that if such proves to be a reality, interim storage of LLW will become necessary. The staff's plan was never implemented.

9.3.5 Performance Assessment Issues

Low-Level Waste Performance Acceptance Methodology *(October 18, 1989)*. As noted earlier in this paper, one of the first tasks undertaken by the NRC staff following the establishment of the LLW program was the development of a LLW performance assessment strategy. At its 14th meeting, in October 1989, the ACNW was briefed on that strategy (see Starmer and others, 1988). In its comments to the Commission, the Committee expressed the view that the strategy (the paper) was well-written and of value. To assure that the paper received the attention that it deserves, it was recommended that it be issued as a technical position, guidance paper, or in another suitable form. Other Committee comments included the recommendation that dose limits should be expressed in both metric and English units, and that the paper should include the concept of "effective dose equivalent." However, resource availability was noted by the staff as minimal at the time and the Committee urged that additional resources be made available to support this program.

NRC Capabilities in Computer Modeling and Performance Assessment of Low-level Waste Disposal Facilities *(December 2, 1991).* This letter report was prepared in response to several questions addressed to the Committee by then Commissioner Rogers. The Committee addressed its response to the differences in capabilities in addressing the management and disposal of HLW and LLW. HLW disposal capabilities were addressed separately in the letter. After a several page discussion which provided specific comments and addressed computer modeling capabilities, the ACNW concluded that the NRC staff were developing sound computer modeling and performance assessment capabilities and was assembling a competent group of analysts. The Committee as felt that a (overall) strategy document should be developed for the program, that existing computer hardware and software should be upgraded, that closer ties with other groups involved in related activities should be established (both nationally and internationally), and that adequate resources should be provided to achieve the Committee's recommendations. It was also noted at that time that the Committee felt it there should be timely action on its recommendations in light of the impending needs to license new LLW disposal facilities.

Review of the Low-Level Radioactive Waste Performance Assessment Program *(June 3, 1994).* This letter summarized the Committee's views based on discussions and presentations by the staff over a three-month period. Comments were provided on the capability of the staff's LLW performance assessment program applied to the review of LLW facilities as well as the development of the draft BTP – NUREG-1573, which was undergoing development at the time. (See Appendix D of this paper.)

Committee comments on the staff LLW performance assessment capability included the following:

- The staff had a sound and functional understanding of the bases of comprehensive performance assessments. Staff was also knowledgeable and appeared to have the necessary resources for developing the capability.

- The staff should seek ways to demonstrate that its performance assessment results are in agreement with actual data obtained from sites. Although such data are difficult to obtain, the benefits from such a demonstration are worthy of the effort.

- The staff was urged to develop a rational basis for the scope and depth of its required capability in performance assessments. The thrust should be the ability to review a LLW performance assessment for credibility and completeness.

- Risk calculations from a LLW performance assessment should be made using, to the extent feasible, dose models that are applied elsewhere in the NRC for such purposes. The presentations by the NRC staff indicated no such consistency.

- Committee agrees with, and strongly supports, the proposed used of probabilistic techniques in the performance assessment-process. These techniques are essential to capture uncertainty, to clearly delineate the current state of knowledge, and to serve as a guide to the acquisition of additional data.

In its June 1994 letter report, the Committee also offered detailed comments on the draft BTP for the staff to consider.

Regulatory Issues In Low-Level Radioactive Waste Disposal Performance Assessment *(June 28, 1995).* This letter was a continuation of the Committee's earlier review of the NRC LLW performance assessment program. In undertaking the development of the performance assessment methodology outlined in draft NUREG-1573, the staff identified areas in the Part 61 regulation that pertain to LLW performance assessment for which supplemental advice should be provided. The staff sought the ACNW's advise on its proposed resolution of comments on four regulatory issues received during a 1994 public workshop on the draft NUREG. They included:

- Consideration of site conditions, processes, and events in a LLW performance assessment.

- Performance of engineered barriers.

- Time frame for conducting a LLW performance assessment.

- Treatment of sensitivity and uncertainty in a LLW performance assessment.

The staff later expressed its views on the aforementioned regulatory issues and sought direction from the Commission in SECY-96-103 (NRC, 1996).

Time of Compliance for Low-Level Nuclear Waste Disposal Facilities *(February 11, 1997)*. In this letter, the ACNW built upon the principles it had outlined in an earlier Committee letter on the time span of compliance for the proposed Yucca Mountain HLW repository (Pomeroy, 1996), and recommended a two-part approach to establishing a time frame for LLW compliance. The first part utilizes a site-specific time span based on an analysis to determine the time at which release and transport of the more mobile radionuclides produce a peak dose to the critical population group. The second part is a qualitative evaluation, not requiring a specific measure of compliance, which is used to identify any significant deficiencies in the performance of the disposal system.

The ACNW noted that the current NRC LLW regulation did not specify the length of time over which the calculated dose should be compared to the specified standard of regulation (the time span of compliance). The Committee expressed the view that the rule was concerned with the minimum times of analyses. For example, in Part 61 it is stated that "... in choosing a disposal site, characteristics should be considered in terms of the indefinite future and evaluated for at least a 500-year time frame ...." The Committee suggested that this statement is, in part, the origin of the misconception that Part 61 is a "500 year rule," which only requires a demonstration of compliance for this time period. A time specification of 10,000 years was recommended in draft NUREG-1573 at the time, and was also included in the Part 61 Draft EIS scoping calculations (NUREG-0782). However, the Committee noted that the Part 61 FEIS (NUREG-0945) did not include (specify) a compliance period for the required analyses.

The staff's final views and recommendations on an appropriate time frame for a LLW performance assessment can be found in the final published version of NUREG-1573 (NRC, 2000). Also see Table D-1 of this paper.

The NRC Staff Research on Generic Post-Disposal Criticality at Low-Level Radioactive Waste Facilities *(July 30, 1998)*. In response to SECY-98-010 (NRC, 1998a), entitled "Petition for Envirocare of Utah to Possess Special Nuclear Material in Excess of Current Regulatory Limits," the NRC staff was directed to consult with the ACNW on whether to pursue a research project on the potential for post disposal criticality as a result of hydrogeochemical processes (including reconcentration) at licensed LLW disposal facilities.

On the basis of the information provided by the staff at the time, the ACNW agreed that the likelihood of reconcentration in a LLW disposal facility was remote and the consequences of any resulting criticality appear similarly minimal. The Committee could not conclude that any significant research on post-criticality is warranted. However, it did believe that much could be learned from limited additional research, namely a quantitative risk (performance) assessment of a specific site. At the time, the analyses performed to date contain elements of risk assessment but lack consistency of application in the propagation of realistic uncertainties thought the analytical models.

Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities *(August 2, 2000)*. Following publication of a draft for public comment, and the resolution of the comments received, the ACNW was briefed on the final proposed NUREG-1573 at its 119th meeting. It its subsequent August 2000 letter to the Commission, the ACNW recommended that the final NUREG be issued. The Committee also provided some comments for the Commission to consider, which were responded to by the staff in Appendix E to the final NUREG. A summary of the ACNW's comments and the staff's responses to them can also be found in Table D-2 of this paper.

Lesson Learned from the Ward Valley, California, Low-Level Waste Disposal Facility Siting Process *(August 10, 1995).* In 1995, the NAS issued its report examining the validity of seven site suitability issues raised by staff geologists at the USGS.[62] The ACNW reviewed the report (NAS, 1995) and also received a presentation on this topic from a member of the NAS Panel at its 75th meeting. That panel member identified key lessons-learned from the Ward Valley peer review, also endorsed by the Committee in its letter. Foremost among these was that in future LLW siting activities there should be a process to ensure that information developed on the characteristics of site should be accompanied, preferably from its initiation, by an independent, ongoing peer review that is focused on the scientific and technical quality and completeness of the field investigations, analytical programs, and the planning on the work that accompanies them, Such a review should be conducted by a recognized and demonstrably competent panel of experts.

The Committee also recognized at the time that any future LLW sites to be developed were likely to be developed under the purview of Agreement States. Nevertheless, for those states in which a LLW waste facility is contemplated, the developer should provide a plan that describes

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[62]In 1993, the State of California approved a license to construct a new LLW disposal facility in Ward Valley, on lands held by the Bureau of Land Management (BLM). The Department of Interior (DOI) was later asked by the State to transfer those lands to State control, to allow for the construction of the disposal facility. While the transfer was being considered by DOI, three USGS geologists (acting as individuals rather than in an official capacity) expressed seven concerns about the suitability of the site. Prior to making a decision to transfer the BLM land, DOI asked the NAS to convene a committee to act as a peer review to study the validity of the issues in dispute. Also see GAO (1997).

the process of forming such peer panels and the way their output could best be used in the decision-making.

9.3.6 Comments on Waste Package and Waste Form Issues

Suitability of High-Density Polyethylene High Integrity Containers *(August 9, 1988).* Section 61.56(b) of NRC's LLW regulation requires that for the disposal of Class-B and -C LLW, an HIC of sufficient structural stability be used. Guidance on demonstrating on how to meet this structural stability is given in NUREG-1199 (NRC, 1991a). The staff have previously investigated the suitability of fabricating HICs from high-density polyethylene (HPDE). Based on presentation material from its 3rd and 4th meetings as well as the review of selected technical documents, the Committee expressed the view in its letter that the HPDE HIC designs under consideration at the time would have difficulty in meeting the NRC criteria that define their mechanical properties for Class-B and -C waste containers. The Committee recommended coupling (integrating) HDPE with another suitable material to satisfy the pertinent NRC criteria. The Committee recommended that the staff bring the HPDE HIC studies to closure for those whose designs that had already been submitted to the NRC for approval, thus allowing the industry to better plan its response and further action.

Source Term and Other Low-Level Waste Considerations *(March 31, 1993*). The ACNW convened a Working Group to obtain better information concerning the source term of LLW going into disposal facilities. At the time, the Commission was considering amendments to its regulations to improve the quality and uniformity of information of LLW transfers between generators and operators. The Committee noted that one of the guiding criteria in the ongoing development of the *Uniform Low-Level Waste Manifest System* was to provide data deemed essential to LLW disposal facility performance assessments. In its 1993 letter, the Committee observed that the staff should confirm that the manifest data collected can be used through the full range of disposal environments likely to be found consistent with the site-specific data requirements imposed by the Part 61 regulation for estimating the release and transport of radio nuclides from disposal facilities. The letter discussed many other source term observations/considerations proposed or discussed by the Working Group participants. Also see NRC (1995b, 60 FR 15649) for more background on this issue.

10 References

Adam, J.A., and V.L. Rogers, "A Classification System for Radioactive Waste Disposal – What Waste Goes Where?," U.S. Nuclear Regulatory Commission, NUREG-0456, July 1978.

Advisory Committee on Nuclear Waste, "A Compilation of Reports of the Advisory Committee on Nuclear Waste – July 1988 – August 2004," U.S. Nuclear Regulatory Commission, NUREG-1423, 14 vols., August 1990-September 2005.

Battelle Memorial Institute, "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle," U.S. Energy Research and Development Administration, ERDA 76-43, 5 Vols., May 1976.

Bennett, R.D., and others, "Alternative Methods for Disposal of Low-Level Radioactive Wastes – Task 1: Description of Methods and Assessment of Criteria," U.S. Nuclear Regulatory Commission, NUREG/CR-3774, Vol. 1, April 1984. [Prepared by the U.S. Army Engineer Waterways Experiment Station.]

Bennett, R.D., "Alternative Methods for Disposal of Low-Level Radioactive Wastes – Task 2e: Technical Requirements for Shaft Disposal of Low-Level Radioactive Waste," U.S. Nuclear Regulatory Commission, NUREG/CR-3774, Vol. 5, October 1985. [Prepared by the U.S. Army Engineer Waterways Experiment Station Geotechnical Laboratory.]

Bennett, R.D. and J.B. Warriner, "Alternative Methods for Disposal of Low-Level Radioactive Wastes – Task 2b: Technical Requirements for Above-Ground Vault Disposal of Low-Level Radioactive Waste," U.S. Nuclear Regulatory Commission, NUREG/CR-3774, Vol. 3, October 1985. [Prepared by the U.S. Army Engineer Waterways Experiment Station Geotechnical Laboratory.]

Berglund, J.W., "Mechanisms Governing the Direct Removal of Wastes from the Waste Isolation Pilot Plant Repository Caused by Exploratory Drilling," Albuquerque, Sandia National Laboratories, SAND92-7295, December 1992. [Prepared by the New Mexico Engineering Institute for DOE.]

Central Interstate Low-Level Radioactive Waste Commission, "Annual Report 2003-2004," Lincoln, [2004].

Charles, D., and T.J. McEwen, "Radiological Consequences of Drilling Intrusion into a Deep Repository for High Level Waste," United Kingdom, Intera Sciences, [Report] I244-1, January 1991. [Prepared for the Swedish National Institute of Radiation Protection.]

Diaz, N.J., and others, Memorandum and Order [in the matter of Louisiana Energy Services, L.P. (National Enrichment Facility)], U.S. Nuclear Regulatory Commission, CLI-05-20, October 19, 2005.

Denham, D.H., R.D. Stenner, P.A. Eddy, R.E. Jaquish, and J.V. Ramsdell, Jr., "Recommendations to the NRC for Review Criteria for Alternative Methods of Low-Level Radioactive Waste Disposal – Environmental Monitoring and Surveillance Programs," U.S. Nuclear Regulatory Commission, NUREG/CR-5054, July 1988.

EG&G Idaho, Inc., "Corrective Measures Technology for Shallow Land Burial," Idaho Falls, Idaho National Engineering Laboratory, *Low-Level Waste Management Handbook Series*, DOE/LLW-13Te, October 1984. [Prepared for DOE.]

EG&G Idaho, Inc., "Radioactive Waste Management: A Summary of State Laws and Administration," Idaho Falls, Idaho National Engineering Laboratory, DOE/LLW-18T (Rev. 6), December 1985. [Prepared for DOE.]

EG&G Idaho, Inc., "Environmental Monitoring for Low-Level Waste Disposal Sites," Idaho Falls, Idaho National Engineering Laboratory, *Low-Level Waste Management Handbook Series*, DOE/LLW-13Tg (Rev. 1), 2 vols., September 1989. [Prepared for DOE.]

EG&G Idaho, Inc., "Directions in Low-Level Radioactive Waste Management: A Brief History of Commercial Low-Level Radioactive Waste," Idaho Falls, Idaho National Engineering Laboratory, DOE/LLW-103 (Rev. 1), August 1994. [Prepared for DOE.]

Eisenberg, N.A., and others, "Development of a Performance Assessment Capability in the Waste Management Programs of the U.S. Nuclear Regulatory Commission," *Risk Analysis*, 19(5): 847–876 [1999].

Fuchs, R.L., "1995 State-by-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites," Idaho Falls, EG&G Idaho, Inc., DOE/LLW-237, September 1996. [Prepared for DOE.]

Fuchs, R.L., "1996 State-by-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites," Idaho Falls, EG&G Idaho, Inc., DOE/LLW-243, September 1997. [Prepared for DOE.]

Fuchs, R.L., "1997 State-by-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites," Idaho Falls, EG&G Idaho, Inc., DOE/LLW-247, August 1998. [Prepared for DOE.]

Fuchs, R.L., “1998 State-by-State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites,” Idaho Falls, EG&G Idaho, Inc., DOE/LLW-252, May 1999. [Prepared for DOE.]

Goode, D.J., S.M. Neuder, R.A. Pennifill, and T. Ginn, “Onsite Disposal of Radioactive Waste – Estimating Potential Groundwater Contamination,” U.S. Nuclear Regulatory Commission, NUREG-1101, Vol. 3, November 1986.

Gruhlke, J.M., F.L. Galpin, W.F. Holcomb, and M.S. Bandrowski, “USEPA’s Proposed Environmental Standards for the Management and Land Disposal of LLW and NARM Waste," in R.G. Post (ed.), “WM ’89,” *Proceedings of the Symposium on Waste Management, February 26 – March 2, 1989, Tucson, Arizona*, 2:273–276 (1989).

Hulse, R.A., “Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics,” U.S. Department of Energy, DOE/LLW-114, August 1991.

Howekamp, D.P., Director/Region IX [San Francisco] Air and Toxics Division, U.S. Environmental Protection Agency, Letter to J.E. Lemley, Chief Executive Officer/U.S. Ecology, Houston, Texas [Subject: “Renewal of Approval to Operate a Chemical Waste Landfill for PCB Disposal”], January 16, 1996. [Available from the American Ecology Internet web site at *http://www.americanecology.com/usecology/pdf/beatty/tsca_permit.pdf*.]

Higginbotaham, L.B., K.S. Dragonette, and C.L. Pittiglio, Jr., “Licensing of Alternative Methods of Disposal of Low-Level Radioactive Waste – Branch Technical Position,” U.S. Nuclear Regulatory Commission, NUREG-1241, December 1986.

International Commission on Radiological Protection, "Report of ICRP Committee II on Permissible Dose for Internal Radiation (1959), with Bibliography for Biological, Mathematical and Physical Data," *Health Physics*, Vol. 3 [1959]. [Reprinted in 1975 as *ICRP Publication 2*.]

International Commission on Radiological Protection, “Recommendations of the International Commission on Radiological Protection,” *Annals of the ICRP*, Vol. 1, No. 3, [1977]. [ICRP Publication 26]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," *Annals of the ICRP*, Vol. 2, Nos. 3/4 [1979]. [ICRP Publication 30, Part 1]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," *Annals of the ICRP*, Vol. 4, Nos. 3/4 [1980]. [ICRP Publication 30, Part 2]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," *Annals of the ICRP*, Vol. 6, Nos. 2/3 [1981]. [ICRP Publication 30, Part 3. Includes addendum to Parts 1 and 2.]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers: An Addendum," *Annals of the ICRP*, Vol. 19, No. 4 [1988]. [ICRP Publication 30, Part 4]

King, W.C., and J.J. Cohen, "Interim Report to the NRC on Radioactive Waste Classification System," Livermore, Lawrence Livermore Laboratory, UCID-17497, April 18, 1977. [Prepared for the NRC.]

Kocher, D.C., and A.G. Croff, "A Proposed Classification System for High-Level and Other Radioactive Wastes," Oak Ridge, Oak Ridge National Laboratory, ORNL/TM-10289, 1987.

Lauer, M.T., "Is There Relief Ahead on the Low-Level Waste Front? – A Look at Waste Control Specialists in Texas," *Radwaste Solutions*, 10(4):12–16 (July/August 2003).

Lockheed Idaho Technologies Company, "Greater-Than-Class-C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics," Idaho Falls, Idaho Engineering National Laboratory, DOE/LLW-114, Rev. 1, September 1994. [Prepared for DOE.]

Lockheed Idaho Technologies Company, "Greater-Than-Class-C Sealed Sources," Idaho Falls, Idaho Engineering National Laboratory, DOE/LLW-163, 3 vols., September 1994. [Prepared for DOE.]

Long, S.W., "The Incineration of Low-Level Radioactive Waste," Advisory Committee on Nuclear Waste, NUREG-1393, June 1990.

Macbeth, P.J., D.E. Christensen, B.J. Thamer, and G. Wehmann, "Screening of Alternative Methods for the Disposal of Low-Level Radioactive Wastes," U.S. Nuclear Regulatory Commission, NUREG/CP-0308, October 1978. [Prepared by Ford, Bacon, & Davis Utah, Inc.]

Mazuzan, G.T., and J.S. Walker, "Controlling the Atom – The Beginnings of Nuclear Regulation 1946-1962," U.S. Nuclear Regulatory Commission, NUREG-1610, April 1997.

Meyer, G. L., "Modeling and Analyses to Support EPA's Low-Level Radioactive Waste Standards," in C.A. Little and L.E. Stratton (compilers), *Modeling and Low-Level Waste Management, Proceedings of December 1-4, 1980, Workshop, Denver, Colorado*, Oak Ridge National Laboratory June 1981, pp. 9–19.

Meyer, P.D., M.L. Rockhold, and G.W. Gee, “Uncertainty Analyses of Infiltration and Subsurface Flow and Transport for SDMP Sites,” U.S. Nuclear Regulatory Commission, NUREG/CR-6565, September 1997.

Meyer, P.D., and S. Orr, “Evaluation of Hydrologic Uncertainty Assessments for Decommissioning Sites Using Complex and Simplified Models,” U.S. Nuclear Regulatory Commission, NUREG/CR-6767, March 2002.

Meyer, P.D., M. Ye, S.P. Neuman, and K.J. Cantrell, “Combined Estimation of Hydrogeologic Conceptual Model and Parameter Uncertainty,” U.S. Nuclear Regulatory Commission, NUREG/CR-6843, March 2004.

Miller, W.O., and R.D. Bennett, "Alternative Methods for Disposal of Low-Level Radioactive Wastes – Task 2c: Technical Requirements for Earth-Mounded Concrete Bunker Disposal of Low-Level Radioactive Waste," U.S. Nuclear Regulatory Commission, NUREG/CR-3774, Vol. 4, October 1985. [Prepared by the U.S. Army Engineer Waterways Experiment Station Geotechnical Laboratory.]

Moeller, D.W., *Environmental Health*, Cambridge, Harvard University Press, 1992.

Monitored Retrievable Storage Review Commission, “Nuclear Waste: Is there a Need for Federal Interim Storage?,” Washington, November 1, 1989.

National Academy of Sciences, “Radioactive Waste Disposal into Atlantic and Gulf Coastal Waters,” Washington, National Research Council, Committee on Oceanography, NAS-NRC Publication 655, 1959.

National Academy of Sciences, “Disposal of Low-Level Radioactive Waste Pacific Coastal Waters,” Washington, National Research Council, Committee on Oceanography, NAS-NRC Publication 985, 1962.

National Academy of Sciences, “Radioactivity in the Environment,” Washington, National Research Council, Committee on Oceanography, 1971.

National Academy of Sciences, “The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Wastes,” Washington, National Research Council, 1976.

National Academy of Sciences, “Considerations of Health Benefit-Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives – A Report of [the] Advisory Committee on Biological Effects of Ionizing Radiations [BEIR],” U.S. Environmental Protection Agency, EPA 520/4-77-003, 1977.

National Academy of Sciences, “Decision Making in the Environmental Protection Agency,” Washington, Washington, National Research Council, Vol. II, 1977.

National Academy of Sciences, *Ward Valley: An Examination of Seven Issues in Earth Science and Ecology,* Washington, National Academy Press, 1995.

National Academy of Sciences,“The State of Development of Waste Forms for Mixed Wastes – U.S. Department of Energy’s Office of Environmental Management, Washington, National Academy Press, 1999.

National Academy of Sciences, “Improving the Regulation and Management of Low-Activity Radioactive Wastes – Interim Report on Current Regulations, Inventories, and Practices,” Washington, National Academy Press, 2003.

National Advisory Committee on Oceans and the Atmosphere, “Nuclear Waste Management and the Use of the Sea – A Special Report to the President and the Congress,” Washington, April 1984.

National Bureau of Standards, “Radioactive-Waste Disposal in the Ocean – Recommendations of the National Committee on Radiation Protection,” U.S. Department of Commerce*, National Bureau of Standards Handbook 58*, August 25, 1954.

National Safety Council, “A Guide to the U.S. Department of Energy’s Low-Level Radioactive Waste,” Washington, Environmental Health Center, January 2002. [Prepared in cooperation with DOE.]

Neuman, S.P., and P.J. Wierenga, “A Comprehensive Strategy of Hydrologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites,” U.S. Nuclear Regulatory Commission, NUREG/CR-6805, July 2003.

Newberry, W.F., T.A. Kerr, and D.H. Leroy, “Assured Storage Facilities: A New Perspective on LLW Management,” *Radwaste Magazine*, 2(5):13–22 (September 1995).

Newberry, W.F., T.A. Kerr, and D.H. Leroy, “Assured Storage: The Most Frequently Asked Questions,” *Radwaste Magazine*, 3(5):20–25 (September 1996).

Nicholson, T.J., and J.D. Parrott, “Proceedings of the Workshop on Review of Dose Modeling Methods for Demonstration of Compliance with the Radiological Criteria for License Termination, held at NRC in November 13-14, 1997,” U.S. Nuclear Regulatory Commission, NUREG/CP-0163, May 1998.

Nicholson, T.J., J.E. Babendreier, P.D. Meyer, S. Mohanty, B. Hicks, and G. Leavesley (eds.), “Proceedings of the International Workshop on Uncertainty, Sensitivity, and Parameter Estimation for Multimedia Environmental Modeling held at NRC in August 19-21, 2003,” U.S. Nuclear Regulatory Commission, NUREG/CP-0187, October 2004.

Nuclear Energy Agency [NEA], “Future Human Actions at Disposal Sites,” Paris, France, NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites, Safety Assessment of Radioactive Waste Repositories Series, Organisation for Economic Co-Operation and Development, 1991.

Neuder, S.M., “Onsite Disposal of Radioactive Waste – Guidance for Disposal by Subsurface Burial,” U.S. Nuclear Regulatory Commission, NUREG-1101, Vol. 1, March 1986.

Neuder, S.M., and W.E. Kennedy, “Onsite Disposal of Radioactive Waste – Methodology for the Radiological Assessment of Disposal by Subsurface Burial,” U.S. Nuclear Regulatory Commission, NUREG-1101, Vol. 2, February 1987.

Oak Ridge National Laboratory, “Chapter 5. Miscellaneous Wastes” in “Characteristics of Potential Repository Wastes,” Oak Ridge, DOE/RW-0184-R1, Vol. 2, July 1992.

O’Donnell, E., and J. Lambert, “Low-Level Radioactive Waste Research Program Plan,” U.S. Nuclear Regulatory Commission, NUREG-1380, November 1989. [Prepared by the Office of Nuclear Regulatory Research/Division of Engineering.]

Office of Technology Assessment, “An Evaluation of Options for Managing Greater than Class C Low-Level Radioactive Waste – Background Paper,” Congress of the United States, OTA-BP-0-50, October 1988.

Office of Technology Assessment, “Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste,” Congress of the United States, OTA-O-426, November 1989.

Oztunali, O.I., and G.W. Roles, "Update of Part 61 Impacts Analysis Methodology – Methodology Report,"   U.S. Nuclear Regulatory Commission, NUREG/CP-4370, Vol. 1, January 1986.

Oztunali, O.I., W.D. Pon, R. Eng, and G.W. Roles, "Update of Part 61 Impacts Analysis Methodology – Codes and Example Problems,"   U.S. Nuclear Regulatory Commission, NUREG/CP-4370, Vol. 2, January 1986.

Papdopulos, S.S., and I.J. Winograd, “Storage of Low-Level Radioactive Wastes in the Ground: Hydrogeologic and Hydrochemical Factors,” U.S. Environmental Protection Agency/Office of Radiation Programs, EPA-520/3-74-009, 1974. [Prepared by the USGS.]

Parler, W.C., General Counsel/U.S. Nuclear Regulatory Commission, Memorandum to Lando W. Zech (and others), U.S. Nuclear Regulatory Commission [Subject: “RCRA and the Atomic Energy Act”], dated April 11, 1989.

Pittiglio, C.L., Jr., “Review Process for Low-Level Radioactive Waste Disposal License Application Under Low-Level Radioactive Waste Amendments Act,” U.S. Nuclear Regulatory Commission, NUREG-1274, August 1987.

Pittiglio, C.L., Jr., R.J. Starmer, and D. Hedges, “Guidance on the Application of Quality Assurance for Characterizing a Low-Level Radioactive Waste Disposal Site: Final Report," U.S. Nuclear Regulatory Commission, NUREG-1383, October 1990.

Pittiglio, C.L., Jr., and D. Hedges,"Quality Assurance Guidance for a Low-Level Radioactive Waste Disposal Facility," U.S. Nuclear Regulatory Commission, NUREG-1293, Revision 1, April 1991.

Pittman, F.K., Director, Division of Waste Management and Transportation, U.S. Atomic Energy Commission Letter to C. Klingsberg, National Research Council [General subject: “Request for a National Research Council Committee Review of Current AEC Radioactive Waste Land Disposal Practices”], dated May 31, 1973.

Pomeroy, P.W., Chairman/Advisory Committee on Nuclear Waste, Letter to the Honorable Shirley Ann Jackson, Chairman/U.S. Nuclear Regulatory Commission [Subject: “Time Span for Compliance of Proposed Yucca Mountain High-Level Waste Repository”], dated June 7, 1996.

Pomeroy, P.W., Chairman/Advisory Committee on Nuclear Waste, Letter to the Honorable Shirley Ann Jackson, Chairman/U.S. Nuclear Regulatory Commission [Subject: “Comments on Selected Direction-Setting Issues Identified in NRC’s Strategic Assessment of regulatory Activities”], dated January 30, 1997.

Powers, D.A., Chairman/Advisory Committee on Reactor Safety, Letter to the Honorable Shirley Ann Jackson, Chairman/U.S. Nuclear Regulatory Commission [Subject: “The Role of Defense in Depth in a Risk-Informed Regulatory System”], dated May 19, 1999.

Raubvogel, R.J., “Nuclear Waste Disposal in the Oceans: A Current Status Report and Issues for Congress,” Washington, Congressional Research Service, The Library of Congress, 1982.

Rogers, V.C., “A Radioactive Waste Disposal Classification System,”U.S. Nuclear Regulatory Commission, NUREG/CR-1005, Vol. 1, September 1979. [Prepared by Ford, Bacon, & Davis Utah, Inc.]

Rogers, V.C., R.D. Baird, B.C. Robertson, and P.J. Macbeth, “A Radioactive Waste Disposal Classification System – The Computer Program and Groundwater Migration Models,”U.S. Nuclear Regulatory Commission, NUREG/CR-1005, Vol. 2, September 1979. [Prepared by Ford, Bacon, & Davis Utah, Inc.]

Schneider, R., E.H. Roseboom, Jr., J.B. Robertson, and P.R. Stevens, “Low-Level Waste” in “U.S. Geological Survey Research in Radioactive Waste Disposal – Fiscal Year 1979,” U.S. Geological Survey Circular 847, 1982.

Schweitzer, D.G., and C. Sastre, “Level of Evidence for Reasonable Assurance Guidelines to Prediction (Draft),” Upton, Brookhaven National Laboratory, BNL-52075, April 1987.

Siefken, D., G. Pangburn, R. Pennifill, and R.J. Starmer, “Site Suitability, Selection and Characterization – Branch Technical Position, Low-Level Waste Licensing Branch,” U.S. Nuclear Regulatory Commission, NUREG-0902, April 1982.

Starmer, R.J., L.G. Deering, and M.F. Weber, "Performance Assessment Strategy for Low-Level Waste Disposal Sites," in *10th Annual U.S. Department of Energy Low-Level Waste Management Conference: Conference Proceedings, Denver, Colorado*, *August 30-September 1, 1988,* EG&G Idaho, December 1988.

Stevens, P.R. and T.J. Nicholson (eds.), “Joint USGS-USNRC Workshop on Research Related to Low-Level Radioactive Waste Disposal, May 4-6, 1993, National Center, Reston, Virginia,” U.S. Geological Survey Water Resources Investigations Report 95-4015, 1996.

Taylor, J.M., Executive Director for Operations/U.S. Nuclear Regulatory Commission, Memorandum to Ivan M. Selin (and others), U.S. Nuclear Regulatory Commission [Subject: “Strategies and Options for Encouraging the States and Compacts to Develop New Low-Level Radioactive Waste Disposal Facilities”], dated April 23, 1993.

The White House [Richard M. Nixon, President], “Presidential Documents, Title 3 – The President, Reorganization Plan No. 3 of 1970," *Federal Register*, Vol. 35, No. 194, October 6, 1970, pp. 15623–15626.

Trask, N.J., and P.R. Stevens, “U.S. Geological Survey Research in Radioactive Waste Disposal – Fiscal Years 1986-90,” U.S. Geological Survey, Water Resources Investigations Report 91-4084, 1991.

Trigilio, G., “Volume Reduction Techniques in Low-Level Radioactive Waste Management,” U.S. Nuclear Regulatory Commission, NUREG/CR-2006, September 1981. [Prepared by Teknekron, Inc.]

U.S. Department of Energy, “Recommendations for Management of Greater-than-Class-C Low-Level Radioactive Waste – Report to Congress in Response to Public Law 99-240,” Assistant Secretary for Nuclear Energy, DOE/NE-0077, February 1987.

U.S. Department of Energy, "Strategy for Management and Disposal of Greater-Than-Class C Low-Level Radioactive Wastes [Notice of Inquiry]," *Federal Register*, Vol. 60, No. 48, March 13, 1995, pp. 13424–13425.

U.S. Department of Energy, "Notice of Availability; Draft DOE Order and manual on Radioactive Waste Management [Notice of Availability]," *Federal Register*, Vol. 63, No. 151, August 6, 1998, pp. 42012–42013.

U.S. Department of Energy, “DOE [Order] 435.1, Radioactive Waste Management,” Office of Environmental Management, DOE O 435.1, July 9, 1999. [Change 1 dated August 28, 2001.]

U.S. Department of Energy, “Radioactive Waste Management Manual,” Office of Environmental Management, DOE M 435.1-1, July 9, 1999. [Revised June 19, 2001.]

U.S. Department of Energy, “Inventory and Characteristics of Spent Nuclear Fuel, High-Level Radioactive Waste, and Other Materials,” in “Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada,” Office of Civilian Radioactive Waste Management, DOE/EIS-0250, Vol. II, Appendix A, February 2002.

U.S. Department of Energy,"Advance Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class C Low-Level Radioactive Wastes [Advance Notice of Intent]," *Federal Register*, Vol. 70, No. 90, May, 11, 2005, pp. 24775–24778.

U.S. Environmental Protection Agency, “Part 141 – Interim Primary Drinking Water Regulations [Promulgation of Regulations on Radionuclides],” *Federal Register*, Vol. 41, No. 133, July 9, 1976, pp. 28402–28409.

U.S. Environmental Protection Agency, “Part 190 – Environmental Radiation Protection Standards for Nuclear Power Operations, Subchapter F – Radiation Protection Programs [Final Rule]," *Federal Register*, Vol. 42, No. 9, January 13, 1977, pp. 2858–2861.

U.S. Environmental Protection Agency, *Proceedings of a Public Forum on Environmental Protection Criteria for Radioactive Wastes, March 30 – April 1, 1878, Denver, Colorado,* Office of Radiation Programs, ORP/CSD-78-2, May 1978.

U.S. Environmental Protection Agency, “Improving Government Regulations,” Washington, July 1978.

U.S. Environmental Protection Agency, "Recommendations for Federal Radiation Guidance, Criteria for Radioactive Wastes," *Federal Register*, Vol. 43, No. 221, November 15, 1978, pp. 53262–53268.

U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants; Addition of Radionuclides to List of Hazardous Pollutants" *Federal Register*, Vol. 44, No. 249, December 27, 1979, pp. 76738–76746.

U.S. Environmental Protection Agency, "Withdrawal of Proposed Regulations," *Federal Register*, Vol. 46, No. 53, March 19, 1981, p. 17567.

U.S. Environmental Protection Agency, “PRESTO-EPA: A Low-Level Radioactive Waste Environmental Transport and Risk Assessment Code – Methodology and User’s Manual,” Washington, EPA-D-89-F-000-60, April 1989.

U.S. Environmental Protection Agency, "Environmental Radiation Protection Standards for Low-Level Radioactive Waste Disposal [Advanced Notice of Proposed Rulemaking]," *Federal Register*, Vol. 48, No. 170, August 31, 1983, p. 39563.

U.S. Environmental Protection Agency, "Environmental Standards for Uranium and Thorium Mill Tailings at Licensed Commercial Processing Sites [Final Rule]," *Federal Register*, Vol. 48, No. 196, October 7, 1983, pp. 45926–45947.

U.S. Environmental Protection Agency, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes [Final Rule]," *Federal Register*, Vol. 50, No. 182, September 19, 1985, pp. 38066–38089.

U.S. Environmental Protection Agency Science Advisory Board, “Report on the March 1985 Draft Background Information Document for Proposed Low-Level Radioactive Waste Standards,” Office of Radiation Programs, EPA Report SAB-RAC-85-002, November 1985.

U.S. Environmental Protection Agency, “Low-Level and NARM Radioactive Wastes – Draft Environmental Impact Statement for Proposed Rules, Volume 1 – Background Information Document,” Office of Radiation Programs, EPA 520/1-87-012-1, June 1988.

U.S. Environmental Protection Agency, “National Emission Standards for Hazardous Air Pollutants; Radionuclides [Final Rule and Notice of Reconsideration],” *Federal Register*, Vol. 54, No. 240, December 15, 1989, pp. 51654–51715.

U.S. Environmental Protection Agency, “Guidance on Implementing the Radionuclide NESHAPS,” Office of Radiation Programs, July 1991.

U.S. Environmental Protection Agency, “National Emission Standards for Radionuclide Emissions from Facilities Licensed by the Nuclear regulatory Commission and Federal facilities not Covered by Subpart H [Final Rule],” *Federal Register*, Vol. 61, No. 251, December 30, 1996, pp. 68972–68981.

U.S. Environmental Protection Agency, "Radiation Protection at EPA – The First 30 Years," Office of Radiation Programs, EPA 402-B-00-001, August 2000.

U.S. Environmental Protection Agency, “National Primary Drinking Water Regulations; Radionuclides [Final Rule],” *Federal Register*, Vol. 65, No. 236, December 7, 2000, pp. 76708–76753.

U.S. Environmental Protection Agency, "Approaches to an Integrated Framework for Management and Disposal of Low-Activity Waste [Advanced Notice of Proposed Rulemaking]," *Federal Register*, Vol. 68, No. 222, November 18, 2003, pp. 65119–65151.

U.S. General Accounting Office, "Improvements Needed in the Land Disposal of Radioactive Wastes – A Problem of Centuries," Washington, RED-76-54, January 1976.

U.S. General Accounting Office, "Hazards of Past Low-Level Radioactive Waste Ocean Dumping Have Been Overemphasized," Washington, EMD-82-9, 1981.

U.S. General Accounting Office, “Regional Low-Level Radioactive Waste Disposal Sites – Progress Being Made but New Sites Will Probably Not be Ready by 1986,” Washington, GAO/RCED-83-48, April 1983.

U.S. General Accounting Office, “Slow Progress Developing Low-Level Radioactive Waste Disposal Sites,” Washington, GAO/RCED-92-61, January 1992.

U.S. General Accounting Office, “New York’s Adherence to Site Selection Procedures is Unclear,” Washington, GAO/RCED-92-172, August 1992.

U.S. General Accounting Office, “Interior’s Review of the Proposed transfer of the Ward Valley Waste Site," Washington, GAO/RCED-97-184, July 1997.

U.S. General Accounting Office, "Low-Level Radioactive Waste – States Are Not Developing Disposal Facilities," Washington, GAO/RCED-99-238, September 1999.

U.S. General Accounting Office, "Low-Level Radioactive Waste – Disposal Availability Adequate in the Short Term, but Oversight Needed to Identify Any Future Shortfalls," Washington, GAO/RCED-04-604, June 2004.

U.S. General Accountability Office, "Improved Guidance, Oversight, and Planning are Needed to Better Identify Cost-Saving Alternatives for Managing Low-Level Radioactive Waste," Washington, GAO-06-94, October 2005.

.S. General Accountability Office, "Examination of Best Practices to Improve Low-Level Radioactive Waste Management in the United States [Announcement]," Denver, November 8, 2005.

U.S. Nuclear Regulatory Commission, “NRC Task Force Report on Review of the Federal/ State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds,” Office of Nuclear Material Safety and Safeguards/Office of State Programs, NUREG-0217, March 1977.

U.S. Nuclear Regulatory Commission, “The Nuclear Regulatory Commission Low-Level Radioactive Waste Management Program,” Office of Nuclear Material Safety and Safeguards, NUREG-0240, September 1977.

U.S. Nuclear Regulatory Commission, "Management and Disposal of Low-Level Wastes by Shallow Land Burial and Alternative Disposal Methods [Advanced Notice of Proposed Rulemaking]," *Federal Register*, Vol. 43, No. 207, October 25, 1978, pp. 49811–49812.

U.S. Nuclear Regulatory Commission, "Branch Technical Position – Low-Level Waste Burial Ground Site Closure and Stabilization," Office of Nuclear Material Safety and Safeguards, Low-Level Waste Branch, Rev. 1, May 17, 1979. [Reproduced as Appendix I in Volume 4 of NUREG-0782.]

U.S. Nuclear Regulatory Commission, "Disposal of Low-Level Radioactive Waste; Availability of Preliminary Draft Regulation [Notice of Availability of Preliminary Draft Regulation 10 CFR Part 61 for Disposal of Low-Level Radioactive Waste]," *Federal Register*, Vol. 45, No. 41, February 28, 1980, pp. 13104–13106.

U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Burial of Radioactive Waste [Proposed Rulemaking]," *Federal Register*, Vol. 46, No. 142, July 24, 1981, pp. 38081–83105.

U.S. Nuclear Regulatory Commission, "Draft Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes," Office of Nuclear Material Safety and Safeguards, NUREG-0782, 4 vols., September 1981.

U.S. Nuclear Regulatory Commission, "Policy Statement on Low-Level Waste Volume Reduction," *Federal Register*, Vol. 46, No. 200, October 16, 1981, p. 51101.

U.S. Nuclear Regulatory Commission, "Final Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes," Office of Nuclear Material Safety and Safeguards, NUREG-0945, November 1982.

U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste [Final Rule]," *Federal Register*, Vol. 47, No. 248, December 27, 1982, pp. 57446–57248.

U.S. Nuclear Regulatory Commission, "Disposal of High-Level Radioactive Wastes in Geologic Repositories [Final Rule]," *Federal Register*, Vol. 48, No. 120, June 21, 1983, pp. 28194–28229.

U.S. Nuclear Regulatory Commission, "Standard Format and Content of Environmental Report for Near-Surface Disposal of Low-Level Radioactive Waste," Regulatory Guide 4.18, June 1983.

U.S. Nuclear Regulatory Commission, "Radioactive Waste Below Regulatory Concern [Policy Statement]," *Federal Register*, Vol. 51, No. 168, August 29, 1986, pp. 30839–30847.

U.S. Nuclear Regulatory Commission. "Below Regulatory Concern – A Guide to the Nuclear Regulatory Commission's Policy on the Exemption of Very Low-Level Radioactive Materials, Wastes, and Practices," NUREG/BR-0157, [1986].

U.S. Nuclear Regulatory Commission, "Definition of 'High-Level Radioactive Waste' ," [Advance Notice of Proposed Rulemaking]," *Federal Register*, Vol. 52, No. 39, February 27, 1987, pp. 5992-6001.

U.S. Nuclear Regulatory Commission, "Environmental Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility (Environmental Report)," Office of Nuclear Material Safety and Safeguards, NUREG-1300, April 1987.

U.S. Nuclear Regulatory Commission, "Low-Level Radioactive Waste Disposal Facility; Availability and Request for Public Comments on a Branch Technical Position Paper

Concerning Environmental Monitoring [Request for Public Comments],” *Federal Register*, Vol. 52, No. 214, November 5, 1987, pp. 42486–42487.

U.S. Nuclear Regulatory Commission, "Disposal of Radioactive Wastes [Proposed Rule],” *Federal Register*, Vol. 53, No. 96, May 18, 1988, pp. 17709–17711.

U.S. Nuclear Regulatory Commission, "Criteria and Procedures for Emergency Access to Non-Federal and Regional Low-Level Waste Disposal Facilities [Final Rule]," *Federal Register*, Vol. 54, No. 22, February 3, 1989, pp. 5409–5424.

U.S. Nuclear Regulatory Commission, "Disposal of Radioactive Wastes [Final Rule],” *Federal Register*, Vol. 54, No. 100, May 25, 1989, pp. 22578–22583.

U.S. Nuclear Regulatory Commission, “Regulating the Disposal of Low-Level Radioactive Waste – A Guide to the Nuclear Regulatory Commission’s 10 CFR Part 61,” Office of Nuclear Material Safety and Safeguards, NUREG/BR-0121, August 1989.

U.S. Nuclear Regulatory Commission, "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility (Rev. 2)," Office of Nuclear Material Safety and Safeguards/Division of Low-Level Waste Management and Decommissioning, NUREG-1199, January 1991.

U.S. Nuclear Regulatory Commission, "Technical Position on Waste Form (Revision 1)," Division of Low-Level Waste Management and Decommissioning, January 1991. [Also see the NRC *Federal Register* notice dated January 28, 1991.]

U.S. Nuclear Regulatory Commission, "Standards for Protection Against Radiation [Final Rule],” *Federal Register*, Vol. 56, No. 98, May 21, 1991, pp. 23360–23474.

U.S. Nuclear Regulatory Commission, “Low-Level Radioactive Waste Performance Assessment Development Program Plan,”Commission Paper, SECY-92-060, February 21, 1992.

U.S. Nuclear Regulatory Commission, "Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility (Rev. 2)," Office of Nuclear Material Safety and Safeguards/Division of Low-Level Waste Management and Decommissioning, NUREG-1200, January 1994.

U.S. Nuclear Regulatory Commission, "Land Ownership Requirements for Low-Level Radioactive Waste Sites [Advance Notice of Proposed Rulemaking]," *Federal Register*, Vol. 59, No. 148, August 3, 1994, pp. 39485–39486.

U.S. Nuclear Regulatory Commission, “Branch Technical Position on Concentration Averaging and Encapsulation,” Division of Waste Management, January 17, 1995.

U.S. Nuclear Regulatory Commission, “Low-Level Waste Shipment Manifest Information and Reporting [Final Rule]," *Federal Register*, Vol. 60, No. 58, March 27, 1995, pp. 15649–15667.

U.S. Nuclear Regulatory Commission, “Alternatives to Terminating the Nuclear Regulatory Commission Low-Level Radioactive Waste Disposal Program,”Commission Paper, SECY-95-201, July 31, 1995.

U.S. Nuclear Regulatory Commission, "Portland General Electric Company; Receipt of Petition for Rulemaking [Petition for Rulemaking; Notice of Receipt]," *Federal Register*, Vol. 61, No. 22, February 1, 1996, pp. 3619–3621.

U.S. Nuclear Regulatory Commission, “Regulatory Issues in Low-Level Radioactive Waste Performance Assessment,” Commission Paper, SECY-96-103, May 17, 1996.

U.S. Nuclear Regulatory Commission, “Strategic Planning Framework,” September 16, 1996.

U.S. Nuclear Regulatory Commission, “Interim Storage for Greater than Class C Waste, Changes to 10 CFR Part 72,” Commission Paper, SECY-97-056, March 5, 1997.

U.S. Nuclear Regulatory Commission, “Petition for Envirocare of Utah to Possess Special Nuclear Material in Excess of Current Regulatory Limits,” Commission Paper, SECY-98-010, January 20, 1998.

U.S. Nuclear Regulatory Commission, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Current Licensing Basis,” Regulatory Guide 1.74, June 1998.

U.S. Nuclear Regulatory Commission, “A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities – Recommendations of NRC’s Performance Assessment Working Group,” Office of Nuclear Material Safety and Safeguards/Office of Nuclear Regulatory Research, NUREG-1573, October 2000.

U.S. Nuclear Regulatory Commission, "Interim Storage for Greater than Class C Waste [Final Rule]," *Federal Register*, Vol. 66, No. 197, October 11, 2001, pp. 51823–51841.

U.S. Nuclear Regulatory Commission, “Rulemaking Plan: Assured Isolation Facilities,” Commission Paper, SECY-03-0223, December 24, 2003.

U.S. Nuclear Regulatory Commission, “Options and Recommendations for the Potential Role of the Nuclear Regulatory Commission During the Development of the Department of Energy Environmental Impact Statement on Disposal of Greater-than-Class-C Radioactive Waste,” Commission Paper, SECY-05-0104, June 13, 2005.

Walker, J.S., *Permissible Dose – A History of Radiation Protection in the Twentieth Century*, Berkeley, University of California Press, 2000.

Warriner, J.B., and R.D. Bennett, "Alternative Methods for Disposal of Low-Level Radioactive Wastes – Task 2a: Technical Requirements for Below-Ground Vault Disposal of Low-Level Radioactive Waste," U.S. Nuclear Regulatory Commission, NUREG/CR-3774, Vol. 2, October 1985. [Prepared by the U.S. Army Engineer Waterways Experiment Station Geotechnical Laboratory.]

Washington State Department of Department of Health, “Final Environmental Impact Statement – Commercial Low-Level Radioactive Waste Disposal Site, Richland, Washington,” Olympia, DOH Publication 320-031, Vol. 1, May 28, 2004. [Final EIS published in 5 volumes.]

Wescott, R.G., “Consequences of Human Intrusion,” in T.J. McCartin and M.P. Lee (eds.), “Preliminary Performance-Based Analyses Relevant to Dose-Based Performance Measures for a Proposed Geologic Repository at Yucca Mountain,” NUREG-1538, December 2001.

Whelan, G. and T.J. Nicholson (eds.), "Proceedings of the Environmental Software Systems Compatibility and Linkage Workshop, held at NRC in March 7-9, 2000," NUREG/CP-0177, U.S. Nuclear Regulatory Commission, May 2002.

Yalcintas, M.G., and D.G. Jacobs (compilers), *Proceedings of the Symposium of Low-Level Waste Disposal – Site Suitability Requirements, Crystal City, Virginia, December 8-9, 1981,* U.S. Nuclear Regulatory Commission, NUREG/CP-0028, Vol. 1, September 1982. [Proceedings prepared by ORNL.]

Yalcintas, M.G. (compiler), *Proceedings of the Symposium of Low-Level Waste Disposal – Site Characterization and Monitoring, Arlington, Virginia, June 16-17, 1982,* U.S. Nuclear Regulatory Commission, NUREG/CP-0028, Vol. 2, December 1982. [Proceedings prepared by ORNL.]

Yalcintas, M.G. (compiler), *Proceedings of the Symposium of Low-Level Waste Disposal – Facility Design, Construction, and Operating Practices, Washington, D.C., September 29-30, 1982,* U.S. Nuclear Regulatory Commission, NUREG/CP-0028, Vol. 3, March 1983. [Proceedings prepared by ORNL.]

APPENDIX A
STRUCTURE OF 10 CFR PART 61

The U.S. Nuclear Regulatory Commission's (NRC's) regulations can be found in Chapter I of Title 10, "Energy," of the *Code of Federal Regulations*. Chapter I is divided into Parts 1 through 199. Part 61 is entitled "Licensing Requirements for Land Disposal of Radioactive Waste." It describes how the Commission will license construction authorization, operation, and permanent closure of a low-level radioactive waste disposal facility. The key regulatory features of Part 61 are listed below. A full-text version of the Part 61 regulation can be found at NRC's web site at *http://www.nrc.gov/reading-rm/doc-collections/cfr/part061/* .

Subpart	Subpart Title	Section	Section Title
A	General Provisions	61.1	Purpose and scope
		61.2	Definitions
		61.3	License Required
		61.4	Communications
		61.5	Interpretations
		61.6	Exemptions
		61.7	Concepts
		61.8	Information collection requirements: OMB approval
		61.9	Employee protection
		61.9a	Completeness and accuracy of information
		61.9b	Deliberate misconduct
B	Licenses	61.10	Content of application
		61.11	General information
		61.12	Specific technical information
		61.13	Technical analyses
		61.14	Institutional information
		61.15	Financial information
		61.16	Other information
		61.20	Filing and distribution of application
		61.21	Elimination of repetition
		61.22	Updating of application
		61.23	Standards for issuance of a license

Subpart	Subpart Title	Section	Section Title
		61.24	Conditions of licenses
		61.25	Changes
		61.26	Amendment of license
		61.27	Application for renewal or closure
		61.28	Contents of application for closure
		61.29	Post-closure observation and maintenance
		61.30	Transfer of license
		61.31	Termination of license
C	Performance Objectives	61.40	General requirement
		61.41	Protection of the general population from releases of radioactivity
		61.42	Protection of individuals from inadvertent intrusion
		61.43	Protection of individuals during operations
		61.44	Stability of the disposal site after closure
D	Technical Requirements for Land Disposal Facilities	61.50	Disposal site suitability requirements for land disposal
		61.51	Disposal site design for land disposal
		61.52	Land disposal facility operation and disposal site closure
		61.53	Environmental monitoring
		61.54	Alternative requirements for design and operations
		61.55	Waste classification
		61.56	Waste characteristics
		61.57	Labeling
		61.58	Alternative requirements for waste classification and characteristics
		61.59	Institutional requirements
E	Financial Assurances	61.61	Applicant qualifications and assurances
		61.62	Funding for disposal site closure and stabilization
		61.63	Financial assurances for institutional controls
F	Participation by State Governments and Indian Tribes	61.70	Scope
		61.71	State and Tribal government consultation
		61.72	Filing of proposals for State and Tribal participation
		61.73	Commission approval of proposals

Subpart	Subpart Title	Section	Section Title
G	Records, Reports, Tests, and Inspections	61.80	Maintenance of records, reports, and transfers
		61.81	Tests at land disposal facilities
		61.82	Commission inspections of land disposal facilities
		61.83	Violations
		61.84	Criminal penalties

APPENDIX B
FINAL COMMISSION *POLICY STATEMENT*
ON THE USE OF PRA METHODS
IN NUCLEAR REGULATORY ACTIVITIES

A-1 INTRODUCTION

The following statement presents the policy that the U.S. Nuclear Regulatory Commission (NRC) will adopt in the use of probabilistic risk assessment (PRA) methods in nuclear regulatory matters. This policy was developed because the Commission believed that the potential applications of PRA methodology could improve public health and safety decision-making while promoting stability and efficiency in the regulatory process and reducing unnecessary burdens on licensees. After a public workshop, the *Policy Statement* was published in draft form in the *Federal Register* in 1994 (59 *FR* 63389). On receipt and consideration of public comments, it was published in final form in 1995 (60 *FR* 42622).

A-2 THE COMMISSION POLICY (at 60 *FR* 42628)

1. The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data and in a manner that complements NRC's deterministic approach and supports NRC's traditional defense-in-depth philosophy.

2. PRA and associated analyses (e.g., sensitivity studies, uncertainty analyses, and importance measures) should be used in regulatory matters, where practical within the bounds of the state of the art, to reduce the unnecessary conservatism associated with current regulatory requirements, regulatory guides, license commitments, and staff practices. Where appropriate, PRA should be used to support the proposal for additional regulatory requirements in accordance with 10 CFR 50.109 ("Backfit Rule"). Appropriate procedures for including PRA in the process for changing regulatory requirements should be developed and followed. It is, of course, understood that the intent of this policy is that existing rules and regulations shall be complied with unless these rules and regulations are revised.

3. PRA evaluations in support of regulatory decisions should be as realistic as practicable, and appropriate supporting data should be publicly available for review.

4. The Commission's safety goals for nuclear power plants and subsidiary numerical objectives are to be used with appropriate consideration of uncertainties in making

regulatory judgments on the need for proposing and backfitting new generic requirements on nuclear power plant licensees.

A-3 REFERENCES

U.S. Nuclear Regulatory Commission, "Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities [Proposed Policy Statement]," *Federal Register,* Vol. 59, No. 235, December 8, 1994, pp. 63389–63391.

U.S. Nuclear Regulatory Commission, "Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities [Final Policy Statement]," *Federal Register,* Vol. 60, No. 158, August 16, 1995, pp. 42622–42630.

APPENDIX C
REGULATORY EVOLUTION OF THE LLW DEFINITION

C-1 INTRODUCTION

Kocher (1990) has previously summarized the historical development of regulatory definitions of low-level radioactive waste (LLW) and other classes of radioactive waste. That review suggests that the term "LLW" has carried an imprecise definition over the years. Prior to the promulgation of the U.S. Nuclear Regulatory Commission's (NRC's or the Commission's) LLW disposal regulations found at 10 CFR Part 61, the term LLW was exclusionary. It generally meant that portion of the solid radioactive waste stream that did not fit the prevailing definition of high-level or intermediate-level radioactive wastes at the time, and whose concentrations of transuranic elements was less than 100 ηCi/gm. Some LLW has activity comparable to that of spent nuclear fuel (SNF) and this waste is considered by the NRC to be greater-than-Class C (GTCC) radioactive waste. As noted earlier, such wastes are the responsibility of the U.S. Department of Energy (DOE) .

C-2 DISCUSSION

The use of nuclear power reactors to produce fissionable materials for defense purposes, beginning in the 1940s, and to generate electric power in the civilian sector beginning in the 1950s, has been the primary source of radioactive wastes, and the regulatory systems that define them.

C-2.1 Initial Radioactive Waste Definitions[1]

The earliest description of radioactive waste was based on the operational aspects of handling and storing those liquid wastes generated following the reprocessing of nuclear fuel for defense purposes. At the time, Kocher (1990, p. 59) notes that the primary concern was worker protection from radiation exposures during waste handling operations rather than protection of the public. The liquid wastes contained varying concentrations of radionuclides, primarily fission products, and long-lived alpha-omitting transuranium radionuclides. To permit their safe handling and storage, the Atomic Energy Commission (AEC) introduced a 3-tier classification system based on the radionuclide concentration of the fission products. In decreasing order of hazard, the wastes *high-level* , *medium or intermediate-level*, and *LLW*. There were no uniform concentration limits for each liquid waste class. Each AEC site developed its own concentration limits based on the site-specific management practices prevailing at each facility.

As noted earlier in this paper, the AEC assumed responsibility for the disposal of civilian-produced solid radioactive waste in the early 1960s until disposal facilities for those wastes could be developed. As part of that program, the AEC defined three categories of solid

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[1]It should be noted that researchers have proposed alternative radioactive waste classification systems for the United States (Kocher and Croff, 1987; 1988; Smith and Cohen, 1989; LeMone and Jacobi (1993). The proposals are summarized in (National Council on Radiation Protection – NCRP, 2002) along with the details of the waste classification system recommended by the NCRP. The proposals of these researchers have similarities to the International Atomic Energy Agency (1994) recommendations in that the association of waste classes with available disposal systems was generally recognized, all included a class of exempt waste or equivalent, and all suggested quantitative boundaries between the various waste classes.

radioactive waste that would be acceptable for disposal based on concentration limits:

High-Level waste (HLW)	greater than 1000 Ci/ft^3
Intermediate-level waste	10 to 1000 Ci/ft^3
LLW	less than 1000 Ci/ft^3

In the late 1960s, a fourth solid waste category came into existence – *transuranic or TRU waste*. In 1970, the AEC established a policy that solid radioactive waste whose concentrations of alpha-emitting radionuclides was greater than 10 nCi/g was not acceptable for shallow land burial but required storage and/or burial in a retrievable manner.

C-2.2 Definition of HLW

The first constituent of the commercial radioactive waste stream to receive a regulatory definition was HLW. In 1970, the AEC promulgated regulations at 10 CFR Part 50 entitled "Licensing of Production and Utilization Facilities." Appendix F ("Policy Relating to the Siting of Fuel Reprocessing Plants and Related Waste Management Facilities") to that regulation defined HLW as (35 FR 17533):

> "... those aqueous wastes resulting from the operation of a first-cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels ...."

HLW was thus defined at the time as liquid materials resulting from fuel reprocessing in terms of source rather than its constituents.

In 1982, Congress passed the Nuclear Waste Policy Act (NWPA – Public Law 97-425) and provided further clarification regarding the definition of HLW. In Section 2.(12) of the act, the term "HLW" was now defined as:

> "(A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and
>
> (B) other highly radioactive material that the [Nuclear Regulatory] Commission, consistent with existing law, determines by rule requires permanent isolation."

In 1983, in response to NWPA, the Commission promulgated generic geologic disposal regulations for the disposal of HLW at Part 60 ("Disposal of High-Level Radioactive Wastes in Geologic Repositories"). In §60.2, the Commission expanded the definition of HLW to now include irradiated fuel assemblies from commercial nuclear power plants[2] and dry solid

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[2]The Marine Protection, Research and Sanctuaries Act of 1972 (Public Law 95-532), as amended, broaden the AEC's 1970 definition of HLW to include unprocessed spent nuclear fuel.

materials[3] (48 FR 28218) as follows:

> "...(1) irradiated reactor fuel, (2) liquid wastes resulting from operations of a first-cycle solvent extraction system, or equivalent, and concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for fuel reprocessing, and (3) solids into which such liquid wastes have been converted."

C-2.3 Definition of TRU

TRU wastes are the by-products of fuel assembly and weapons fabrication and reprocessing operations. These wastes contain isotopes higher than uranium (no. 238 on the periodic table of elements). This waste stream was originally defined by the AEC (Hollingsworth, 1970) as;

> "... as solid waste containing long-lived alpha-emitting transuranium radionuclides and/or ^{233}U in concentrations greater than 10 nCi/g ...."

TRU was first given a statutory definition by Congress when the Low-Level Waste Policy Act of 1980 (Public Law 96-425) was passed but the definition was later rescinded in 1985 when the Act was amended. In 1982, Federal Agencies concurred with a recommendation to increase the concentration of the long-lived alpha-emitting transuranium radionuclides from 10 to 100 nCi/g. See Steindler and others (1982, p. 590).

In 1985, the U.S. Environmental Protection Agency (EPA) promulgated environmental radiation standards that applied to both a geologic repository for SNF, HLW, and TRU at 40 CFR Part 191. In those standards, EPA defined TRU at §191.102 (50 FR 38084), as waste:

> "....containing more than 100 nanocuries of alpha-emitting transuranium isotopes, with half-lives greater than twenty years, per gram of waste, except for (1) high-level radioactive wastes; (2) waste that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this Part; or (3) waste that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 60 ...."[4]

NRC considers TRU as a higher activity form of LLW – i.e., GTCC waste, subject to disposal in a HLW repository or some other disposal facility approved and licensed by the NRC (see Section 6.5.1 of this paper). Since 1999, defense-generated TRU wastes have been disposed on at the Waste Isolation Pilot Plant (or WIPP), in New Mexico. See DOE (1990) and Murray (2003; p. 158).

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[3]This later addition to the definition reflected the production of dry solid materials produced during the limited reprocessing demonstration of SNF at the West Valley, New York. See DOE (2003). In the organic legislation for that project (Public Law 96-368), HLW was defined to include:

> "...liquid wastes produced directly in reprocessing , dry solid material derived from such liquid waste, and such other material as the NRC designates as high-level waste for the purposes of protecting public health and safety...."

[4]Kocher (1990, p. 67) notes that the NRC has not developed a regulatory definition of TRU because only small amounts are produced in the civilian sector and their disposal is currently subject to regulation by the EPA.

C-2.4 Definition of LLW

The current regulatory definition of LLW is one of exclusion. As noted above, the category of "LLW" had already been defined by default for it included the definition of wastes not otherwise classified (52 FR 5994). In NWPA, as amended, LLW is defined as radioactive waste that is not:

> "... high-level radioactive waste, transuranic waste, spent fuel, or uranium or thorium mill tailings ...."

Moreover, in the Low-Level Waste Policy Amendments Act of 1985, there is no definition of LLW. LLWPAA at Section 9 – "Definitions," at paragraph (2)(A) again makes note that LLW is not HLW, SNF, or byproduct material and at paragraph (2)(B) simply says that:

> ".... the Nuclear Regulatory Commission, consistent with existing law, classifies ... low-level waste ...."

The *Reorganization Plan No. 3 of 1970* (The White House, 1970) granted EPA its standard setting authority at Section 2(a)(6) to establish "generally applicable environmental standards for the protection of the general environment from radioactive material (35 FR 15624)." Standards were to be developed for all commercial radioactive waste streams. As noted earlier, EPA promulgated radiation standards for SNF, HLW, and TRU at Part 191. In August 1983, EPA published an *Advance Notice of Proposed Rulemaking* (48 FR 395563) announcing its plans for establishing general environmental radiation protection standards for LLW.[5] In 1987, those proposed standards were forwarded to the Office of Management and Budget (OMB) for approval. The agency also published a draft environmental impact statement (EPA, 1988) in connection with the development of those standards.

In describing the proposed LLW standards, Gruhlke and others (1989; p. 273) notes that the EPA proposed to define LLW as:

> "... radioactive waste that was not (1) spent fuel, high-level radioactive waste, or transuranic waste, as previously defined in 40 CFR Part 191, (2) or uranium or thorium mill tailings subject to 40 CFR Part 192,[6] or (3) or NARM as defined in 40 CFR 764 ...."

EPA's proposed LLW standards never cleared the OMB review process. The rule encountered significant interagency opposition during the review due to concerns over the ground-water provisions of the proposed standard (EPA, 2000; p. 21). In 1994, a second LLW standard "pre-proposal" was circulated for public comment. One major concern identified during the public comment period was that the new proposed LLW standard would delay the development of new compact disposal sites (Op cit.) As a compromise, in 1995, EPA proposed (unsuccessfully) to limit the applicability of its new standard to federal LLW disposal sites.

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[5]EPA also proposed to require the disposal of naturally-occurring and accelerator-produced radioactive materials (NARM) in concentrations exceeding 2 nCi/g in a LLW disposal facility. See Gruhlke and others (1989, p. 275).

[6]Consistent with NWPA and LLWPAA, mill tailings are not considered a form of LLW.

As noted in Section 6.4.2 of this paper, EPA's LLW standards and criteria were not available at the time NRC was developing its LLW regulatory framework. Rather than delay the development of its disposal regulations, the NRC staff decided to postulate a reasonable set of "study guidelines" that could be used as surrogates for the EPA standard. At the time, there was no nationally accepted set of safety guidelines defining what level of safety (protection) disposal facilities should provide the public from the ionizing effects of radiation. Consequently, the staff decided to review the literature[7] and consider the recommendations of national and international standard-setting organizations to identify surrogate dose guidelines for the scoping analyses and later, the proposed and final rule. (See Table 13 in the body of the main paper.)

As a result of the environmental impact statement scoping and rulemaking processes, the staff developed a three-tier LLW classification system whereby LLW forms with increasing concentrations of radionuclides have increasingly more stringent disposal requirements (NRC, 1982) Section 61.55 defined three classes of LLW that were acceptable for SLB disposal in near-surface facilities. They were designated waste *Classes A*, *B*, and *C*, with the highest being Class-C. Class designations were tied to certain minimum requirements and stability requirements,[8] and specifications for maximum allowable concentrations of certain radionuclides in each class. *Class-A waste* includes primarily lightly-contaminated paper, cloth, and plastics. These wastes must be segregated from other LLW during disposal because of their potential for degrading over time and causing subsidence in disposal cells. The isotope concentrations in this class of wastes are not to exceed the values listed in the regulation. *Class-B waste* by definition meets more rigorous physical stability requirements than Class-A wastes. This waste class is also permitted higher isotope concentrations. The physical form and characteristics of Class-B waste must also the meet the *minimum* [§61.51(a)] and *stability* [§61.51(b)] requirements of the regulation. *Class-C waste* was generally considered intruder waste. This higher-activity, longer-lived LLW is generally suitable for SLB required special measures to protect against human intrusion after institutional controls had lapsed. The regulation required that any Class-C waste with concentrations of radionuclides that would cause exposures greater than 500 mrem need to be protected from intrusion by deeper burial and/or through the use of some type of engineered intruder barrier. Wastes exceeding the Class-C concentration limits are, by regulation at §61.55(a), generally not suitable for SLB.

In an 1987 *Advance Notice of Proposed Rulemaking* (or ANPR), the Commission proposed to redefine the existing definition of HLW in a manner that would apply the term "high-level radioactive waste" to radioactive materials in amounts and concentrations exceeding numerical values that would be stated explicitly in the form of the table (52 FR 5995). This rulemaking was intended to address the certain LLW with radionclide concentrations above the existing Class-C limits of Part 61 as wastes classified as "LLW" were not subject to any regulatory limit and some LLW may have concentrations approaching those of HLW (52 FR 5994). Following a

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[7]See Appendix N ("Analysis of Existing Recommendations, Regulations, and Guides") in Volume 4 of NUREG-0782 (NRC, 1981).

[8]The minimum requirements that all waste forms must meet, to be acceptable for near-surface disposal, are given in §61.56(a). In addition to these minimum requirements, certain wastes (i.e., Classes B and C wastes, and Class-A waste that is to be co-disposed with Classes B and C waste) must be stabilized (structurally) and meet the requirements of §61.56(b). Stability is defined in terms of the ability to keep dimensions and form under disposal conditions. Stability can be provided by the waste form (e.g., activated metals); by processing the waste to an acceptable form (e.g., cement solidification); placing the waste in a high-integrity container; or by the disposal unit itself (e.g., vault disposal).

review of public comments on the ANPR, the Commission adopted an alternative strategy. In 1988, NRC published its proposed amendments to Part 61 recommending, in the first instance, their disposal in a separate facility licensed under Part 60, NRC's existing generic regulations for the disposal of HLW (NRC, 1983; 53 FR 17709). In 1989, the so-called GTCC disposal amendments were finalized by the Commission (54 FR 22578).

C-3 REFERENCES

Atomic Energy Commission, "Siting of Fuel Reprocessing Plants and Related Waste Management Facilities," *Federal Register*, Vol. 35, No. 222, November 14, 1970, pp. 17530–17533.

Gruhlke, J.M., F.L. Galpin, W.F. Holcomb, and M.S. Bandrowski, "USEPA's Proposed Environmental Standards for the Management and Land Disposal of LLW and NARM Waste," in R.G. Post (ed.), "WM '89," *Proceedings of the Symposium on Waste Management, Tucson, Arizona*, *February 26 – March 2, 1989,* 2:273–276 (1989).

Hollingsworth, K.S., "Policy Statement Regrading Solid Waste Burial," U.S. Atomic Energy Commission, AEC Directive IAD No. 0511-21,1970.

International Atomic Energy Agency, "Classification of Radioactive Wastes – A Safety Guide," Vienna, Safety Series No. 111-G-1.1, June 1994. [English edition.]

Kocher, D.C., "Classification and Disposal of Radioactive Wastes – History and Legal and Regulatory Requirements," *Radiation Protection Management*, 7(4): 58-78 (July/August 1990).

Kocher, D. C. and Croff, A. G.. "A Proposed Classification System for High-Level and Other Radioactive Wastes," *Radioactive Waste Management and the Nuclear Fuel Cycle,* 11(3):227–268 (1988).

LeMone, D. V. and L. R. Jacobi, Jr., "Radioactive Waste Reclassification," in R.G. Post (ed.), "WM '93 – Working Towards a Cleaner Environment," *Proceedings of the Symposium on Waste Management, Tucson, Arizona*, *February 28 – March 4, 1993,*1:61–66 (1993).

Murray, R.L., *Understanding Radioactive Waste (5th edition)***,** Columbus, Battelle Press, 2003.

National Council on Radiation Protection, "Risk-Based Classification of Radioactive and Hazardous Chemical Wastes," Bethesda, NCRP Report No. 139, December 31, 2002.

Smith, C. F. and J.J. Cohen, "Development of a Comprehensive Waste Classification System," in R.G. Post (ed.), "*WM '89, Proceedings of the Symposium on Waste Management, Tucson, Arizona*, *February 26 – March 2, 1989*, 2:311–312 (1989).

Steindler, M., and others, “Summary Statement from the Workshop on the Management of Alpha-Contaminated Waste,” in Science Applications, Inc., *Proceedings of Alpha-Contaminated Waste Management Workshop, Gaithersburg, Maryland, August 10–13, 1982*, Oak Ridge, CONF-820845, December 1982, pp. 591–592. [Prepared for the Oak Ridge National Laboratory.][9]

The White House [Richard M. Nixon, President], “Presidential Documents, Title 3 – The President, Reorganization Plan No. 3 of 1970," *Federal Register*, Vol. 35, No. 194, October 6, 1970, pp. 15623–15626.

U.S. Department of Energy, “Waste Isolation Pilot Plant – WIPP,” Carlsbad, [1990]. [Prepared by the Westinghouse Electric Corporation/Waste Isolation Division.]

U.S. Department of Energy, “West Valley Demonstration Project Waste Management Environmental Impact Statement – Final,” Waste Valley Area Office, DOE/EIS-0337F, December 2003.

U.S. Environmental Protection Agency, "Environmental Radiation Protection Standards for Low-Level Radioactive Waste Disposal [Advanced Notice of Proposed Rulemaking]," *Federal Register*, Vol. 48, No. 170, August 31, 1983, p. 39563.

U.S. Environmental Protection Agency, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes [Final Rule]," *Federal Register*, Vol. 50, No. 182, September 19, 1985, pp. 38066–38089.

U.S. Environmental Protection Agency, “Low-Level and NARM Radioactive Wastes – Draft Environmental Impact Statement for Proposed Rules,” Washington, Office of Radiation Programs, 2 vols., EPA 520/1-87-012-1, June 1988.

U.S. Environmental Protection Agency, "Radiation Protection at EPA – The First 30 Years," Washington, Office of Radiation Programs, EPA 402-B-00-001, August 2000.

U.S. Nuclear Regulatory Commission, "Draft Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes," Office of Nuclear Material Safety and Safeguards, NUREG-0782, 4 vols., September 1981.

U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste [Final Rule]," *Federal Register*, Vol. 47, No. 248, December 27, 1982, pp. 57446–57248.

U.S. Nuclear Regulatory Commission, "Disposal of High-Level Radioactive Wastes in Geologic Repositories [Final Rule]," *Federal Register*, Vol. 48, No. 120, June 21, 1983, pp. 28194–28229.

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[9] Also reprinted as Steindler, M., and others, “Limits for the Disposal of Waste Containing Alpha-Contaminated Radionuclides,” *Nuclear and Chemical Waste Management*, 4:9–10 (1983).

U.S. Nuclear Regulatory Commission, "Definition of 'High-Level Radioactive Waste'," [Advance Notice of Proposed Rulemaking]," *Federal Register*, Vol. 52, No. 39, February 27, 1987, pp. 5992–6001.

U.S. Nuclear Regulatory Commission, "Disposal of Radioactive Wastes [Proposed Rule]," *Federal Register*, Vol. 53, No. 96, May 18, 1988, pp. 17709–17711.

U.S. Nuclear Regulatory Commission, "Disposal of Radioactive Wastes [Final Rule]," *Federal Register*, Vol. 54, No. 100, May 25, 1989, pp. 22578–22583.

APPENDIX D
A SUMMARY OF NUREG-1573: A PERFORMANCE ASSESSMENT METHODOLOGY FOR LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES

In terms of measuring LLW disposal facility designs and performance against the Part 61 performance objectives, the information provided by other NRC guidance documents was general, and many specific implementation issues and acceptable approaches for resolving them were not addressed. Moreover, the relationships between the overall Part 61 data and design requirements, and specific LLW performance assessment needs, were not explicitly addressed by existing NRC guidance documents. Previously, site characterization, facility design, and performance modeling were activities that heretofore were considered separate.

To clarify these and other Part 61 implementation issues, the staff developed detailed information and recommendations, to potential applicants, as it relates to the performance objective concerned with the radiological protection of the general public at Section 61.41. The detailed information and recommendations was published in NUREG-1573 (NRC, 2000).

The following is a summary of the information and recommendations contained in that NUREG.

D-1 INTRODUCTION[1]

A disposal facility for the containment and isolation of radioactive wastes is a complex system. It is generally expected to consist of multiple barriers,[2] where each barrier contributes to the overall performance of the system by providing some degree of redundancy to assure the containment and isolation of wastes. Because the future performance of a disposal facility must be estimated for many hundreds of years into the future, the long-term performance of each barrier class as well as the overall system is analyzed through the use of predictive mathematical models, implemented through computer codes relying on numerical methods.

There is general consensus within the international community that to evaluate the safety of these facilities, before their implementation, disposal facility developers and regulators will rely on state-of-the-art *performance assessment* analyses. These analyses are followed by a comparison of the results with appropriate safety standards and criteria to determine compliance with those standards and criteria in the form of a *risk assessment*. Performance assessment may thus be defined as the process of quantitatively evaluating the ability of a disposal facility to contain and isolate radioactive wastes. See Campbell and Cranwell (1988). Because of the inherent uncertainties in the models and data used to evaluate the performance of disposal system components, these analyses are conducted probabilistically (iteratively) – hence a probabilistic risk assessment or PRA.

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[1]It should be noted that *risk assessment*, *safety assessment*, *performance assessment*, *PRA*, and similar concepts are terms of art among practitioners, and thus there is no widely agreed-to set of definitions. The meaning and intent of some of the more widely used terms in the performance assessment lexicon are reviewed in Nuclear Energy Agency (1999). Moreover, the concept of *risk assessment* itself may be subject to some variability in interpretation. See Fjeld and Compton (1998, p. 4166).

[2]Depending on the hazard posed by the waste, there may be up to two barrier classes – engineered and natural – and several individual barriers within each barrier class.

As noted earlier (Appendix B), Commission policy since 1995 has been to use PRA technology and methods (PRA Working Group) as a complement to the deterministic approach in its nuclear regulatory activities.   Over the last few decades, the NRC staff has expanded their use of PRAs in the area of waste management. See Eisenberg and others (1999).   Because waste management systems are passive, PRA methods and analyses – now renamed *performance assessments* – had to be adapted. See NRC (1994; pp. 63389–63390).

D-2 BACKGROUND

In conjunction with the development of Part 61 and after its promulgation in 1982, the NRC staff began to undertake a variety of performance assessment-related projects that addressed waste disposal primarily in shallow land burial (SLB) facilities. These projects were initiated in such areas as waste package performance and leaching, hydrogeological and hydrogeochemical characterization and modeling, and cover performance. The staff also began to investigate alternatives to SLB disposal and developed guidance for the licensing of other types of LLW disposal facilities – e.g., above-ground vaults, below-ground vaults, earth-mounded concrete bunkers, mined cavities, and augured holes. See NRC (1991 and 1994).

As early as 1987, the staff recognized that some type of assessment methodology would need to be acquired" or "developed" for estimating the performance of Part 61 LLW disposal facilities (NRC, 1987; 52 FR 5996). To provide focus and integration of the overall LLW program as well as to address the need for a more integrated approach to evaluating the performance of any LLW disposal facility design, the NRC staff formulated an overall LLW performance assessment strategy in 1987 (Starmer and others*,* 1988). This strategy recommended a modular approach for modeling LLW disposal facility system performance by quantifying potential release and transport of radionuclides through significant environmental pathways. The NRC later sponsored a LLW performance assessment methodology (PAM) based on this strategy. It was developed by the Sandia National Laboratories (SNL) and was published in a five-volume series as NUREG/CR-5453. Concurrently, the staff published a *LLW Research Program Plan* (O'Donnell and Lambert, 1989), which presented the staff's strategy for LLW research.

Shortly thereafter, the staff began developing an LLW performance assessment *Program Plan*. The plan (NRC, 1992) had two primary goals. They were to: (a) enhance the staff's capability to review and evaluate license applications within the 15 months specified by the Low-Level Waste Policy Act, as amended; and (b) develop the in-house capability needed to prepare guidance, should guidance be necessary.[3]   This plan was begun in response to needs identified by both the Agreement States and the staff through interactions with prospective disposal facility developers (applicants), the review of U.S. Department of Energy (DOE) prototype license applications, and in response to specific performance assessment issues raised by the States.

Consistent with its 1992 *Program Plan*, the staff and its technical assistance contractors enhanced NRC's performance assessment expertise by conducting a variety of LLW modeling

[3]Another (later) driver behind the development of the staff's LLW performance assessment program was the Commission's *1995 PRA Policy Statement.*

exercises and analyses.[4] [Dunkelman (1987) provides an extensive summary of NRC-sponsored technical assistance work performed before the publication of NUREG-1573. Technical work since 1987 then is cited extensively in "References" section (Section 4) of NUREG-1573 (NRC, 2000).] The staff also initiated computer simulations of a “test case problem“ for a hypothetical LLW disposal system. Lastly, the staff's efforts to enhance its performance assessment expertise also benefitted from allied performance assessment work in other NRC waste management areas such as high-level radioactive waste and decommissioning.

D-3 NUREG-1573

Through the efforts described above, several areas were identified where additional LLW performance assessment guidance might be needed as applied to NRC’s LLW regulatory framework. For example, the staff found that the relationship between the Part 61 data and design requirements and detailed LLW performance assessment needs was not directly apparent from the existing NRC guidance documents – i.e., NUREG-1199, NUREG-1200, and NUREG-1300.[5] Moreover, many of the performance assessment issues of concern were not apparent at the time the staff were conducting the Part 61 EIS scoping process or later, during the LLW rulemaking effort. The areas of staff concern (NRC, 1990; p. 1-13) included:

- Achieving a common understanding that defined the (minimum) elements of a LLW performance assessment process;
- Defining the relationship between site characterization and performance assessment data collection;
- Modeling approaches to infiltration rate estimation, source-term release behavior, and concrete and engineered barrier degradation;
- Modeling of radionuclide transport in the environment;
- Making decisions related to the verification of performance assessment models and the validation of computer models;
- Making decisions related to the use of generic vs. site-specific data the performance assessment models; and
- Developing approaches to uncertainty and sensitivity analyses.

To address these concerns as well as to develop consensus approaches, the staff undertook development of a LLW performance assessment methodology guidance document. The principal focus of the guidance document, designated NUREG-1573, as well as the earlier NUREG guidance documents, were recommendations on acceptable approaches and methods

[4] An early LLW performance assessment analysis performed by the NRC staff was published in 1992 as part of a survey of Federal risk assessment efforts. See DOE and others (2002).

[5] It should be noted that the scope of these documents were intended to provide guidance on demonstrating compliance with all Subpart C performance objectives, including the §61.41 performance objective.

that could be used to demonstrate compliance with the Part 61's performance objectives.

In January 1994, a preliminary draft of NUREG was prepared and distributed for comment to all LLW-sited and host Agreement States; the Advisory Committee on Nuclear Waste; DOE; the U.S. Environmental Protection Agency; and the U.S. Geological Survey. After that initial review process, the NRC staff sponsored a 2-day workshop on the preliminary draft NUREG and a attendant LLW test case[6] held at NRC Headquarters on November 16-17, 1994. They also sponsored a half-day LLW performance assessment workshop in conjunction with the *16th Annual DOE/LLW Management Conference* on December 13-15, 1994. NUREG-1573 was subsequently modified to reflect information received during these interactions as well as specific direction from the Commission (NRC, 1996), and was then made available as a draft for formal public comment on May 29, 1997 (62 *FR* 29164) as a Branch Technical Position or BTP. Following a review of public comments, some clarifications were made to the final NUREG and it was published in October 2000, but not as a BTP.[7]

D-3.1 Recommended Approaches, Attributes of Acceptable Approaches, and Staff Advice

In NUREG-1573, the staff proposed that applicants should develop and use a defensible methodology to demonstrate the compliance of a LLW disposal facility design with the post-closure performance objective set forth in Section 61.41. To help prospective applicants achieve this goal, the staff provided its views on three key performance assessment issues: (a) an acceptable LLW performance assessment approach (process); (b) the interpretation and implementation of five Part 61 regulatory requirements related to LLW performance assessment; and (c) ways to implementation of NRC's PAM.

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[6] The results of NRC's so-called "LLW test case" were presented at a November 1994 two-day public workshop. The test case was an analysis of the performance a hypothetical LLW site and design to evaluate the implementability of the approaches being recommended in NUREG-1573. Using actual site data representative of a humid environment and a hypothetical facility design and source term inventory, the staff: (a) tested a number of models that could used in conducting an LLW performance assessment; and (b) gained experience with the use and limitations of LLW performance assessment modeling. Following its completion, the staff concluded that the test case demonstrated that the approaches being recommended in the NUREG could be implemented. Formal documentation of the test case by the NRC staff was never achieved due to resource constraints. However, detailed discussion of the test case can be found in the transcripts of that meeting. These transcripts are available for inspection and/or copying in NRC's Public Document Room. In addition to the meeting transcripts, preliminary results from the LLW test case have been presented by Cady and Thaggard (1994), Campbell (1994), Campbell and McCartin (1994), and Krupka and Serne (1998).

[7] As a result of the public comment process on draft NUREG-1573, several commenters expressed concern that the earlier proposed guidance, particularly in the area of recommended policy approaches, once finalized, would be viewed by LLW disposal facility developers and other regulatory entities as *defacto* NRC standards by virtue of their codification in the form of a BTP. The staff noted (NRC, 2000; p. B-1) that the recommended technical and policy approaches in this document were not intended as substitutes for NRC's regulations, and compliance with those recommendations was never intended to be obligatory. To avoid the potential for future confusion in this area, the final version of NUREG-1573 was published as a *technical report.* Moreover, what were formerly *staff positions* or *technical positions* in the draft BTP were referred to as *recommended approaches*, *attributes of an acceptable approach*, *staff advice*, or words to that effect in the final NUREG.

D-3.1.1 Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 61.41

In NUREG-1573, the staff recommended that prospective Part 61 license applicants develop a performance assessment process that systematically integrates site characterization data, facility design information, and predictive modeling results. The process is designed to build confidence in model estimates of LLW disposal site performance by providing a useful decision-making framework for evaluating and defending the appropriateness of data, assumptions, models, and codes used in a performance assessment compliance demonstration with the Part 61 post-closure performance objective.

To achieve the degree of desired integration, NUREG-1573 recommended an nine-step performance assessment process. These steps are depicted in Figure E-1. The staff noted that the central attribute of the process being proposed was that it be conducted iteratively – starting with a combination of generic and limited site-specific information in support of relatively simple conservative models and analyses, and progressing to more realistic, site-specific and detailed analyses, as necessary, to reduce uncertainty in assessing performance of an LLW disposal facility (NRC, 2000; pp. xi–x). Initial screening analyses identify the most important issues and data needs, and as more site and design information is collected, modeling assumptions, conceptual models, and data needs are reevaluated. Site characterization and design bases are then revised to obtain data or modify the design as needed to reduce uncertainty and defend assessment results.

The performance assessment process outlined in NUREG-1573 was intended to be open and transparent so that all data, assumptions, and models would be well-documented and understood. Moreover, the process intended that the rationale for any subsequent modification of those assumptions and models would also be documented and supported by an appropriate combination of site investigation and assessment data, valid technical reasoning, and sound professional judgment. Lastly, the NUREG-1573 process incorporates a formal, probabilistically-based treatment of uncertainty to provide a basis for performance assessment decision-making, provides a technical basis for identifying the completion of site characterization, and helps build confidence that the disposal site meets the performance objectives.

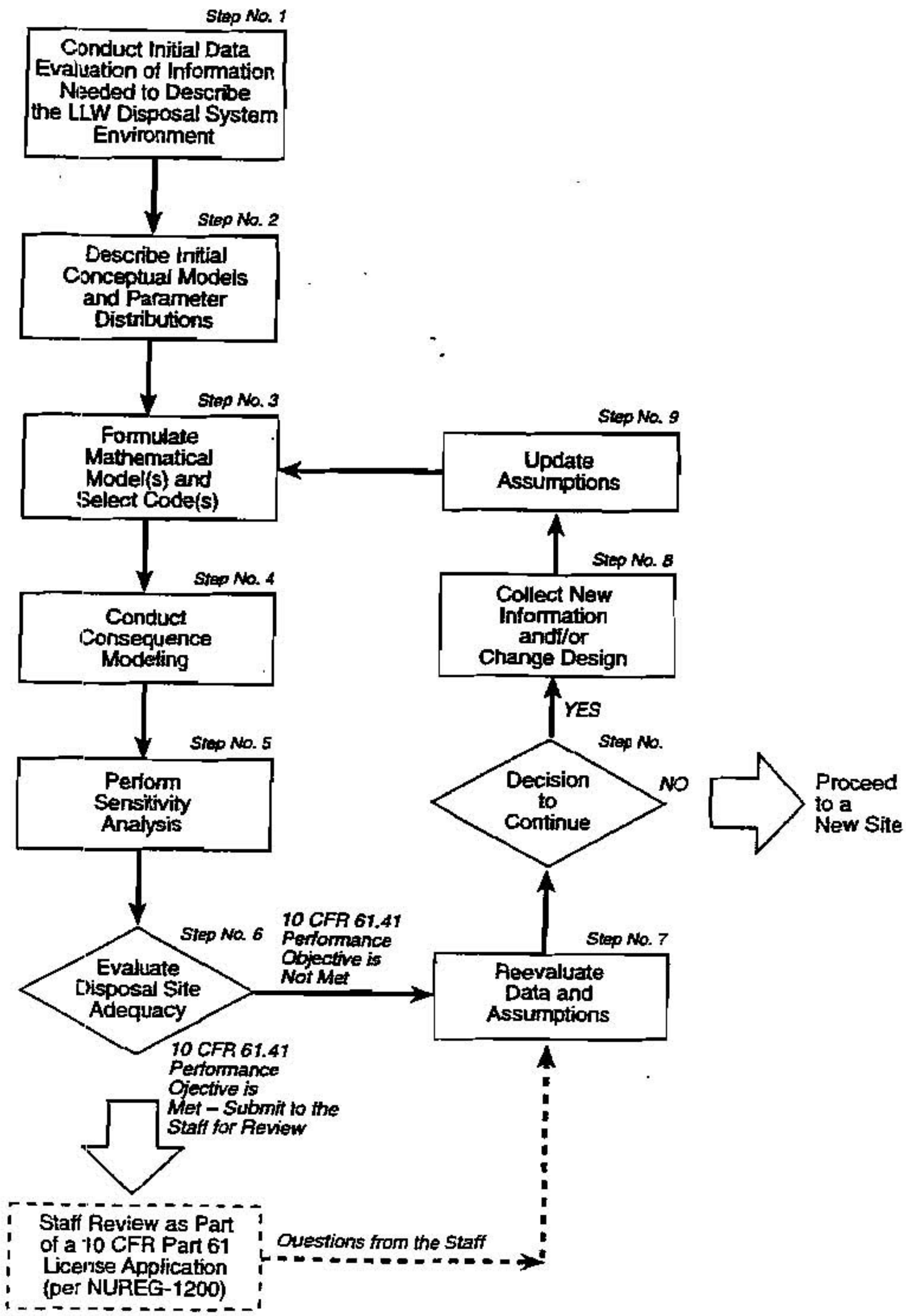
Finally, consistent with the Commission's views regarding the use of PRA, the staff also expressed the view that the application of the performance assessment techniques to LLW disposal facility designs should be tempered according to the complexity of the disposal system, uncertainties surrounding system performance, and the estimated risks due to the types and kinds of wastes being disposed (NRC, 2000; p. x).

D-3.1.2 Recommended Approaches to Technical Policy Issues

Technical policy issues represent fundamental questions pertaining to the interpretation and implementation of specific Part 61 performance objectives. In undertaking the development of the performance assessment methodology outlined in NUREG-1573, the staff identified five areas in the regulation that pertain to LLW performance assessment for which supplemental advice should be provided (NRC, 1996):

- consideration of future site conditions, processes, and events;
- performance of engineered barriers;

Figure D-1. Details of an "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 61.41." Taken from NRC (2000, p. 3-2).



- time frame for an LLW performance assessment;

- treatment of sensitivity and uncertainty in LLW performance assessments; and

- role of performance assessment during operational and closure periods.

Theses areas (issues) had not been identified earlier as part of the EIS scoping process or the Part 61 rulemaking as the generic LLW dose assessment methodology that had been developed in conjunction with those earlier activities (Adam and Rogers, 1978; and Rogers, 1979) was, in many respects, much simpler than the performance assessment process now envisioned by the staff. The issues in question concern how LLW performance assessment are conducted and evaluated. The staff's proposed views on these principal regulatory issues can be found in Table D-1.

D-3.1.3 Recommended Analytical Approaches to Modeling Issues

The 1987 performance assessment strategy proposed by Starmer and others advocated a modular approach to modeling LLW disposal facility systems. They recommended that the disposal facility "system" be divided into the following separate modeling areas:

- infiltration and unsaturated (vadose) zone flow;

- engineered barrier performance (coupled with infiltration analysis to calculate the water flux into disposal units);

- radionuclide releases from waste forms and the bottoms of disposal units (container failure, leaching, and near-field transport);

- transport media – groundwater, surface water, and air;

- plant and animal uptake (food chain); and

- dose to humans.

The PAM, which was subsequently developed around this strategy, assumes a generalized conceptual model of an LLW disposal site, necessary for undertaking performance assessment analyses. It was developed by the Sandia National Laboratories (SNL). Consistent with the 1987 performance assessment strategy published by the staff, PAM was published in a five-volume series as NUREG/CR-5453[8] and provided a basic set models and computer codes for evaluating the following:

- infiltration behavior;

- source term release;

- engineered barrier performance;

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[8] See Shipers (1989); Shipers and Harlan (1989); Kozak and others (1989a and 1989b); and Kozak and others (1990a and 1990b).

Table D-1. NUREG-1573 Recommendations on Part 61 Regulatory Issues. Taken from NRC (2000, pp.xii–xv).

Regulatory Issue (NRC, 1996)	Staff NUREG-1573 Recommendation
Consideration of Future Site Conditions, Processes, and Events	The use of realistic assumptions and ranges of parameters to effectively reflect the reference geologic setting for the site. To capture the variability in natural processes and events and dynamic site behavior, the range of siting assumptions and data should be sufficient to understand the long-term trends in natural phenomena acting on the site. NUREG-1573 also emphasized that there should be a limit on the range of possible site conditions, processes, and events to be considered in an LLW performance assessment and that unnecessary speculation in the assessment should be eliminated. Additionally, consideration of societal changes would result in unnecessary speculation and therefore should not be included in a LLW performance assessment.
Performance of Engineered Barriers	That an applicant assign and justify the credit given to engineered barrier performance. Any period of time claimed for performance of engineered barrier should be supported by suitable information and technical justification evaluated on a case-by-case basis. However, to limit unnecessary speculation as to their performance, the staff believed that materials typically used in engineered barriers can alternatively be assumed to have physically degraded after 500 years following site closure. Thus, at 500 years and beyond, the engineered barriers can be assumed to function at levels of performance that are considerably less than their optimum level, but credit for structural stability and chemical buffering effects may be taken for longer periods of time. For time frames longer than 500 years, it is unreasonable to assume that any physical engineered barrier such as a cover or a reinforced concrete vault can be designed to function long enough to influence the eventual release of long-lived radionuclides such as ^{14}C ($t_{½}$: 5300 years); ^{99}Tc ($t_{½}$: 213,000 years); and ^{129}I ($t_{½}$: 15,700,000 years), if they are present. However, credit for structural stability and chemical buffering effects may be taken for the long-term provided that the applicant provides suitable information and justification. But again, this would have to be evaluated on a case-by-case basis.
Time Frame for an LLW Performance Assessment	Part 61 does not specify a time of compliance for meeting the Section 61.41 post-closure performance objective. To reduce unnecessary speculation regarding the performance assessment, a period of 10,000 years (i.e., the period of regulatory interest or concern) is sufficiently long to capture the peak dose from the more mobile long-lived radionuclides and to demonstrate the relationship of site suitability to the performance objective. Shorter periods, such as the 1000 years being used in dose assessments for site decommissioning, were considered generally inappropriate by the staff for assessments of LLW disposal facilities. Assessments beyond 10,000 years can be carried out, to ensure that the disposal of certain types of waste does not result in markedly high doses to future generations, or to evaluate waste disposal at arid sites with extremely long ground-water travel times. However, assessments of doses occurring after 10,000 years were not recommended for use as a basis for compliance with the performance objective.
Treatment of Sensitivity and Uncertainty in a LLW Performance Assessment	That formal sensitivity and uncertainty analyses be conducted in support of performance assessment calculations. The staff considered two different approaches for representing system performance in the context of the post-closure performance objective. One approach provides a single bounding estimate of system performance supported by data and assumptions that clearly demonstrate the realistic nature of the analysis. The other approach provides a quantitative evaluation of uncertainty with regard to system performance represented by a distribution of potential outcomes. When compliance, as measured against Section Part 61.41, is based on a single (deterministic) estimate of performance, the applicant is relying on the demonstration of the conservative nature of the analysis, rather than a quantitative analysis of uncertainty. Therefore, if it is to be used as a performance measure, a single estimate of performance should be at or below the Section 61.41 performance objective. In cases where a formal uncertainty analysis is performed and a distribution of potential outcomes for system performance is provided, NUREG-1573 recommended that the peak of the mean dose as a function of time be less than the performance objective, and a plot of the upper 95th percentile of doses at each discrete time be less than 1 mSv (100 mrem), to consider a facility in compliance.

Regulatory Issue (NRC, 1996)	Staff NUREG-1573 Recommendation
Role of Performance Assessment during the Operational and Closure Periods	Part 61 requires that final LLW site closure plans demonstrate the long-term safety of the facility, and include any additional geologic, hydrologic, or other disposal site data obtained during the operational period pertinent to the long-term containment of waste, and the results of tests, experiments, or analyses pertaining to long-term containment of waste. This could include testing of assumptions about the performance of engineered aspects of the facility that are amenable to confirmation during operations. The site closure requirements suggest a need to keep performance assessments up to date as new information brings into question the bases of earlier assessments of LLW site safety.

- contaminant transport via groundwater, surface water, and air; and
- dose to receptors.

The PAM's modular structure allows for a mix of both complex and simple models to be used in the overall LLW performance assessment. Given the technical uncertainty of modeling LLW site performance and the diversity of sites and facility designs being considered by various States and compacts, flexibility to select appropriate subsystem models and codes is an important PAM attribute. Although it is possible to implement the PAM manually, creating input to one subsystem model based on the results of another, NUREG-1573 outlined the potential benefits of automating subsystem model or code inputs and outputs with an overall "system"code, in the context of a broader performance assessment model. (See Section E-3.1.1, above.) The staff noted that the benefits of an automated system code over manually-linked subsystem models may include: (a) increased ability to step through successive iterations of the performance-assessment process and perform uncertainty and sensitivity analyses; (b) a higher degree of quality assurance; (c) explicit recognition of assumptions that might be vague or addressed inconsistently; and (d) use of consistent parameters and values among subsystem models. The PAM provided a general methodology for conducting LLW performance assessments whereas NUREG-1573 was intended to provide recommendations and Advice (guidance) to address specific performance assessment issues assuming that an analytical approach similar to the PAM would be used.

After applying the PAM to the hypothetical LLW test case problem, the staff found that its views regarding PAM's technical issues had evolved and needed updating. The updating was achieved in NUREG-1573. In the course of developing the PAM, a number of significant policy and technical issues were also identified and described but not addressed (Kozak and others, 1993). These issues (NRC, 1996) were later referred to the Commission for consideration and reviewed in the context of the staff's recommendations in NUREG-1573. See Table D-1.

D-3.2 Internal Dosimetry

NUREG-1573 noted that the Part 61 performance objective set forth in §61.41 was based on the International Commission on Radiation Protection (ICRP) *Publication 2* dose methodology (ICRP, 1959), but current health physics practices follow the dose methodology used in 10 CFR Part 20 ("Standards for Protection Against Radiation"), which is currently based on the ICRP *Publication 30* methodology (ICRP, 1979). The staff noted that any Part 61 LLW license application would contain many other assessments of potential exposures (e.g., worker exposure, accident exposures, and operational releases) that would rely on the ICRP *Publication 30* dose methodology. For internal consistency in the application, the staff thus recommended that the LLW performance assessment be consistent with the methodology approved by the NRC in Part 20 for comparison with the Part 61 performance objective. In this regard, the staff noted that the calculation of the total effective dose equivalent (TEDE) – a summation of the annual external dose and the CEDE – is acceptable for comparison with the performance objective.

As a matter of policy, NUREG-1573 also noted the Commission considered 0.25 mSv/year (25 mrem/year) TEDE as the appropriate dose limit to compare with the range of potential doses represented by the older limits that had whole-body dose limits of 0.25 mSv/year (25 mrem/year – see Footnote 1 in NRC, 1999). The staff noted that potential applicants did not need to consider organ doses individually because the low value of the TEDE should ensure that no organ dose will exceed 0.50 mSv/year (50 mrem/year).

D-3.3 Treatment of the Intruder Scenario

Another Subpart C performance objective potentially bearing on the overall performance objective at §61.41 is the performance goal at §61.42. This requirement establishes the need to "... protect inadvertent human intruders to the facility once disposal operations ceased and the facility decommissioned ...."

In NUREG-1573, the staff determined that separate intruder scenario dose analyses were not expected to be included in a LLW performance assessment (NRC, 2000; p. 1-13). In making this determination, the staff noted that §61.13(b) already required that "... analyses of the protection of individuals from inadvertent intrusion must include demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided ...."[9]

D-3.4 Public Comments on NUREG-1573

NUREG-1573 was made available as a draft for formal public comment on May 29, 1997 (62 *FR* 29164). The staff received 175 comments from 17 organizations and entities.[10] The staff reviewed the comments and found, on balance, the overall public reaction to the draft NUREG was favorable, with commenters stating agreement with staff proposed positions, that the document fulfills a need, that the document is well-written, and that the document should be finalized. Following a review of the public comments, the staff determined that its original advice and recommendations were fundamentally sound and generally acceptable to stakeholders. Hence, no significant changes were necessary to address the comments received. Only two major changes made to the final version of NUREG-1573. First, it was to no longer be referred to as a "BTP." Second, that the staff's views on the treatment of uncertainties in a LLW performance assessment were modified to better reflect the approach used by the staff in other NRC waste management programs. See NRC (2000a).

The staff's response to each of the 175 public comments received can be found in Appendix B of the final NUREG. A summary of those comments as well as the staff's disposition of them can be found in Table D-2. In addition to the modifications described in the table, other additions made to the final NUREG to address public comments included the following:

- an expanded "glossary" of technical terms used in the NUREG (as an appendix);

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[9]The staff did acknowledge separate intruder scenario analyses may be necessary in cases where the projected waste spectra are fundamentally different from those considered in the technical analyses supporting any Part 61 draft EIS (DEIS – see NRC, 1981). For example, an intruder analysis might be necessary if the waste form(s) proposed for disposal contain anomalous quantities and concentrations of certain long-lived radionuclides (e.g., uranium or thorium) such that the intruder cannot reasonably be protected by the waste classification and intruder barrier requirements of Part 61. To the extent that there may be a need for guidance on how to perform an intruder consequence analysis at an LLW disposal facility, NUREG-1573 did note that disposal facility developers and/or other regulatory entities should consult NRC's Part 61 DEIS (NRC, 1981).

[10]Including NRC Agreement States (Illinois, Massachusetts, Nebraska, South Carolina, and Texas), non-Agreement States (New Jersey and Pennsylvania), DOE, the U.S. Environmental Protection Agency (EPA), the Nuclear Energy Institute, and other interested stakeholders.

- an expanded bibliography on engineered and natural barrier performance (as Appendix C); and

- the inclusion of the Commission's 1995 PRA Policy Statement (as an appendix).

Following a review and modification of NUREG-1573, NRC's Advisory Committee on Nuclear Waste (ACNW) was briefed on the proposed final document at its 119th meeting in June 2000. In its review, the ACNW received the document favorably but did made certain recommendations for the Commission's consideration (Garrick, 2000). See Table D-3.

D-4 REFERENCES

Adam, J.A., and V.L. Rogers, "A Classification System for Radioactive Waste Disposal – What Waste Goes Where?," U.S. Nuclear Regulatory Commission, NUREG-0456, July 1978.

Cady, R. and M. Thaggard, "Summary and Insights from the NRC Branch Technical Position Test Case," in *16th Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference (Abstracts), Phoenix, Arizona, December 13-15, 1994,* U.S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho [1994], pp. 4-13.

Campbell, J.E., and R.M. Cranwell, "Performance Assessment of Radioactive Waste Repositories," *Science*, 239(4846):1389-1394 (1988).

Campbell, A.C., "Approaches for Uncertainty and Sensitivity Analysis in Performance Assessment," in *16th Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference (Abstracts), Phoenix, Arizona, December 13-15, 1994,* U.S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho [1994], pp. 4-15.

Campbell, A.C., and T.J. McCartin, "Application of Geochemical Data and Modeling in Performance Assessment of Low-Level Radioactive Waste Disposal Facilities," *EOS (Transactions of the American Geophysical Union),* 75(Supplement 16):171 (1994). [Spring meeting abstracts.]

Dunkelman, M.M., "Plans and Schedules for Implementation of U.S. Nuclear Regulatory Commission Responsibilities under the Low-Level Radioactive Waste Amendments Act of 1985 (P.L. 99-240)," U.S. Nuclear Regulatory Commission, NUREG-1213, Revision 1, August 1987. [Appendix E of NUREG-1213 document contains a comprehensive bibliography of NRC LLW publications issued through 1987.]

Eisenberg, N.A., and others, "Development of a Performance Assessment Capability in the Waste Management Programs of the U.S. Nuclear Regulatory Commission," *Risk Analysis*, 19(5): 847–876 (1999).

Table D-2. Summary of Staff Responses to Public Comments on NUREG-1573. Taken from ACNW transcript of ACNW's 119th meeting, dated June 13, 2000.

Issue	Public Comment	Staff Response/NUREG-1573 Disposition [a]
	Part 61 Regulatory Issues [b]	
Time Frame for a LLW Performance Assessment	Varied opinions. Shorter, 500-year TOC more appropriate than staff recommendation. Alternatively, LLW performance assessment calculations should be to peak dose.	Original staff recommendation will generally include the period of time when LLW is the most hazardous. 10,000 years is consistent with other waste management regulations and supporting analyses. *No change made to final NUREG.*
Performance of Engineered Barriers	Assumed 500-year duration is arbitrary and without technical justification.	500 years generally sufficient. Performance periods greater than 500 years permitted, subject to justification by licensees. *No change made to final NUREG.*
Consideration of Future Site Conditions, Processes, and Events	Uncertainties in future human activities should be considered.	Consideration of future human activities is highly speculative. Use of a "reference biosphere" or "critical group concept" consistent with other radioactive waste management applications. *No change made to final NUREG.*
Treatment of Sensitivity and Uncertainty in a LLW Performance Assessment	Varied opinions. Use of mean to provide best estimate of system performance not justified. Probabilistic analyses not supportable politically.	Proposed approach in NUREG consistent with other NRC regulatory activities. *No change made to final NUREG.*
	Other Comments	
Dose Methodology	NUREG inconsistent in recommending total effective dose equivalent (TEDE) calculation while the regulation calls for the use of the older ICRP 2 methodology.	*Final version of NUREG modified to clarify inconsistency. In response, the staff noted that as a matter of policy, the Commission considers 0.25 mSv/year [25 millirem/year (mrem/yr)] TEDE to be an appropriate dose limit to compare with the range of potential doses represented by the older whole body dose limits.*
ALARA Considerations	NUREG should provide guidance on how to comply with ALARA requirements of §61.41.	*Final version of NUREG modified to include discussion on how to address ALARA requirements by looking at costs and benefits of various disposal facility designs.*
Institutional Controls	Institutional controls should be maintained at site as long as wastes remain hazardous.	100 years of caretaker oversight generally considered conservative; institutional controls likely, in practice, to remain in effect indefinitely. *No change made to final NUREG.*
Ground Water Protection	Compliance with §61.41 will not ensure that EPA's MCLs will be met.	Meeting MCLs beyond the scope of the NUREG. Current regulations provide adequate protection. *No change made to final NUREG.*

Issue	Public Comment	Staff Response/NUREG-1573 Disposition [a]
Miscellaneous	Documentation of NRC LLW Test Case should be completed and published.	Test case results were already released and there are no resources available to complete requested documentation. *No change made to final NUREG.*
	NUREG should encourage use of peer reviews to increase confidence in performance assessment process.	*Final version of NUREG modified recommending peer reviews and formal/informal use of expert judgment.*
	Potential for nuclear material criticality should be addressed.	Staff considers potential for criticality to be remote and believes that appropriate measures will be taken during disposal facility operations. *No change made to final NUREG.*

a. Refer to Appendix B of NUREG-1573 for a full discussion of the public comments received and how there were treated by the staff in the final NUREG.
b. See Table D-1.

Table D-3. Summary of Staff Responses to ACNW Comments on NUREG-1573. Taken from Appendix E of final NUREG. Refer to that appendix for a complete discussion of the ACNW's comments (Garrick, 2000) and how there were treated by the staff in the final NUREG.

ACNW Recommendation	Staff Response/NUREG-1573 Disposition
The document should be issued as a "BTP."	The staff decision to now issue the BTP as simply a NUREG reflects the recognition of the need to make it clear that other approaches may be taken by these other organizations, in implementing their respective programs. In addition, the PAWG believes that, given the Agency's currently reduced role in licensing activities for LLW disposal, there is less need for providing specific guidance to licensees, which is the primary purpose of staff technical positions. *No change made to final NUREG.*
The staff should indicate in the technical report that a risk assessment is the acceptable method of safety analysis, the scope of which should be commensurate with the complexity of the facility.	*Final version of NUREG modified to address ACNW recommendation, including the Commission's 1995 PRA Policy Statement.*
The staff should provide guidance to the applicant to use realistic ranges and distributions of parameter values and conceptual models when conducting [probabilistic] risk analyses.	*Final version of NUREG modified to address ACNW recommendation.*
The staff should consider recommending a complimentary cumulative distribution function type of an approach to treating uncertainty in a probabilistic interpretation of the dose standard.	The staff disagreed with the ACNW that the proposed approach for addressing uncertainty disregards all information about the distribution, except the mean and the 95th percentile. In the NUREG, the staff noted that it was envisioned that the whole distribution would be considered, in that the recommended approach calls for looking at both the spread of doses at the time of the peak of the mean dose and also the spread in peak doses. Although the staff agrees that it may be useful for the regulatory agency to see the whole distribution of results before making a finding on the compliance demonstration, ultimately, only part of the distribution will be used in determining compliance with the dose criteria and guidance must be provided on what specific part(s) of the distribution should be used for this purpose. *No change made to final NUREG.*
The staff should consider eliminating the suggestion of a 500-year engineered barrier lifetime.	The staff agreed with the basic thrust of the ACNW recommendation but declined to modify NUREG. Staff view was that 500-year performance period is useful guidance. Generally, 500 years will be sufficient for the short-lived radionuclides, in LLW, to decay to insignificant levels. Because of the diminished radiological hazard at about 500 years and because of limitations in data and experience in the performance of engineered barrier materials beyond 10^2 years, the staff believes that it is not necessary for LLW disposal facility developers to spend large amounts of resources trying to justify engineered barrier performance over periods beyond 500 years. Also, any decision regarding engineered barrier performance will need to ultimately rest with the LLW disposal facility developer, subject to an adequate technical basis. *No change made to final NUREG.*

ACNW Recommendation	Staff Response/NUREG-1573 Disposition
The decision on a time frame time frame for a LLW performance assessment should be make on a case-by-case basis.	The staff considered the earlier advise of the ACNW in its February 11, 1997, memorandum. In that advice (Pomeroy, 1997), the Committee recommended the use of a two-part approach to addressing the time-of-compliance issue. The staff believed that the use of a such a two-part approach, as advocated by the Committee, is consistent with the approach recommended in the NUREG. *No change made to final NUREG.*

Fjeld, R.A., and K.L. Compton, “Risk Assessment“ in R.A. Meyers (ed.), *Encyclopedia of Environmental Analysis and Remediation*, New York, John Wiley and Sons, 1998.

Garrick. B.J., Advisory Committee on Nuclear Waste, Letter to Richard A. Meserve, U.S. Nuclear Regulatory Commission/Office of the Chairman [Subject: “Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities”], Washington, D.C., August 2, 2000.

International Commission on Radiological Protection, "Report of ICRP Committee II on Permissible Dose for Internal Radiation (1959), with Bibliography for Biological, Mathematical and Physical Data," Health Physics, Vol. 3 [1959]. [Reprinted in 1975 as *ICRP Publication* 2.]

International Commission on Radiological Protection, “Recommendations of the International Commission on Radiological Protection,” *Annals of the ICRP*, Vol. 1, No. 3 (1977). [ICRP Publication 26]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," *Annals of the ICRP*, Vol. 2, Nos. 3/4 (1979). [ICRP Publication 30, Part 1]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," *Annals of the ICRP*, Vol. 4, Nos. 3/4 (1980). [ICRP Publication 30, Part 2]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," *Annals of the ICRP*, Vol. 6, Nos. 2/3 (1981). [ICRP Publication 30, Part 3. Includes addendum to Parts 1 and 2.]

International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers: An Addendum," *Annals of the ICRP*, Vol. 19, No. 4 (1988). [ICRP Publication 30, Part 4]

Kozak, M.W., *et al.,* "Background Information for the Development of a Low-Level Waste Performance Assessment Methodology – Selection and Integration of Models," U.S. Nuclear Regulatory Commission, NUREG/CR-5453, Vol. 3, December 1989a. [Prepared by SNL, GRAM, Inc., and Science Applications International Corporation.]

Kozak, M.W., *et al.*, "Background Information for the Development of a Low-Level Waste Performance Assessment Methodology – Identification and Recommendation of Computer Codes," U.S. Nuclear Regulatory Commission, NUREG/CR-5453, Vol. 4, December 1989b. [Prepared by SNL and Science Applications International Corporation.]

Kozak, M.W., *et al.,* "Background Information for the Development of a Low-Level Waste Performance Assessment Methodology – Computer Code Implementation and Assessment," U.S. Nuclear Regulatory Commission, NUREG/CR-5453, Vol. 5, August 1990a. [Prepared by SNL.]

Kozak, M.W., and others*,* "Evaluation of a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities – Evaluation of Modeling Approaches," U.S. Nuclear Regulatory Commission, NUREG/CR-5927, Vol. 1, August 1993. [Prepared by SNL.]

Krupka, K.M., and R.J. Serne, “Effects of Radionuclide Concentrations by Cement/Ground-Water Interactions in Support of Performance Assessment of Low-Level Radioactive Waste Disposal Facilities,” U.S. Nuclear Regulatory Commission, NUREG/CR-6377, May 1998. [Prepared by the Pacific Northwest National Laboratory.]

Nuclear Energy Agency, “Confidence in the Long-Term Safety of Deep Geologic Repositories – Its Development and Communication,” Vienna, Organisation for Economic Cooperation and Development, 1999.

O'Donnell, E., and J. Lambert, "Low-Level Radioactive Waste Research Program Plan," U.S. Nuclear Regulatory Commission, NUREG-1380, November 1989. [Prepared by the Office of Nuclear Regulatory Research/Division of Engineering.]

Pomeroy, P.W., Advisory Committee on Nuclear Waste, Letter to Shirley Ann Jackson, U.S. Nuclear Regulatory Commission/Office of the Chairman [Subject: “Time of Compliance for Low-Level Nuclear Waste Disposal Facilities”], Washington, D.C., February 11, 1997.

PRA Working Group, “Review of NRC Staff Uses of Probabilistic Risk Assessment,” U.S. Nuclear Regulatory Commission, NUREG-1489, March 1994.

Rogers, V.C., “A Radioactive Waste Disposal Classification System,” U.S. Nuclear Regulatory Commission, NUREG/CR-1005, Vol. 1, September 1979. [Prepared by Ford, Bacon, & Davis Utah, Inc.]

Rogers, V.C., R.D. Baird, B.C. Robertson, and P.J. Macbeth, “A Radioactive Waste Disposal Classification System – The Computer Program and Groundwater Migration Models,” U.S. Nuclear Regulatory Commission, NUREG/CR-1005, Vol. 2, September 1979. [Prepared by Ford, Bacon, & Davis Utah, Inc.]

Shipers, L.R., "Background Information for the Development of a Low-Level Waste Performance Assessment Methodology – Identification of Potential Exposure Pathways," U.S. Nuclear Regulatory Commission, NUREG/CR-5453, Vol. 1, December 1989. [Prepared by SNL.]

Shipers, L.R., and C.P. Harlan, "Background Information for the Development of a Low-Level Waste Performance Assessment Methodology – Assessment of Relative Significance of Migration and Exposure Pathways," U.S. Nuclear Regulatory Commission, NUREG/CR-5453, Vol. 2, December 1989. [Prepared by SNL.]

Starmer, R.J., L.G. Deering, and M.F. Weber, "Performance Assessment Strategy for Low-Level Waste Disposal Sites," in *10th Annual U.S. Department of Energy Low-Level Waste Management Conference: Conference Proceedings, Denver, Colorado, August 30-September 1, 1988*, EG&G Idaho, December 1988, pp. 75-83.

U.S. Department of Energy and others, “Risk Assessment – A Survey of Characteristics, Applications, and Methods Used by Federal Agencies for Engineered Systems (submitted to the Federal Coordinating Council for Science, engineering and Technology, As Hoc Working Group on Risk Assessment),” U.S. Nuclear Regulatory Commission, November 1992. [PRA survey involving 8 Federal agencies.]

U.S. Nuclear Regulatory Commission, "Draft Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes," Office of Nuclear Material Safety and Safeguards, NUREG-0782, September 1981.

U.S. Nuclear Regulatory Commission, "Definition of 'High-Level Radioactive Waste' ," [Advance Notice of Proposed Rulemaking]," *Federal Register*, Vol. 52, No. 39, February 27, 1987, pp. 5992–-6001.

U.S. Nuclear Regulatory Commission, "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility (Rev. 2)," Office of Nuclear Material Safety and Safeguards/Division of Low-Level Waste Management and Decommissioning, NUREG-1199, January 1991.

U.S. Nuclear Regulatory Commission, "Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities [Proposed Policy Statement]," *Federal Register,* Vol. 59, No. 235, December 8, 1994, pp. 63389–63391.

U.S. Nuclear Regulatory Commission, "Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility (Rev. 2)," Office of Nuclear Material Safety and Safeguards/Division of Low-Level Waste Management and Decommissioning, NUREG-1200, January 1994.

U.S. Nuclear Regulatory Commission, "Regulatory Issues in Low-Level Radioactive Waste Performance Assessment," Commission Paper, SECY-96-103, May 17, 1996.

U.S. Nuclear Regulatory Commission, "Technical Report on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities," Commission Paper, SECY-00-0182, August 24, 2000.

U.S. Nuclear Regulatory Commission, "A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities – Recommendations of NRC's Performance Assessment Working Group," Office of Nuclear Material Safety and Safeguards/Office of Nuclear Regulatory Research, NUREG-1573, October 2000.

- Collection of environmental monitoring data is required during the operational and institutional control periods. These data could be used to increase confidence in long-term predictions of performance of LLW facilities.

- Credit for engineered barriers for waste form, waste packaging, disposal site design, and cover design were not explicitly included in Part 61. It would be an improvement to consider appropriate credit for the contribution of these engineered features to system performance.

We are forwarding the LLW White Paper as a draft final version, subject to limited peer review. We plan to issue the final version shortly as a NUREG report. Using the white paper as a starting point, the Committee is prepared to interact with the NMSS staff and stakeholders on risk-informing the management of LLW. Because of significant stakeholder interest in LLW activities, the ACNW plans to sponsor a working group meeting with NMSS to solicit stakeholder views on what changes to the regulatory framework for managing LLW should be recommended for Commission consideration.

Sincerely,

Michael T. Ryan
Chairman

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