Update of Low-Level Radioactive Waste Disposal History in the United States

Fuel Cycle Research & Development

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SUMMARY AND CONCLUSION

The history of Low-Level Radioactive Waste (LLW) disposal since the turn of the century (i.e., after prior histories were published) is discussed. This report separately discusses Nuclear Regulatory Commission (NRC) and Department of Energy (DOE) regulated LLW disposal.

For NRC regulated LLW disposal, a prior history (ACNW 2007) had been published; this document updates that history by discussing seven topics: 1) the closure of the Barnwell disposal facility to out-of-compact states, 2) the status of the Waste Control Specialists (WCS) disposal facility in Texas, 3) greater-than-class C LLW, 4) blending of LLW, 5) unique waste streams, 6) including dose from radon and progeny in air in performance assessments (PA) and 7) revision of 10 CFR 61.

For DOE regulated LLW disposal, a prior history (Bradley 1997) had been published; this document updates that history by discussing seven topics: 1) DOE 435.1 and the LFRG, 2) the cementitious barriers partnership, 3) the PA community of practice, 4) the advanced simulation capability for environmental modeling (ASCEM) project, 5) reviews under section 3116 of the 2005 National Defense Authorization Act (NDAA) of closure of DOE High-Level Waste (HLW) facilities, 6) Update of DOE 435.1, and 7) Performance Assessment of LLW Disposal.

Unfortunately, this history illustrates the failure of the State Compact system established by Congress in the Low-Level Radioactive Waste Policy Act of 1980 and the Low-Level Radioactive Waste Policy Amendments Act of 1985. Those acts empowered the States to band together in regional compacts for the purpose of establishing new LLW disposal facilities.

The Southeast Compact, which included Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia, was formed in 1983[1]. South Carolina had hosted a LLW disposal facility near Barnwell, SC for many years. North Carolina was designated by the Compact to host the next LLW disposal facility. However, after several years, with no progress toward establishing a new facility, South Carolina withdrew from the Southeast Compact. The Barnwell facility is now open only to waste from the Atlantic Compact (i.e., New Jersey, Connecticut, and South Carolina), which has left 36 states with no disposal option for their Class B and C LLW.

The Ward Valley, California site, a Southwest Compact site, was licensed in the late 1990s, but the facility was never opened due to opposition. No other Compact has opened a new LLW disposal facility. Over the past several years, Waste Control Specialists have been working to open a new LLW disposal facility in Andrews County, Texas and have recently begun to accept some Federal LLW for storage pending approval of disposal. However, there have been a succession of delays for commercial waste disposal and there is probable opposition to this facility receiving out-of-compact waste (i.e., waste from states other than Texas and Vermont).

Two professional societies, the Health Physics Society (HPS) and the American Nuclear Society (ANS), have published position statements calling for an overhaul of the nation’s LLW management system (HPS 2005, ANS 2009). Papers noting the need for changes in regulations for radioactive waste disposal have also been presented (Parker 2004, Regnier and Wallo 2006, Parker 2010). The Government Accountability Office (GAO) has indicated the need for improvements in the nation’s management of LLW (GAO 1999, 2004, 2007, and 2008). These and other considerations have caused the NRC to examine their LLW regulatory program and consider revising 10 CFR 61 (NRC 2007a).

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1 At this time, the LLW disposal facility at Richland, WA, became the disposal facility for the Northwest Compact, which is comprised of the States of Washington, Oregon, Montana, Idaho, Wyoming, and Utah. Another disposal facility, located at Clive, Utah and now operated by EnergySolutions, was opened in 1991 for Class A LLW as well as mixed waste (i.e., waste containing radioactive material and hazardous material). The Clive facility can receive waste from all states as well as the Federal government.

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ABBREVIATIONS

ACNW	Advisory Committee on Nuclear Waste
ACRS	Advisory Committee on Reactor Safeguards
AEC	Atomic Energy Commission
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ASCEM	Advanced Simulation Capability for Environmental Management
ATSDR	Agency for Toxic Substances and Disease Registry
CBP	Cementitious Barriers Partnership
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
CRS	Congressional Research Service
Ci	Curie (unit for radioactivity) 1 Ci = 3.7×10^{10} decays per second or Becquerels
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
DU	Depleted Uranium
EM	DOE Office of Environmental Management
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GAO	Government Accountability Office (formerly known as the General Accounting Office)
GTCC	Greater Than Class C
HLW	High-Level Waste
HPS	Health Physics Society
ICRP	International Commission on Radiological Protection
INL	Idaho National Laboratory
LANL	Los Alamos National Laboratory
LFRG	Low-Level Waste Disposal Facility Federal Review Group
LLW	Low-Level Waste
LLWPA	Low-Level Waste Policy Act
LLWPAA	Low-Level Waste Policy Amendments Act
MLLW	Mixed Low-Level Waste

mrem	milli ($1x10^{-3}$) rem
NAPA	National Academy of Public Administration
NAS	National Academy of Sciences
NCRP	National Council on Radiation Protection and Measurements
NDAA	National Defense Authorization Act
NIST	National Institute of Standards and Technology
NRC	Nuclear Regulatory Commission
NRDC	Natural Resources Defense Council
OSHA	Occupational Safety and Health Administration
PA	Performance Assessment
pCi	pico ($1x10^{-12}$) Curie
RCRA	Resource Conservation and Recovery Act
Rem	Unit of dose received from radioactive material
SCDHEC	South Carolina Department of Health and Environmental Control
SCW	Special Case Waste
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TCEQ	Texas Commission on Environmental Quality
TRU	Transuranic Waste
U.S.	United States
WCS	Waste Control Specialists
WIPP	Waste Isolation Pilot Plant
WL	Working Level
WLM	Working Level Month
WSRC	Washington Savannah River Company

1. INTRODUCTION

Disposal of Low-Level Radioactive Waste (LLW) is essential to a viable nuclear enterprise, not only for power production, but also for the use of radioactive material in medicine, commerce, and research. Previously, two reports on the history of LLW management in the United States were prepared. One, *History and Framework of Commercial Low-Level Radioactive Waste Management in the United States* (ACNW 2007), dealt with waste regulated by the Nuclear Regulatory Commission (NRC). The other, *Fifty Years of Federal Radioactive Waste Management Policies and Practices* (Bradley 1997), dealt with Department of Energy (DOE) waste management.

This report has been prepared to augment the previous reports. Recent issues and events that have occurred since the publication of the prior NRC and DOE reports are discussed as well as emerging issues that may impact low level waste disposal in the future.

2. NRC REGULATED LLW DISPOSAL

2.1 Prior History

In 2005, the NRC's Advisory Committee on Nuclear Waste (ACNW) agreed to examine issues related to the management of commercial LLW. As part of that effort, the ACNW prepared NUREG-1853, *History and Framework of Commercial Low-Level Radioactive Waste Management in the United States* (ACNW 2007).

NUREG-1853 is organized into three parts. The first is a history of the national LLW program including early approaches to the management of commercial LLW by the Atomic Energy Commission (AEC), NRC's efforts to develop LLW disposal regulations (i.e., 10 CFR 61 *Licensing Requirements for Land Disposal of Radioactive Waste* (NRC 1982a)), state efforts to site new LLW disposal facilities per the Low-Level Waste Policy Act (LLWPA) of 1980 and the Low-Level Waste Policy Amendments Act (LLWPAA) of 1985.

The second part is focused on NRC's regulatory framework in 10 CFR 61 (NRC 1982a). It provides general background on the approach to developing the regulation and highlights key issues. It also reviews the U.S. Environmental Protection Agency's (EPA) efforts to promulgate LLW standards and reviews the waste classification system that is the basis for Part 61.

The third part summarizes advice generated by a subcommittee of the Advisory Committee on Reactor Safeguards (ACRS) as well as that from the ACNW. This summary is organized into six areas: general LLW management issues, NRC LLW regulatory framework, ground-water monitoring, chemically mixed radioactive waste, performance assessment (PA), and waste package and waste form.

NUREG-1853 also includes six appendices containing the following background information: a review of the DOE approach to the management of government-owned LLW, a review of the evolution of the regulatory definition of commercial LLW, a summary of the structure of the NRC's LLW disposal regulation at 10 CFR Part 61 (NRC 1982a), a summary of the NRC staff's recommendations for the conduct of a LLW PA in NUREG-1573 (NRC 2000), a selected bibliography of LLW technical reports sponsored by the NRC Office of Nuclear Regulatory Research since the publication of NUREG 1573 (NRC 2000), and the Commission's 1995 policy statement on the use of probabilistic risk assessment methods in nuclear regulatory activities.

2.2 Recent And Emerging Events/Issues

Recent and emerging events and issues that significantly affect low level waste disposal in the United States include the following: 1) the closure of the Barnwell disposal facility to out-of-compact states, 2) the status of the Waste Control Specialists (WCS) disposal facility in Texas, 3) greater-than-class C LLW, 4) blending of LLW, 5) unique waste streams, 6) inclusion of dose due to radon and decay products in air in PA, and 7) revision of 10 CFR 61. Each is discussed separately below.

2.2.1 Closure of Barnwell to Out-of-Compact States

The LLW disposal facility near Barnwell, SC, which is operated by Chem-Nuclear Systems, a subsidiary of EnergySolutions, was initially licensed by the State of South Carolina through the South Carolina Department of Health and Environmental Control (SCDHEC) under their agreement with the NRC for the storage of LLW in 1969 (SCDHEC 2007). In 1971, the license was amended to permit disposal of Class A, B, and C LLW. The Barnwell facility has disposed of waste since 1971. During the 1970s, the Barnwell facility was one of six commercially operated LLW disposal facilities in the U.S. (the others were in West Valley, New York, Sheffield, Illinois, Maxey Flats, Kentucky, Beatty, Nevada, and Richland, Washington) and received a proportionate share of the nation's LLW. However, by 1979, three of the facilities (i.e., West Valley, Maxey Flats, and Sheffield) had been closed and the Barnwell facility was receiving 75% of the nation's LLW. During this time, the amount of LLW disposed at the Barnwell facility had increased from 50,000 cubic feet in 1971 to 2.2 million cubic feet in 1979. In 1981, the State of South Carolina imposed an annual volumetric limit of 1.2 million cubic feet.

To correct the imbalance of the LLW disposal burden, Congress passed the Low-Level Waste Policy Act in 1980 and, in 1985, the lack of progress in disposal site development among the regional compacts, which were formed per the 1980 Act, resulted in the passage of the Low-Level Waste Policy Amendments Act. The 1985 Act established milestones for disposal facility development[2]. However, by 1995, South Carolina withdrew from the Southeast Compact because North Carolina had failed to comply with milestones to develop a new disposal facility[3]. No other Compact has opened a new LLW disposal facility except for the Texas facility discussed below.

From 1995 to 2000, the Barnwell facility was open to receive waste from all states except North Carolina. In 2000, South Carolina enacted the Atlantic Compact Act, which provided for South Carolina to join with the Northeast Compact, which was made up of the states of New Jersey and Connecticut. This Act also allowed the Barnwell facility to receive out-of-compact waste through June 2008.

In 2004, the Barnwell facility was accepting about 99% of the nation's Class B & C LLW and the disposal facility in Clive, Utah, operated by EnergySolutions, was receiving about 99% of the nation's Class A waste (GAO 2004, GAO 2007, GAO 2008, DOE 2008a).

After July 2008, with the Barnwell facility being closed to most states, operating nuclear power plants in the 36 States not in the Atlantic, Northwest, or Rocky Mountain Compacts have stored their Class B & C LLW pending availability of suitable disposal capacity (Jensen 2007).

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[2] At this time, the LLW disposal facility at Richland, WA, became the disposal facility for the Northwest Compact, which is comprised of the States of Washington, Oregon, Montana, Idaho, Wyoming, and Utah. Another disposal facility, located at Clive, Utah and now operated by EnergySolutions, was opened in 1991 for Class A LLW as well as mixed waste (i.e., waste containing radioactive material and hazardous material). The Clive facility can receive waste from all states as well as the Federal government.

[3] There are 10 compacts: the Appalachian, Atlantic, Central, Central Midwest, Northwest, Midwest, Rocky Mountain, Southeast, Southwestern, and Texas Compacts. Together, these 10 compacts encompass 42 states (GAO 2008).

2.2.2 Status of WCS Texas Disposal Facility

Waste Control Specialists (WCS) has planned to develop a LLW disposal facility in Andrews County, Texas since 1992 (Monitor 2009). The WCS site is planned to have two disposal facilities, one for LLW from the Texas-Vermont Compact and one for waste from the federal government. The site was licensed by the Texas Commission on Environmental Quality (TCEQ) in January, 2008 (Monitor 2008). This is only the second Compact site to be licensed (the Barnwell, Beatty, and Richland sites were licensed before the Compacts were formed). The Ward Valley, California site, a Southwest Compact site (National Research Council 1995), was licensed in the late 1990s, but the facility has never opened due to opposition.

There has been much speculation about whether the WCS site will be opened to out-of-compact waste. If it were, that would alleviate the lack of disposal capacity for Class B and C LLW following the closure of the Barnwell, SC site to out-of-compact waste in July 2008. If the WCS site is not opened to out-of-compact waste, the 36 States not in the Atlantic, Northwest, or Rocky Mountain Compacts will have to continue to store their Class B&C wastes. It has also been conjectured that the WCS site could only be viable if approval is given for receipt of out-of-compact waste.

The disposal facility for federal waste received its first shipment of waste on October 7, 2009 (Andrews County News 2009). The waste is from the K-65 silos at the Fernald, Ohio DOE site. Currently, WCS is awaiting funds from an Andrews County bond issue to finance construction of the facility for commercial waste. The bond issue has been under a legal challenge for over a year. Due to the delay in obtaining funding, WCS has indicated that the facility would not be operational until mid-2011.

2.2.3 GTCC EIS

Greater-Than-Class C (GTCC) LLW is LLW that is generated commercially and that exceeds the Class C limits in 10 CFR 61 (NRC 1982a). Per the NRC requirements, GTCC LLW is not generally suitable for near-surface (i.e., in or within the upper 30 meters of the earth's surface) disposal. The LLWPAA of 1985 (Public Law 99-240) established that the federal government is responsible for disposal of GTCC LLW and that GTCC LLW is to be disposed in a facility licensed by the NRC.

Assuming that the Department of Energy is the federal agency responsible for GTCC LLW, DOE has been planning for its disposition for some time. DOE is in the final stages of preparing a draft Environmental Impact Statement (EIS) for the disposal of GTCC LLW (DOE 2010a). The EIS will also consider LLW generated by DOE that is similar to GTCC LLW. This waste is termed "GTCC-Like" waste.

In the draft EIS, DOE has evaluated five alternatives. They are (1) a No Action Alternative, (2) Disposal of GTCC and GTCC-Like wastes in a geologic repository at the Waste Isolation Pilot Plant (WIPP) in New Mexico, (3) Disposal in a new borehole disposal facility, (4) Disposal in a new trench disposal facility, and (5) Disposal in a new above-grade vault disposal facility. The latter three alternatives were evaluated at regional commercial locations and at seven federally owned sites. They are the Hanford Site, Idaho National Laboratory, Los Alamos National Laboratory, Nevada Test Site, Oak Ridge Reservation, Savannah River Site, and the vicinity of the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

The draft EIS is currently in the DOE concurrence process and will then be published for public comment.

2.2.4 Blending of Low-Level Radioactive Waste

Low-Level radioactive waste is subdivided into four classes according to the concentration of certain radionuclides (NRC 1982a). These classes are designated as Class A, Class B, Class C and GTCC, in order of increasing radionuclide concentration. The classification system is based on calculations of the dose received by a hypothetical person who inadvertently intrudes into a LLW disposal facility after the prescribed 100 years of institutional control. Class A waste is waste that will not pose much risk to the inadvertent intruder. Consequently, Class A waste is not required to be stabilized. Class B waste, due to its higher radionuclide concentrations, is required to be treated to produce a physical form which is stable for 300 years. Class C waste must be stabilized and it must also be disposed under a durable (i.e., effective for 500 years) intruder barrier. Waste that exceeds the Class C limits (i.e., GTCC waste) is not generally suitable for near-surface disposal.

The NRC has issued staff guidance on blending of LLW (NRC 1995)[4]. The guidance includes methods of radionuclide concentration averaging such as encapsulation of sealed sources and mixing of components with different waste concentrations in containers. The guidance places limits on the degree of mixing that should be done by recommending that the batches of LLW to be mixed should be within an order of magnitude of the resulting average concentration when mixing is complete, except when the classification is dictated by primary gamma-emitting radionuclides (i.e., Co-60, Nb-94, or Cs-137) in which case the concentrations within the individual items or components of the mixture cannot exceed a factor of 1.5 of the averaged concentration value for each radionuclide. This emphasized the NRC's position that mixing should not be used solely to reduce the classification of the resulting mixture.

Blending of LLW is now seen as a potential mitigating factor in dealing with the closure of the Barnwell, SC LLW disposal facility to States not in the Atlantic Compact (i.e., the States of Connecticut, New Jersey, and South Carolina). LLW generators in 36 States (i.e., those not in the Atlantic, Northwest, or Rocky Mountain Compacts) must store their Class B and C LLW until suitable disposal capacity is developed. The Waste Control Specialists disposal facility in Andrews County, Texas is seen as a possible outlet for Class B and C waste, but it is not currently operational; in fact, it is conjectured that it could only be viable if approval is given for receipt of out-of-compact waste.

The NRC staff recently examined blending or mixing of LLW (NRC 2010a) in response to the nuclear industry's examination of methods for reducing the amount of Class B and C wastes for disposal. The NRC study recommends that current blending guidance would be improved if it were risk-informed and performance based. Furthermore, the NRC staff considers large quantities of blended waste to be a unique waste stream, which should be included in current rulemaking on this topic.

2.2.5 Unique Waste Streams (e.g., Depleted Uranium)

Existing NRC regulations at 10 CFR 61.55, "Waste Classification" (NRC 1982a) specify criteria for classifying LLW for disposal in a near-surface facility. The development of 10 CFR 61 did not consider impacts resulting from disposal of unique waste streams (e.g., significant quantities of depleted uranium (DU) arising from the operation of a uranium enrichment facility or blended wastes) (NRC 1981, NRC 1982b). At that time, there were no commercial facilities generating significant quantities of depleted uranium (enrichment was a government operation and management of the DU tails was not under the purview of the NRC) and blending of LLW to affect classification was not contemplated.

However, in 2006 and 2007, the NRC issued licenses for two commercial uranium enrichment facilities, the Louisiana Energy Services National Enrichment Facility near Eunice, New Mexico and the United States Enrichment Corporation American Centrifuge Plant in Piketon, Ohio, which are expected to generate significant quantities of depleted uranium (NRC 2008, NRC 2009). Also the large stock of DU

4 Blending, as defined by the NRC is "mixing of LLRW with higher concentrations of radionuclides with LLRW with lower concentrations of radionuclides to form a final homogeneous mixture" (NRC 2010a)

tails from decades of government operation of enrichment facilities will be subject to NRC regulation if disposed of in NRC-licensed LLW facilities. Depleted uranium is unique in comparison with most LLW in that, due to production of shorter-lived radionuclides (e.g., radium-226, radon-222) in its decay, the radioactivity of depleted uranium increases over time, as illustrated in Figure 2-1. Depleted uranium is also unique in the magnitude of the waste that must be managed (i.e., potentially millions of tons).

The closure of the Barnwell, SC disposal facility to out-of-Compact LLW has resulted in 36 States not having a disposal outlet for Class B and C LLW, as discussed in Section 2.1.1. As a consequence, consideration is being given to blending of Class B and C LLW with larger volumes of Class A waste to result in a Class A waste that could be disposed in a facility accepting Class A waste only. As with depleted uranium, such blended waste was not contemplated when 10 CFR 61 was developed.

The NRC is considering rulemaking to accommodate these, and potentially, other unique waste streams (NRC 2009).

2.2.6 Inclusion of dose due to radon and decay products in air in PA

Radon, atomic number 86, is a radioactive inert noble gas, which occurs naturally as the decay product of uranium and thorium. Radon has 31 isotopes. Its most stable isotope, ^{222}Rn, has a half-life of 3.8 days. The half-lives of the other isotopes range from 0.27 micro-seconds for Rn-214 to 14.6 hours for Rn-211 (Tuli 2005). Radon-222, which is commonly called radon, is formed as part of the natural radioactive decay chain of uranium, which is illustrated in Figure 2-1 (ANL 2005). Radon-220, which is commonly called thoron, is part of the natural decay chain of thorium. Another isotope, Rn-219, arises from the decay of the most stable isotope of actinium, Ac-227, which is produced in nature by decay of U-235, and is called actinon (ATSDR 2008). The decay chains for thorium and U-235 are not shown because the half-lives of the radon isotopes are too short for them to be of practical significance. Radon and thoron are major contributors to the annual average radiation exposure in the United States (NCRP 2009), as illustrated in Figure 2-2. Radon-222 is the radon isotope of most interest to LLW disposal, due to its production from the decay of uranium and its relatively long half-life.

There are a number of standards and regulations for radon in air (ATSDR 2010). The Environmental Protection Agency has established an action level of 4 pCi/L in indoor, residential, air (EPA 2009). The Occupational Safety and Health Administration (OSHA) has established an occupational limit on radon in air of 4 Working Level Months (WLM) per year. The WLM unit is commonly used in regulation of occupational environments. For radon, it takes into account the energy of alpha particle decay of radon and its progeny as well as the length of exposure. To convert between units of Rn-222 radioactivity in pCi and WLM, the equilibrium between radon and its progeny must be known. When they are in equilibrium, one Working Level (WL) is about 100 pCi/L. In residential applications, the progeny are generally assumed to be at about 40% equilibrium, which would result in one WL being equivalent to 250 pCi/L. The WLM is defined as exposure to radon at a concentration of one WL for a period of one working month, which is assumed to be 170 hours. For residential exposure, the receptor is assumed to spend only 70% of his time indoors, which results in 1 pCi/L of radon in indoor air being equivalent to about 0.1 WLM per year. The dose resulting from exposure to indoor air containing 1 pCi of Rn-222 per liter is about 90 mrem/year (HPS 2001). Thus, residential exposure to the EPA's radon action level would result in a dose of about 360 mrem/year.

Regulations for disposal of LLW are inconsistent with respect to the inclusion of dose due to radon in performance objectives (NCRP 2005). Radon is regulated based on a flux rate and a concentration in air in Uranium related regulations (e.g., 10 CFR Part 40 (NRC 1991b), 40 CFR Part 192 (EPA 1983), 40 CFR Part 190 (EPA 1977), 40 CFR Part 61 (EPA 1979), etc.) and is excluded from the dose calculations. NRC guidance for decommissioning (NRC 2006a) is also consistent in assessing radon separately. Separate consideration of radon is consistent with federal public radiation protection standards (DOE 1990, NRC 1991a).

The regulation for commercial disposal of LLW, 10 CFR 61 (NRC 1982), does not explicitly address radon. However, the NRC staff has recommended that the dose due to radon should be included in radiological assessments (NRC 2000). In the notice for a public workshop on disposal of unique waste streams (NRC 2009), the NRC included modeling of radon as one of six issues.

However, given that a background dose of about 360 mrem/year due to radon is considered acceptable today, including dose due to radon and its progeny in air as part of compliance with a 25 mrem/year all-pathways dose limit creates the perception that there is more stringent protection of hypothetical future persons than is afforded actual persons today.

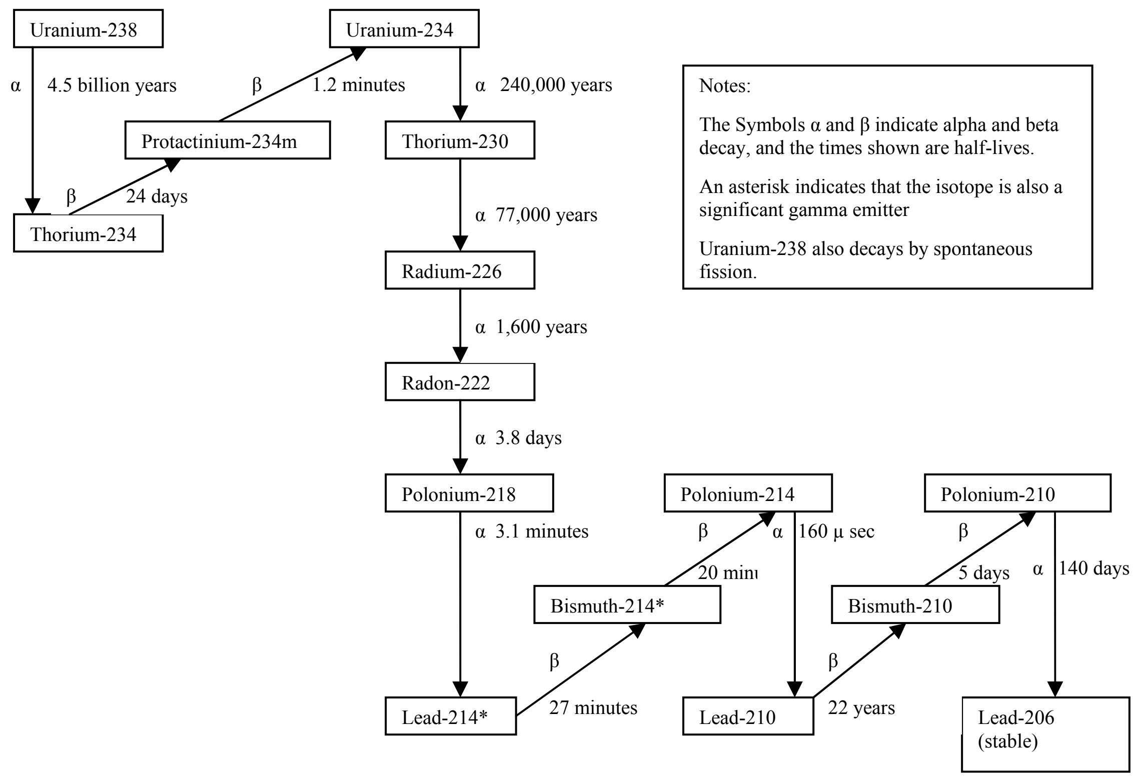

Figure 2-1. Uranium-238 Radioactive Decay Chain (ANL 2005)

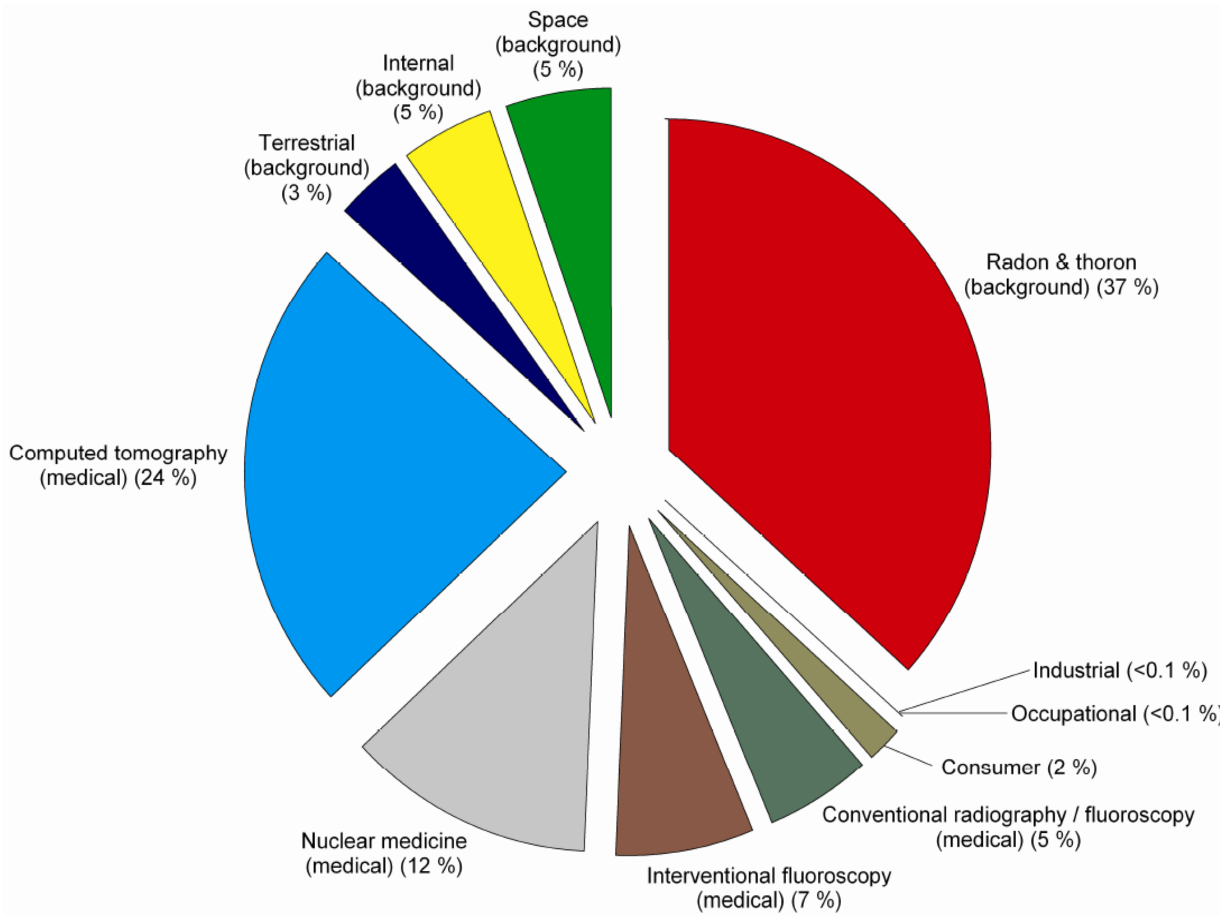

Figure 2-2. Major Sources of Radiation Exposure in the U.S. (from NCRP 2009) (percentages based on an annual average dose of 620 mrem)

2.2.7 Revision of 10 CFR 61

The NRC's regulation for commercial disposal of LLW was issued in 1982 (NRC 1982a). The national LLW disposal process operated reasonably well until 2008. In 2008, the Barnwell, SC LLW disposal facility was closed to out-of-compact waste. As a result, 36 States do not have an outlet for disposal of Class B and C LLW. A number of organizations, including the Government Accountability Office (GAO 1999, GAO 2004), the Health Physics Society (HPS 2005), and the American Nuclear Society (ANS 2009) have called for changes in the national LLW system.

These and other considerations have caused the NRC to examine their LLW regulatory program and consider revising 10 CFR 61 (NRC 2007a). The NRC staff identified a number of issues that challenge the current LLW regulatory framework. These include:

- The desire of industry for greater flexibility and reliability regarding disposal options, particularly for Low Activity Waste (LAW);
- Increased storage of Class B and C LLW because of the closing to out-of-compact waste generators of the Barnwell, SC disposal facility in 2008;

- Other new waste streams not previously considered in the technical basis for 10 CFR 61 that may be generated (for example, by the next generation of nuclear reactors) and the reemergence of nuclear fuel reprocessing;
- The coming need to dispose of large quantities of power plant decommissioning waste, as well as large quantities of depleted uranium from enrichment facilities;
- Lack of a disposal option for GTCC LLW; and
- Increased security concerns.

3. DOE REGULATED LLW DISPOSAL

3.1 Prior History

In 1997, R. Glenn Bradley, of ATL International, Inc., prepared DOE/EM-0331, *Fifty Years of Federal Radioactive Waste Management Policies and Practices* (Bradley 1997). The report provides a chronological history of policies and practices relating to the management of radioactive waste under the U.S. Atomic Energy Commission and its successor agencies. The report addresses high-level waste (HLW), low-level waste (LLW), Greater-Than-Class C (GTCC) commercial LLW, transuranic waste (TRU), mixed low-level waste (MLLW), and special-case waste (SCW).

The LLW section discusses the history of LLW generation and disposal, including both liquid and solid wastes. It discusses the emergence of TRU waste as a distinct waste type, beginning with the 1970 AEC Immediate Action Directive that required segregation of solid wastes contaminated with transuranic nuclides for packaging and retrievable storage for 20 years. The LLW section also discusses policies and practices for four time periods (i.e., the first 25 years, during the 1970s, during the 1980s, and during the period 1990 through 1996). It traces the development of DOE requirements for managing LLW, starting with AEC Manual Chapter 0511 and including DOE Order 5820.2A, *Radioactive Waste Management*, which for the first time established performance objectives for LLW management and required a PA of LLW disposal facilities.

3.2 Recent And Emerging Events/Issues

Recent and emerging events and issues that significantly affect DOE LLW disposal are 1) DOE 435.1 and the LFRG, 2) reviews by the NRC under Section 3116 of the 2005 NDAA of closure of DOE HLW facilities, 3) the cementitious barriers partnership, 4) the PA community of practice, 5) the advanced simulation capability for environmental modeling project, 6) the update of DOE 435.1, and 7) performance assessment of LLW disposal. Each is discussed separately below.

3.2.1 DOE 435.1 and LFRG

DOE Order, Manual, and Guide 435.1 (DOE 2001)[5] was developed to mitigate inadequacies in the previous DOE waste management Order, DOE 5820.2A (DOE 1988). In particular, for LLW, the Defense Nuclear Facilities Safety Board (DNFSB), in its recommendation 94-2 (DNFSB 1994), noted several deficiencies. These were: (1) DOE LLW disposal has not kept pace with the evolution of commercial practices, (2) Six years after issuance of DOE 5820.2A, which for the first time established the requirement for a PA of LLW disposal facilities, no defense nuclear facility had completed the PA

[5] DOE Order, Manual and Guide were approved on July 9, 1999. There have been two changes since then. The Order was changed on August 28, 2001 to add the National Nuclear Security Administration to the DOE Elements to which the Order applies. The Manual was changed on June 19, 2001 to remove the requirement that Headquarters is to be notified and the Office of Environment, Safety and Health consulted for exemptions for use of non-DOE treatment facilities.

process, (3) The source terms assessed in LLW disposal facility PAs neglect potentially significant sources (e.g., LLW disposed prior to 1988), and (4) Long-range forecasts of LLW to be disposed are very uncertain.

As a consequence, per its implementation plan to respond to DNFSB's recommendation (DOE 1996), DOE prepared DOE 435.1. For LLW disposal, the principal differences are an emphasis on maintenance of PAs and the establishment of a requirement to conduct a Composite Analysis (CA). The CA is to take into account all sources of residual radioactive material expected to remain at a DOE site when operations have ceased that will add to the dose to a future member of the public from the LLW disposal facility being assessed.

DOE 435.1 also required that a panel of DOE personnel be formed to review PAs and CAs and appropriate Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) documentation, to recommend LLW disposal facility compliance determinations, and to prepare disposal authorizations. This panel replaced the Peer Review Panel, a body of contractor personnel established pursuant to DOE 5820.2A to review PAs. The new panel is termed the Low-Level Waste Disposal Facility Federal Review Group (LFRG).

The LFRG is chartered by DOE's Office of Environmental Management. The LFRG has established and documented the process of review and technical criteria for reviews of PAs and CAs (LFRG 2008). The LFRG documents the reviews of PAs and CAs; a recent review is that of the SRS CA (LFRG 2010).

3.2.2 3116 Reviews of DOE HLW Facility Closure

Disposition of DOE High-Level Waste (HLW) tanks has long been a concern relative to soil and groundwater contamination and radiological protection of the public. DOE has proposed to remove most of the radioactive material in the waste for processing and disposal as HLW in the federal repository. The remainder, which is most of the volume of the waste with a small residue of radioactive material, was to be classed as incidental waste and disposed at the DOE sites. The tanks and residual waste were also to be classed as incidental waste and closed in place under the provisions of DOE 435.1 (DOE 2001). After DOE closed two HLW tanks at the Savannah River Site (SRS) and issued a Record of Decision to proceed with closing the remaining 49 tanks in a similar fashion, the Natural Resources Defense Council (NRDC) sued DOE over the authority to dispose of the waste in that way. The suit was initially adjudicated in NRDC's favor, but that decision was reversed on appeal (CRS 2007).

During that time, DOE had asked Congress to enact legislation to allow it to close HLW tanks in a manner similar to that employed at SRS. Eventually, the 108^{th} Congress passed the Ronald W. Reagan National Defense Authorization Act for FY 2005 (NDAA). Section 3116 of the NDAA (NDAA 2004) authorized DOE, in consultation with the NRC, to manage certain wastes as other than HLW if a determination has been made that such disposition is suitable. The determination includes the following provisions, from NDAA 2004, which must be satisfied in order to manage the waste as other than HLW:

1. Does not require permanent isolation in a deep geologic repository for spent fuel or high-level radioactive waste
2. Has had highly radioactive radionuclides removed to the maximum extent practical
3. *(sic)*
   a. Does not exceed concentration limits for Class C low-level waste as set out in section 61.55 of title 10, Code of Federal Regulations, and will be disposed of—
      (1) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations; and
      (2) pursuant to a State-approved closure plan or State-issued permit, authority for the approval or issuance of which is conferred on the State outside of this section; or

b. Exceeds concentration limits for Class C low-level waste as set out in section 61.55 of title 10, Code of Federal Regulations, but will be disposed of—

(1) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations;

(2) pursuant to a State-approved closure plan or State-issued permit, authority for the approval or issuance of which is conferred on the State outside of this section; and

(3) pursuant to plans developed by the Secretary in consultation with the Commission.

Section 3116 also has provision for monitoring such DOE disposal actions by the NRC. Section 3116 is applicable to the states of Idaho and South Carolina. To date, waste determinations for disposition of salt waste at SRS (DOE 2006a) and HLW tanks at the Idaho National Laboratory (INL) have been issued (DOE 2006b). Although Hanford is not under the purview of Section 3116, DOE is using methods developed at SRS for scoping the PA required for a 3116 Waste Determination with external regulators (i.e., the states, the EPA, and the NRC) at the Hanford Site.

3.2.3 Cementitious Barriers Partnership

Current performance assessment analyses show that engineered barriers are the primary control to prevent the release of radionuclides from nuclear facilities into the environment. In the absence of an adequate predictive tool, assessments cannot fully incorporate the effectiveness of concrete engineered barriers.

In 2006, a workshop on cementitious materials for waste treatment, disposal, remediation and decommissioning was held at the Savannah River National Laboratory; the workshop was sponsored by the DOE Office of Environmental Management (EM). A major need identified at this workshop was for a simulation tool to predict the degradation of cementitious materials over very long times. Arising from this was the Cementitious Barriers Partnership (CBP), a multidisciplinary partnership of DOE, the NRC, the U.S. National Institute of Standards and Technology (NIST), the Savannah River National Laboratory (SRNL), the Consortium for Risk Evaluation with Stakeholder Participation (CRESP), the private sector, and international expertise (DOE 2008b, Bredt, et al 2008).

The CBP will develop a set of simulation and modeling tools to predict the structural, hydraulic, and chemical performance of cement barriers used in nuclear applications over time frames extending from hundreds to thousands of years. These tools are expected to reduce the uncertainties of current methodologies for assessing cementitious barrier performance and increase the consistency and transparency of the assessment process. The main goal is to ultimately reduce both the extent of potential future release and the migration rate for contaminants. The primary goals of the CBP are to:

1. Improve the mechanistic understanding and mechanistic coupling of degradation processes within cementitious barriers for improved modeling;
2. Develop and enhance CBP Partner codes (i.e., a diffusion model, a thermodynamic model and a molecular microstructure model for cementitious materials) in which the data results can be utilized in contaminant transport modeling in performance assessments and/or in ASCEM multidimensional fate and transport modeling;
3. Provide PA support by providing parameters for deterministic modeling which has already been successfully demonstrated for the Savannah River Site's E-Area, Z-Area and Tank Farms; and
4. Provide a probabilistic screening tool for site selection.

Accomplishments to date include:

- Documented the Use of and Need for Cementitious Barriers in the DOE Complex
- Established the Baseline for Identifying R&D Needs Applicable to LLW Disposal Sites
- Provided a Roadmap for Development Work to Enhance Software that Models Aspects of Cementitious Barrier Performance
- Demonstrated the Capabilities of Partner Software on Prototype Case for CBP
- Established a Representative Set of Cementitious Materials that are Applicable to the DOE Complex
- Sponsored a Test Bed Workshop to Provide Future Data to Validate Cementitious Material Performance Modeling
- Developed Methods to Increase Consistency and Defensibility of Test Methods that Provide Data Used to Evaluate Cementitious Material Degradation in PAs
- Provided PA Support Work on Cementitious Material Degradation Specifically ins Support of the SRS Saltstone Disposal Facility

3.2.4 PA Community of Practice

Since the issuance of DOE 435.1, development of lessons learned and attention to continuous improvement activities regarding the preparation of PAs has been ongoing within the community of PA practitioners. To continue to enhance the process of ensuring the preparation of consistent, high-quality, and technically sufficient PA analyses, the EM Tank Waste Corporate Board established the Performance Assessment Community of Practice in 2009.

The goal of the PA Community of Practice is to enhance consistency in the preparation of PAs across the Department of Energy complex, to foster exchange of information among PA practitioners, and to develop appropriate guidance for PAs such that they are based on sound science and are defensible. This guidance should address both methodology and the use of data to help promote consistency in the preparation and application of PAs and consistency and relationships among PAs and other environmental assessments within sites and across the DOE complex.

To that end, the PA Community of Practice has conducted two workshops organized by DOE EM, CRESP, and the Savannah River National Laboratory. The first, held in July 2009, was on modeling the performance of engineered systems for closure and near-surface disposal. This workshop was held in Salt Lake City, Utah. The purpose of the workshop was to understand the current state-of-practice, the state of evolving science and opportunities to improve fidelity and reduce uncertainty in models used to estimate the performance of the engineered systems for environmental assessments. Recorded video and presentation materials from the workshop are available at the CRESP website (http://www.cresp.org/).

The second workshop, in the format of a technical exchange, was held in Richland, WA in April 2010. The general purpose of the technical exchange was to provide a venue for practitioners, managers, and regulators involved in performance and risk assessments and developers working on the Advanced Simulation Capability for Environmental Management (ASCEM) project and on the CBP to share experiences and to collect user ideas and identify user needs related to ASCEM and the CBP. The technical exchange was attended by about 80 people representing DOE headquarters and Field Offices, national laboratories, DOE contractors, NRC, EPA, State regulators, consulting firms, and universities. The agenda, list of participants, the presentations, and podcasts of the presentations are available on the SRNL website (http://srnl.doe.gov/copexchange/index.htm).

3.2.5 Advanced Simulation Capability for Environmental Modeling (ASCEM)

In 2008, DOE's Office of Environmental Management published its Engineering and Technology Roadmap: Reducing Technical Risk and Uncertainty in the EM Program (DOE 2008b). The Roadmap was prepared to guide applied research and technology development and deployment work in the DOE EM engineering and technology program. In 2009, the National Research Council of the National Academy of Sciences (NAS) published *Advice on the Department of Energy's Cleanup Technology Roadmap: Gaps and Bridges*. That report identified and ranked the principal science and technology gaps that could adversely affect EM's ability to meet its cleanup milestones and provides recommendations for improving the Roadmap. To address those gaps, the NAS recommended that DOE develop sophisticated computational models to incorporate understanding of site geohydrology and contaminant geochemistry. To that end, in 2009, DOE formed the Advanced Simulation Capability for Environmental Modeling (ASCEM).

ASCEM is a consortium of five national laboratories, Los Alamos, Berkeley, Oak Ridge, Pacific Northwest, and Savannah River. It was formed to develop transformational, high performance computer modeling capabilities to better meet the challenge of waste disposal and cleanup left over from the creation of the US nuclear stockpile. The ASCEM project is organized into three thrust areas: Platform and Integrated Toolsets, Multi-Process High Performance Computing Simulator, and Site Applications (ASCEM 2010).

An important component of the ASCEM Project is the involvement of end users, including performance assessment and risk assessment practitioners, decision-makers, oversight personnel, and regulators who are engaged in the DOE cleanup mission. Solicitation of end-user feedback is critical at the early stages of ASCEM development to ensure high priority user needs are incorporated into the framework. Engagement of end users throughout the development of ASCEM is considered one of the keys to developing user acceptance and eventual application of the ASCEM toolsets at DOE sites.

Recognizing the importance of involving end users, the Site Applications Thrust has delineated a "user needs interface" task, which focuses on establishing contact with various end users, soliciting their input about ASCEM development plans, and conveying the feedback to members of the High Performance Computing and Platform Thrust areas who are responsible for the tool and code development. Over the longer time frame, the Site Applications Thrust includes several tasks that are designed to engage and support end users, including site demonstrations; development of protocols, documentation, and work flows; and training and support in the use of ASCEM tools (Seitz et al, 2010).

3.2.6 Update of DOE 435.1

Development of DOE 435.1 was informed by a rigorous Complex-Wide Review of radioactive waste management activities that was performed as a part of DOE's response to DNFSB 94-2 (DOE 1996). This Complex-Wide Review identified six complex-wide vulnerabilities. They were:

1) LLW forecasting and capacity planning was inadequate;
2) characterization of LLW was ineffective;
3) LLW that had an identified path forward for disposal remained in storage;
4) storage conditions for LLW were inadequate;
5) some LLW had no technical path forward for disposition; and
6) performance assessments were unapproved and lacked adequate requirements.

DOE 435.1 was issued in July, 1999. Since that time, there has been major progress in radioactive waste management and all of the six vulnerabilities identified in the 1996 complex-wide review have been addressed. There have also been a number of developments in DOE radioactive waste management (e.g., waste determinations per Section 3116 of the 2005 NDAA). Consequently, DOE Headquarters (EM-41) has initiated a project to update DOE 435.1.

The initial effort in the update process was to perform another Complex-Wide Review. That effort has been completed and is documented in DOE 2010b. The review was designed to gather user feedback information, not to assess compliance. The Complex-Wide Review identified 68 best practices as well as 139 suggested areas of improvement that should be considered in the update to DOE 435.1. The following key complex-wide areas of improvement were identified:

1. Significant additional complications and costs are created by the lack of a path forward for high-level waste disposal;
2. DOE Order 435.1-1 has been effective in addressing the 1996 complex-wide review findings and the Defense Nuclear Facilities Safety Board concerns;
3. Program Offices are not, in all cases, executing oversight responsibilities under DOE Order 435.1 consistently;
4. Sites are not, in all cases, executing oversight responsibilities under DOE Order 435.1 consistently;
5. Significant uncertainty is associated with the use of the waste incidental to reprocessing evaluation process because it has not yet been tested; and
6. Improved coordination is needed between DOE Order 435.1 requirements and external requirements such as RCRA and CERCLA and between DOE Order 435.1 and other DOE requirements such as those addressing management of classified materials.

These, and other results of the Complex-Wide Review, will be used to improve existing requirements and practices. Items not appropriate for incorporation into the order or guidance revisions, but having other potential benefits, will be provided to DOE upper management and relevant steering groups.

3.2.7 Performance Assessment of LLW Disposal

As a part of the update to DOE 435.1, the requirements for performance assessment of LLW disposal facilities will be considered. There are at least three issues that must be dealt with.

3.2.7.1 Radon

Radon is a radioactive noble gas, which occurs naturally as the decay product of radium (see Section 2.2.1). DOE 435.1 does not include dose from radon and its decay products in assessments of impacts from disposed LLW (DOE 2001). Rather, a separate assessment of the flux of radon at the ground surface is required. This is consistent with NRC requirements in 10 CFR 40 (NRC 2010b) and 10 CFR 20.1101(b) (NRC 1991a) and EPA requirements in 40 CFR 61 (EPA 1979) and 40 CFR 190 (EPA 1977).

As discussed in Section 2.2.1, NRC is considering whether to require that dose due to radon and its progeny in air be included in assessments of the impacts of LLW disposal. This would be a departure from existing promulgated rules from the NRC and the EPA. If the dose due to radon and its progeny is included as part of compliance with the 25 mrem/year all-pathways dose limit, this would create the perception that there is more stringent protection of a hypothetical future person than is considered acceptable for actual persons today.

3.2.7.2 Time of Compliance

DOE 435.1 requires an assessment of the impacts of LLW disposal for a period of 1,000 years after closure of the LLW disposal facility. The 1,000-year period is based on a consideration of inter-generational equity (NAPA 1997, Regnier and Wallo 2006) and is consistent with other promulgated rules (e.g., 40 CFR 192 (EPA 1983)). One aspect of a requirement of Section 3116 of the 2005 NDAA (see Section 2.1.3) is that DOE, in assessing impacts of closed HLW tanks and in disposal of waste arising from HLW systems, extends PA calculations out to 10,000 years to assess compliance with dose standards due to the NRC Headquarters staff position (NRC 2000). Thus, DOE will have to decide what the appropriate time-frame is for PAs. The International Commission on Radiological Protection (ICRP) has recommended that time frames of 1,000 to 10,000 years be considered for quantitative compliance calculations and longer times be considered in a more qualitative manner.

3.2.7.3 Probabilistic Analysis

DOE 435.1 requires that performance assessments of LLW disposal facilities include a "sensitivity/uncertainty" analysis (DOE 2001) to determine which parameters, model components, and processes are most significant to the results. Over the past several years, PAs have evolved from fulfilling this requirement by deterministic sensitivity analysis (i.e., running the PA model while changing one parameter at a time and assessing the resulting change in the result) to using probabilistic methods to assess uncertainty (INL 2007, WSRC 2008) while using results of a deterministic analysis to assess compliance with performance objectives[6]. The latter has been termed the "hybrid approach". Some PAs have been done completely probabilistically (Bechtel Nevada and Neptune 2006, LANL 2008). DOE recently sponsored a workshop on probabilistic analyses (Seitz et al 2008).

At issue is the interpretation of probabilistic results in the context of compliance with a deterministic performance objective. NRC staff, in NUREG-1573 (NRC 2000) recommended that the mean of the results distribution not exceed the 25 mrem/year performance objective in 10 CFR 61 and the 95th percentile of the distribution not exceed 100 mrem/year. However, more recent NRC guidance emphasizes the use of the peak of the mean results distribution (NRC 1997, NRC 2002, NRC 2006a, NRC 2006b, NRC 2007b) to assess compliance. EPA considers the best estimate (i.e., mean or median, whichever is higher) of the distribution as the appropriate metric for compliance determination (EPA 1985).

[6] Deterministic analysis uses single values for each parameter in the model and produces a single result (e.g., dose, radionuclide concentration) for comparison with performance objectives. Probabilistic, or stochastic, analysis assigns a probability distribution of values for selected parameters and produces a distribution of results.

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