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Transfer of Very Low-Level Waste to Exempt Persons for Disposal

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Transfer of Very Low-Level Waste to Exempt Persons for Disposal

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General Comment

See attached

Attachments

10_21_20_PEER-NRC-VLLW_comments

Exhibit List

EX 2_ Radiation Exposure_ MedlinePlus

EX 3_ Environmental Protection Standards for Yucca Mountain

EX 1_ NAS Low-Level Radwaste Mgmt and Disposition 2017

EX 4_SCFS-CBG Papers to NAS copy

PEER
PUBLIC EMPLOYEES FOR ENVIRONMENTAL RESPONSIBILITY

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October 21, 2020

Secretary
U.S. Nuclear Regulatory Commission
Washington, DC 20555–0001
ATTN: Rulemakings and Adjudications Staff

submitted electronically via Rulemaking.gov

RE: Public Employees for Environmental Responsibility's Comments on Docket ID NRC–2020-0065

Dear Sir/Madam:

Public Employees for Environmental Responsibility (PEER) submits these comments in opposition to NRC's proposal to deregulate the disposal of virtually all radioactive waste from nuclear reactors, aside from irradiated fuel, as well as the deregulation of much other atomic waste. The proposal would endanger public health and the environment.

STATEMENT OF INTEREST

PEER is a service organization for environmental and public health professions, land managers, scientists, enforcement officers and other civil servants dedicated to upholding environmental laws and values. We work with current and former federal, state, local and tribal employees. PEER protects public employees who protect our environment. PEER supports past and present public employees who seek a higher standard of environmental ethics and scientific integrity within their agencies. PEER does this by defending whistleblowers, shining the light on improper or illegal government actions, working to improve laws and regulations, and supporting the work of other organizations.

SUMMARY OF ISSUE: NRC Proposes, in the Guise of An "Interpretive Rule," to Rescind Long-Standing Regulations Requiring a License to Dispose of Radioactive Waste

NRC's long-standing regulations require anyone who wishes to receive and dispose of licensed radioactive waste to have a license to do so and meet detailed requirements to protect public health and the environment.[1] The proposed "interpretive rulemaking" would revoke those requirements and allow the owner of essentially any site such as regular landfill to request an exemption that would allow it to receive and dispose of radioactive waste without a nuclear license and thus without meeting any of the typical health, safety, and environmental requirements.[2] This means, for example, that any regular, municipal garbage dump could be allowed to take radioactive waste, without being licensed to do so and without meeting the safety rules required of licensed radioactive waste sites.

Thus, if you have a nuclear power plant in your community, virtually all of its radioactive waste other than spent fuel could be dumped at your local landfill. The NRC says it would allow this so long as it is estimated by the landfill operator to expose people to no more than 25 millirem of radiation per year,[3] which is the equivalent of receiving, without consent, 900 unwanted and unnecessary chest x-rays over a lifetime.[4] That exposure would result in one in every 500 people exposed getting a cancer from the exposure, using the official risk coefficients from EPA and the National Academy of Sciences for cancer per unit dose of radiation.[5] The cancer risk from that radiation dose is 2,000 times the goal for a Superfund site under CERCLA and 20 times the

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[1] 10 CFR Part 61, "Licensing Requirement for Land Disposal of Radioactive Waste"; U.S. Nuclear Regulatory Commission, "Consolidated Guidance: 10 CFR Part 20 – Standards for Protection Against Radiation," 3.20.2001 General Requirements. https://www.nrc.gov/docs/ML0133/ML013330106.pdf 10 CFR §61.3 ("License Required"): "(a) No person may receive, possess, and dispose of radioactive waste containing source, special nuclear, or byproduct material at a land disposal facility unless authorized by a license issued by the Commission pursuant to this part, or unless exemption has been granted by the Commission under §61.6 of this part."

[2] U.S. Nuclear Regulatory Commission, "Transfer of Very Low-Level Waste to Exempt Persons for Disposal," 85 Fed. Reg. 13,076, March 6, 2020, NRC-2020-0065. https://www.regulations.gov/document?D=NRC-2020-0065-0001

[3] *Ibid*, Section V. Specific Exemptions for Disposal.

[4] U.S. Environmental Protection Agency, "How much radiation am I exposed to when I get a medical x-ray procedure?" https://www.epa.gov/radiation/how-much-radiation-am-i-exposed-when-i-get-medical-x-ray-procedure. EPA states that a single chest x-ray is equal to 2 millirem. An exposure of 25 millirem per year would be equivalent to approximately a chest x-ray every month from conception to death. Over a lifetime of 70-75 years, that would be ~900 chest x-rays.

[5] 0.025 rem/year x 70 years x 1.16×10^{-3} cancers/rem = 2×10^{-3} cancer risk. The 1.16×10^{-3} cancers/rem coefficient is from USEPA, *EPA Radiogenic Cancer Risk Models and Projections for the U.S. Population*, EPA 402-R-11-001, April 2011 (https://www.epa.gov/sites/production/files/2015-05/documents/bbfinalversion.pdf), which in turn is derived from the National Academy of Sciences/National Research Council, *Health Effects from Exposure to Low Levels of Ionizing Radiation, BEIR VII Phase 2,* 2006, https://www.nap.edu/catalog/11340/health-risks-from-exposure-to-low-levels-of-ionizing-radiation

upper limit of EPA's acceptable risk range.[6] EPA has long found that such a dose limit would be "non-protective" of public health.[7]

Furthermore, the 25 millirem per year level that NRC says it will use for exempting dumpsites from licensing requirements is not a measured value but simply a calculated estimate put forward by the owner of the landfill when it is requesting exemption from licensing requirements, before ever receiving any waste. An applicant for an exemption can readily manipulate inputs for the modelling to produce estimates that purportedly show 25 millirem per year doses when the actual doses could be far higher.[8] Furthermore, such models and NRC's reviews of the applicant's models are generally declared "proprietary" and shielded from public review and scrutiny.[9]

Agreement States might be allowed under this proposal to authorize unlicensed landfills to take radioactive waste amounts that produce even higher doses than 25 millirem per year.[10]

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[6] EPA states that 10^{-6} (one in a million) cancer risk is the point of departure for CERCLA cleanup goals and the basis for Preliminary Remediation Goals and that 10^{-4} (one in ten thousand) is the upper limit of the acceptable risk range. National Contingency Plan (NCP), 40 CFR 300.430(e)(A)(2). See also USEPA, *Radiation Risks at CERCLA Sites: Q&A*, OSWER 9285.6-20, June 13, 2014, p. 27. https://semspub.epa.gov/work/HQ/176329.pdf

[7] U.S. Environmental Protection Agency, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination," August 22, 1997, p. 3. https://semspub.epa.gov/work/HQ/176331.pdf. EPA has warned NRC that EPA might have to list sites producing more than 15 millirem per year as Superfund sites because the risk exceeds EPA's acceptable risk range. Letter from EPA Administrator Carol Browner to NRC Chairman Shirley Ann Jackson, February 7, 1997. EPA has since declared even 15 millirem per year to be non-protective. EPA, *Radiation Risks at CERCLA Sites: Q&A,* 2014, p. 28. Note that the EPA risk estimate in that document does not yet employ the newer EPA radiation risk figures cited above and assumes a far shorter exposure period than allowed by the NRC proposal.

[8] NRC states in section V. of the proposed rule that applicants seeking exemptions should submit a safety analysis that includes, "a discussion regarding the conceptual and mathematical models and parameters used in the applicant's dose assessment related to proposed disposal (*e.g.,* site specific parameters and modeling data and results); and (v) site-specific dose assessments or sensitivity and uncertainty analyses when performing the dose assessments to estimate the radiological impacts to members of the public and ensure that the 25 millirem per year cumulative dose limit is not exceeded." The applicant is therefore responsible for choosing the model and controlling the model inputs, and the radiological health impacts are merely estimates made by the applicant in order to get the exemption.

[9] Such models and NRC's reviews of the applicant's models are generally shielded from public review and scrutiny. See e.g., WESTINGHOUSE ELECTRIC COMPANY LLC, "Copy of Letter from L. Camper to J. Weismann approving use of USEI SSDA for 10 CFR 20.2002 Alternate Disposal Authorization Requests," August 24, 2015, p. 2, ML15125A364. https://adamswebsearch2.nrc.gov/webSearch2/view, which declares that the Site-Specific Dose Assessment Methodology of an operator of a dumpsite not licensed to receive low-level radioactive waste who nonetheless wished to receive such waste and the NRC's Technical Evaluation Report of that model and its inputs "are considered proprietary and will not be available for public review."

[10] NRC, "Transfer of Very Low-Level Waste to Exempt Persons for Disposal," Section V, "Specific Exemptions for Disposal." NRC says the regulations in Parts 30.11, 40.14 and 70.17 to be subject to reinterpretation under this rule are Compatibility Category D, which doesn't require state regulations that are identical to NRC rules. *ibid.,* Section III, "Proposed Interpretive Rule."

Under the NRC proposal, once the dumpsite is granted the exemption, the NRC will no longer have any oversight or enforcement authority over the site, the waste, or public exposures to assure that the site is run safely and that the already-too-high supposed dose limit is not exceeded.[11] There would be no NRC inspections, no fines for violation, no authority to take action if closure or post-closure is not undertaken safely, etc.

UNDER THE PROPOSAL, AN UNLICENSED MUNICIPAL DUMP COULD RECEIVE AS MUCH RADIOACTIVE WASTE AS A LICENSED ON, OR EVEN MORE

The NRC is claiming in its proposal that its "intent" is that the exemptions be used for "very low-level radioactive waste,"[12] but admits there is no regulatory or statutory definition for the term.[13] However, NRC says in the proposed interpretive rule that it covers *all* radioactive waste to be received at an unlicensed dump that would collectively be estimated by the dump operator to produce up to 25 millirem per year of radiation to a member of the public.[14]

A licensed "low-level" radioactive waste disposal facility is restricted to producing 25 millirem per year to the whole body or to any critical organ (other than the thyroid, which is permitted 75 millirem).[15] Thus, on its face, the NRC's proposal *could allow as much radioactive waste to go to an unlicensed site as now goes to a licensed one.*

Further, NRC's proposal appears to use a different, more lax measure of radiation dose than is used in the current regulations for a licensed disposal site. It would allow *more* radioactive waste to go to an unlicensed dump than a licensed radwaste disposal facility, and *more* radiation exposure to the public result from the unlicensed site than is allowed for the licensed site.

NRC appears to be proposing that an unlicensed site be allowed to receive radioactive waste if the dump operator's estimate is that it would produce 25 millirem per year "effective dose equivalent," or EDE, rather than actual dose. EDE is a controversial modification of actual dose that takes the dose to an organ and reduces it by averaging it over the whole body and further altering the value by "tissue-dependent weighting factors [that] are a set of subjective committee

[11] Statement by Chris McKenney. Branch Chief for the Risk and Technical Analysis Branch, Division of Decommissioning, Uranium Recovery, and Waste Programs, Official Transcript of Proceedings: "Category 3 Meeting on Draft Interpretive Rule for Very Low-level Waste (VLLW) Disposal Activities," March 31, 2020, ML20112F441, p. 12.

[12] NRC's claim of its current "intent" is meaningless and unenforceable, given that, as it admits, the term "very low-level waste" is not set in either statute or regulation. Non-binding assertions of intent, absent regulatory or statutory restrictions, have no proscriptive power.

[13] NRC, "Transfer of Very Low-Level Waste to Exempt Persons for Disposal," Section IV, "Discussion."

[14] NRC, "Transfer of Very Low-Level Waste to Exempt Persons for Disposal," Section V, "Specific Exemptions for Disposal."

[15] 10 CFR § 61.41.

defined numbers."[16] "The effective dose represents questionable science" and "is prone to misuse."[17]

The current regulations for low-level radioactive waste disposal, for example, would restrict the amount of strontium-90 in licensed disposal sites to levels that would produce no more than 25 millirem per year to the bone, the critical organ.[18] But a 25 millirem per year dose to the bone would be claimed to be only a small fraction (about one tenth) of 25 millirem EDE under the NRC's new proposal, and thus much more strontium-90 could be allowed in the unlicensed dump than in the licensed facility.[19] That is in part because NRC takes the actual dose to the bone and dilutes it over the rest of the body to create a lower EDE.

EPA indicates that one would have to, on average, limit EDE to 10 millirem per year in order to have the same protectiveness as the current limit for licensed sites of 25 millirem to the whole body, 75 millirem to the thyroid, and 25 millirem to any other critical organ.[20] So the NRC proposal of 25 millirem EDE for an unlicensed dumpsite would actually allow 2.5 times as much radiation to the public from an unlicensed dump than from a licensed radioactive waste disposal site.

The NRC proposal thus clearly is not limited to "very low-level waste," but could allow a regular garbage dump to take as much or more of all classes of "low-level radioactive waste" as one licensed and designed for such waste.

Considering that it is much more expensive to operate a licensed radwaste disposal facility than an unlicensed, normal garbage landfill (because of the cost of meeting the safety requirements for the former),[21] and thus the "tipping fee" at the latter is far lower, this proposed deregulation by NRC would render licensed sites virtually obsolete due to lower cost to the waste generator to dump its waste at the local garbage dump.

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[16] U.S. Nuclear Regulatory Commission, "Effective Dose Equivalent," March 21, 2019. https://www.nrc.gov/reading-rm/basic-ref/glossary/effective-dose-equivalent.html; D. J. Brenner, "Effective Dose: A Flawed Concept That Could and Should be Replaced," *British Journal of Radiology*, 81 (2008*), 521–523*.

[17] Brenner, *supra.*

[18] 10 CFR § 61.41.

[19] COMPARISON OF CRITICAL ORGAN AND EDE RADIATION DOSE RATE LIMITS FOR SITUATIONS INVOLVING CONTAMINATED LAND, Prepared for USEPA by S. Cohen & Associates, Inc., April 18, 1997, Exhibits ES-3, 4, and 5.

[20] U.S. Environmental Protection Agency, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination," August 22, 1997, cover letter p. 5, fn. 11; and Attachment B, p. 4. https://semspub.epa.gov/work/HQ/176331.pdf. For key radionuclides of concern at contaminated sites, the difference is even greater; one would have to limit EDE to even lower levels that 10 millirem, on average 7 millirem EDE for residential exposure scenarios. Cohen, *supra,* p.iii.

[21] 10 CFR Part 61; U.S. Nuclear Regulatory Commission, "Low-Level Waste Disposal." https://www.nrc.gov/waste/llw-disposal.html

The NRC is proposing this "interpretive" rule in an attempt to revive the dying nuclear industry – – allowing it to ship large quantities of radioactive waste to unlicensed dump would lower the costs for decommissioning nuclear plants significantly. This reduced cost would be profitable for the industry but would in effect be transferred to the public in terms of health impacts.

NRC is breaching numerous legal and regulatory requirements to push through this massive deregulation of radioactive waste.

Rather than actually changing the regulations, the NRC is claiming to merely reinterpret existing regulations.[22] However, what it is really doing is in effect rescinding the entire 10 CFR 61 regulations specifying safety and licensing requirements for land disposal of radioactive waste.[23] NRC is rescinding those fundamental regulations without following the rulemaking requirements of law.

By misrepresenting this radical change in its regulations as a mere "interpretive change," NRC is bypassing the Administrative Procedure Act.[24] Indeed, NRC is hiding from the public the actual language that it is proposing to adopt.[25] Meaningful comment is impossible when one cannot even see what language is proposed. Furthermore, claims about NRC's "intent" have no binding force if critical terms like "very low-level radioactive waste" are not defined in statute or regulation.

The action is arbitrary and capricious, as NRC had failed to provide a basis for determining that its decades-long existing interpretation of the regulations was wrong.

NRC is also violating the National Environmental Policy Act, by failing to conduct any environmental review of this proposal, one which is clearly a significant federal action that could have major environmental impacts.[26] One notes that EIS's have been required for NRC

[22] NRC, "Transfer of Very Low-Level Waste to Exempt Persons for Disposal," Summary.

[23] 10 CFR Part 61.

[24] Administrative Procedure Act (5 U.S.C. §553. Rule making.)

[25] Under normal circumstances, a proposed rulemaking notice in the Federal Register would include the text of the proposed revised rule, but there is no such language provided here. Furthermore, in its notice, NRC merely says it plans to alter an existing guidance document that requires disposal of licensed radioactive material at a licensed radioactive waste disposal site, but it does not provide the draft new guidance for review and comment, so matters such as how NRC would review such requests are hidden from scrutiny and input. NRC's claims about its current "intent" to in the future limit the scope of the actions proposed to be allowed are meaningless.

[26] The National Environmental Policy Act of 1969, as amended (42 U.S.C. §4321 et seq.) "Section 102 in Title I of the Act requires federal agencies to incorporate environmental considerations in their planning and decision-making through a systematic interdisciplinary approach. Specifically, all federal agencies are to prepare detailed statements assessing the environmental impact of and alternatives to major federal actions significantly affecting the environment. These statements are commonly referred to as Environmental Impact Statements (EIS) and Environmental Assessments (EA)." https://www.epa.gov/nepa/what-national-environmental-policy-act

approvals of individual licensed LLRW disposal sites, which as discussed above, are limited to 25/75/25 millirem doses to the public, whereas this new proposal by NRC would allow multiple unlicensed LLRW disposal sites with doses that are approximately 2.5 times higher — yet without any EIS for the proposal.

Furthermore, the proposal includes no commitment to conduct any environmental review and allow public comment thereon for requests to operate unlicensed radioactive waste disposal sites should the proposal be adopted. The environmental impacts are potentially significantly greater from an unlicensed site allowed to produce 2.5 times more radiation exposure to the public than a licensed site, for which an EIS is required. However, the proposal includes no requirement for an EIS, or indeed, for any environmental review, for granting such authorizations to operate an unlicensed radioactive waste dump.[27]

NRC is also violating the Atomic Energy Act (AEA),[28] which, at its heart, requires licensing of nuclear materials and activities as well as public notice and the right to a hearing over any application for such a license. While very limited exceptions are currently permitted on the margin, here NRC is proposing to exempt most of the arena of radioactive waste disposal, other than spent fuel, from the AEA licensing and hearing requirements.

Finally, the proposed rule envisions these requests to become an unlicensed dump being handled in secret — therefore no right to public notice, no opportunity for adjudicatory hearing, no opportunity to comment on an environmental impact statement or environmental assessment. The public would never know that a local landfill had requested the right to receive large amounts of nuclear waste, exempt from licensing and regulation. The public could not request a hearing; there would be no draft EIS or EA to review and comment on.[29] These matters of great public importance and potential serious risk to public health and environment would be done under cover of darkness. The public would never know, let alone have the right to review, comment on, or request a hearing for a proposal to dump large amounts of radioactive waste in their neighborhood at sites not designed or licensed for radioactive waste. Indeed, under this extraordinary proposal, the public might never even know that radioactive waste was being disposed of in an unlicensed garbage dump, not designed for such wastes, in their own community.

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[27] NRC's guidance for 10 CFR §20.2002 exemptions does not require even Environmental Assessments for all proposals to ship LLRW to unlicensed sites, and if an EA is performed, NRC's guidance is that the EA is not made publicly available for review and comment, and is only made public after the fact, once it has been approved. NRC, GUIDANCE FOR THE REVIEWS OF PROPOSED DISPOSAL PROCEDURES AND TRANSFERS OF RADIOACTIVE MATERIAL UNDER 10 CFR 20.2002 AND 10 CFR 40.13(A), April 2020, pp. 23-25. The current far broader proposal makes no commitment whatsoever regarding NEPA for allowing an unlicensed radioactive waste dump.

[28] Atomic Energy Act of 1946, 42 U.S.C. §2011 et seq.

[29] As indicated above, NRC currently has been waiving disposal requirements on a case by case basis, with either no EA or EIS at all, or if there is an EA, it is made public only after approval, thus preventing public to review or comment before it is adopted. The new proposal contains no requirements whatsoever for environmental review or right of review.

1. NRC WILL HAVE NO CONTINUED OVERSIGHT OR REGULATORY AUTHORITY OVER THE RADIOACTIVE WASTE ONCE IT HAS BEEN TRANSFERRED TO AN EXEMPT FACILITY.

Under the proposed VLLW rule, once NRC grants someone an exemption to dispose of radioactive waste without a license to do so, NRC will have no continued oversight or regulatory authority over the radioactive waste or the facility that receives it.[30]

2. THE RADIOACTIVE WASTE WILL SUPPOSEDLY REMAIN LICENSED, BUT THERE WOULD BE NO LICENSE HOLDER.

Under the proposal, NRC claims the radioactive materials would remain licensed materials. However, *there would be no license holder*—since it was sent to a facility granted an exemption from licensing, they wouldn't be the license holder, and the entity that previously held the license (e.g., a nuclear plant being decommissioned) would also not be the license holder (since decommissioning ends in license termination.) It makes no sense that material could be licensed but no one holds the license to it. Indeed, there would be no license for it.

3. NO ONE WOULD BE RESPONSIBLE FOR OR HAVE AUTHORITY FOR ACTING SHOULD THERE BE LEAKAGE OR OTHER PROBLEMS

If radioactivity from waste transferred to an exempt facility leaks into the environment, as it has at many disposal facilities licensed to receive radioactive waste, under this proposal, unlike for licensed sites, no one would be responsible for or empowered to remedy the situation. NRC would have given up its authority, the facility itself would be exempt from NRC rules, and regulators of Part C and D facilities (if the waste were sent to one) do not have authority over Atomic Energy Act radioactive materials. No one could be held accountable and no one would be responsible to intervene should the waste result in a release to the environment.

The NRC says the waste will go to "regulated" facilities but they are not regulated for radioactive materials**.** Municipal garbage dumps and hazardous waste disposal facilities are regulated, but only as to their garbage or chemical wastes. Sending radioactive wastes to them without requiring them to have a radioactive materials license would be sending them to a facility for which no entity has regulatory authority.

4. POTENTIAL FOR RECYCLING OF CONTAMINATED METALS AND OTHER MATERIALS AND SUCH CONTAMINATED MATERIALS ENTERING COMMERCIAL SUPPLIES

Once the radioactive waste is transferred to an exempt person, it will exist in a regulatory black hole – meaning no entity will be accountable for it. This poses the potential for the waste to be recirculated into the commercial waste stream as recycled material, particularly radioactive metals that could be sold as scrap, but also radioactive tools that could be sold, or contaminated concrete and asphalt that could be recycled. The potential for radioactive metal, for example,

[30] Statement by Chris McKenney. *Official Transcript of Proceedings: "Category 3 Meeting on Draft Interpretive Rule for Very Low-level Waste (VLLW) Disposal Activities,"* March 31, 2020.

enter the consumer metal supply could pose a serious risk to public health, whereby belt buckles, zippers, children's toys, etc. could be made out of metal recycled from radioactive reactor parts.

Furthermore, if the LLW proposal were approved, rescinding decades of NRC interpretation that a license is required to receive radioactive materials, holders of such licensed materials could request exemptions to allow recycling. The changed interpretation, that licenses aren't required to receive such materials, could open the door to such recycling, and widespread exposures to the public from recycled contaminated metals and other materials. NRC's claim that its current "intent" is to only use the exemptions under the reinterpretation for land disposal is non-binding, since the reinterpretation of the requirement for a license to receive radioactive materials would be lifted by this proposal, allowing transfer in the future not just for land disposal but also for recycling. Since disposal costs money but scrap metal can be sold, radioactive recycling would be allowable under this supposed reinterpretation of NRC's long-held prohibition on such unlicensed transfers.

5. THE RADIOACTIVE MATERIALS WOULD HAVE NO REGULATOR—IT WOULD BE IN A REGULATORY LIMBO OR VACUUM.

NRC would have given up its regulatory authority, and regulators of RCRA facilities wouldn't have regulatory authority over the AEA radioactive materials as they aren't covered by RCRA.

6. THE SYNERGISTIC ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS OF COMBINING RADIOACTIVE AND CHEMICAL WASTES OR RADIOACTIVE AND MUNICIPAL WASTES HAVE NOT BEEN MENTIONED, LET ALONE ADDRESSED

a. Mixing radioactive wastes with chemical and/or organic wastes can result in markedly increasing the migration rates for the radioactivity through moisture in soil. Organic complexing agents, or stronger chelating compounds, in chemical and/or municipal wastes can combine with radionuclides to alter the soil retention factor (Kd) and increase the speed by which the radionuclides migrate in the environment. Thus, allowing radioactive waste to be disposed of in dumpsites designed for chemical wastes or regular garbage can cause the radioactivity to travel out of the disposal facility and into the environment far faster than had the materials been isolated in a facility limited to radioactive waste.[31]

b. Disposing of radioactive waste in a dumpsite containing regular garbage can result in fires and/or explosions that can release radioactivity into the air. Regular garbage dumps contain large amounts of organic material which, as it decomposes, releases methane, which can burn or explode. They also contain substantial amounts of organic materials that can catch fire. For example, nuclear wastes from the Manhattan Project were inappropriately disposed of in the Westlake, Missouri, regular municipal dump, now a Superfund site. Portions of the garbage dump caught fire a decade ago, and a subsurface fire has continued now for years, advancing toward the radioactive waste.[32]

[31] "Chelation and Kd Values: The Effect on Radionuclide Migration," in Southern California Federation of Scientists & Committee to Bridge the Gap, *The Proposed Ward Valley Radioactive Waste Facility: Papers Submitted to the National Academy of Sciences,* October 12, 1994

[32] Robert Alvarez, "West Lake story: An underground fire, radioactive waste, and governmental failure,' *The Bulletin of the Atomic Scientists,* February 11, 2016

7. RISK OF BECOMING THE WORLD'S DUMPING GROUND FOR RADIOACTIVE WASTE

The VLW proposal would result in unlicensed landfills being able to take any radioactive waste for which it has received an exemption by the NRC, with NRC no longer exercising any control over such shipments. Nothing would prevent such dumpsites from attracting such radioactive wastes from other countries, because the disposal cost would be vastly lower than in a licensed site in their own country, and NRC would have given up its regulatory authority over disposals at such unlicensed sites.

8. NOTHING IN THE PROPOSAL WOULD LIMIT RADIOACTIVE WASTE DISPOSAL TO PART C AND D LANDFILLS. IT COULD GO VIRTUALLY ANYWHERE

The NRC's proposed "reinterpretation" of its regulations to allow transfer of licensed radioactive wastes to unlicensed persons would allow NRC to exempt not just Part C and D landfills but would permit unlicensed transfer of such wastes to potentially anyone with some vacant land that they wanted to make some money from, e.g. it could go to a vacant lot next to a school, to It is breathtaking in its scope.

9. VIOLATES NEPA BOTH IN PROMULGATION OF THE RULE AND IN CARRYING IT OUT

No EIS has been performed of the environmental impacts of the proposed rule. Similarly, no EIS appears contemplated under the proposal for approving any requests to be exempted from radioactive waste disposal licensing requirements. Both deficiencies violate NEPA.

Conclusion

NRC's proposal to deregulate a large fraction—perhaps almost all—radioactive waste other than irradiated nuclear fuel is fraught with peril and would violate numerous laws. NRC should reverse course and strengthen, rather than weaken, protections of the public and environment from radioactive waste.

Sincerely,

Jeff Ruch
Pacific Director

PEER NRC VLLW Comment Exhibit List

1. National Academies of Sciences, Engineering, and Medicine 2017. Low-Level Radioactive Waste Management and Disposition: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/24715

2. National Institutes of Health, Fact Sheet: http://www.nlm.nih.gov/medlineplus/radiationexposure.html (last visited July 18, 2020).

3. Environmental Radiation Protection Standards for Yucca Mountain, Nevada, 64 Fed. Reg. 46,976, 46,978 (Aug. 27, 1999).

4. Southern California Federation of Scientists and the Committee to Bridge the Gap, "The Proposed Ward Valley Radioactive Waste Facility: Papers Submitted to the National Academy of Sciences," October 12, 1994.

5. National Low-Level Waste Management Program, Environmental Monitoring Report for Commercial Low-Level Radioactive Waste Disposal Sites (1960's Through Early 1990's), DOE/LLW-241, November 1996.

6. Joe Costanzo, "Envirocare prosecutors place focus on extortion," Deseret News, July 23, 1998. https://www.deseret.com/1998/7/23/19392670/envirocare-prosecutors-place-focus-on-extortion.

7. National Research Council/National Academy of Sciences, The Disposition Dilemma: Controlling the Release of Solid Materials from Nuclear Regulatory Commission-Licensed Facilities, 2002.

8. The Energy Policy Act Of 1992. "Revocation Of Related NRC Policy Statements." The policy statements of the Nuclear Regulatory Commission published in the Federal Register on July 3, 1990 (55 Fed. Reg. 27522) and August 29, 1986 (51 Fed. Reg. 30839)

9. SECY-02-0133, Control of Solid Materials: Options and Recommendations for Proceeding, October 25, 2002. https://www.nrc.gov/docs/ML0214/ML021480494.pdf

10. Rulemaking on Controlling the Disposition of Solid Materials: Scoping Process for Environmental Issues and Notice of Workshop, 68 Fed. Reg. 9595 – 9602, February 28, 2003

11. SECY-05-0054, Proposed Rule: Radiological Criteria for Controlling the Disposition of Solid Materials, March 31, 2005. https://www.nrc.gov/docs/ML0507/ML050750495.pdf

12. Letter to NRC Commissioners from 120 organizations, March 31, 2005, Re: Opposition to Proceeding with Rulemaking on the Release of Currently Regulated Radioactive Waste and Materials to Unlicensed Destinations ("Controlling the Disposition of Solid Materials.")

13. Commission Voting Record, June 1, 2005, Disapproving Proposed Rulemaking, "Radiological Criteria for Controlling the Disposition of Solid Materials."

14. NRC, Scoping Study on "Very Low Level Waste." February 22, 2018, ML18040B304. https://adamswebsearch2.nrc.gov/webSearch2/view?AccessionNumber=ML18040B304

15. NRC, Official Transcript of Proceedings, "Very Low-level Radioactive Waste Scoping Study and Greater than Class C Waste Public Meeting," February 22, 2018, ML18068A075. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18068A075

16. NIRS, Comments on VLLW Scoping Study, NRC-2018-0026-0001, May 15, 2018.

17. D'Arrigo Powerpoint presentation "VLLW Radioactive Waste Equals Very Large Loophole Waste" delivered at NRC Regulatory Information Conference, March 13, 2018.

18. Email from Marlayna Doell, Decommissioning Project Manager, NMSS/DUWP/LLWPB at NRC to Diane D'Arrigo, Radioactive Waste Project Director at the Nuclear Information and Resource Service, June 9, 2020.

19. U.S. NRC, "Waste classification (classes of waste)," "Page Last Reviewed/Updated Tuesday, June 30, 2020." https://www.nrc.gov/reading-rm/basic-ref/glossary/waste-classification-classes-of-waste.html

20. Energy Solutions, Utah Clean Transfer Cell Permit Application, April 10, 2020.

21. Statement by Chris McKenney. Branch Chief for the Risk and Technical Analysis Branch, Division of Decommissioning, Uranium Recovery, and Waste Programs, Official Transcript of Proceedings: "Category 3 Meeting on Draft Interpretive Rule for Very Low-level Waste (VLLW) Disposal Activities," March 30, 2020, ML20112F441. https://www.nrc.gov/docs/ML2011/ML20112F441.pdf

22. USNRC Management Directive 5.9, Adequacy and Compatibility of Program Elements for Agreement State Programs, ML18081A070, April 26, 2018. https://www.nrc.gov/docs/ML1808/ML18081A070.pdf

23. Electronic mail exchange between NRC's Marlayna Doell and CBG's Daniel Hirsch, March 29, April 7, and April 8, 2020.

24. **A.** Email from Patricia K. Holahan, Ph.D. Director, Division of Decommissioning, Uranium Recovery, and Waste Programs to Diane D'Arrigo, Radioactive Waste Project Director, June 12th, 2020, and attachment thereto: "10 CFR 20.2002 Alternative Disposal Requests Received by the NRC since 2005."
B. 10 CFR 20.2002 Alternative Disposal Requests Received by the NRC since 2005.

25. WESTINGHOUSE ELECTRIC COMPANY LLC, "Copy of Letter from L. Camper to J. Weismann approving use of USEI SSDA for 10 CFR 20.2002 Alternate Disposal Authorization Requests," August 24, 2015, p. 2, ML15125A364. https://adamswebsearch2.nrc.gov/webSearch2/view

26. US NRC, "Guidance for the Reviews of Proposed Disposal Procedures and Transfers of Radioactive Material Under 10 CFR 20.2002 and 10 CFR 40.13(a)," ML18296A068, April 2020. https://www.nrc.gov/docs/ML1829/ML18296A068.pdf

27. Letter from EPA Administrator Carol Browner to NRC Chair Shirley Jackson, February 7, 1997

COVID-19 is an emerging, rapidly evolving situation.

x

Get the latest public health information from CDC:
https://www.coronavirus.gov
Get the latest research information from NIH: https://www.nih.gov/coronavirus

URL of this page: https://medlineplus.gov/radiationexposure.html

Radiation Exposure

What is radiation?

Radiation is energy. It travels in the form of energy waves or high-speed particles. Radiation can occur naturally or be man-made. There are two types:

- **Non-ionizing radiation,** which includes radio waves, cell phones, microwaves, infrared radiation and visible light
- **Ionizing radiation,** which includes ultraviolet radiation, radon [https://medlineplus.gov/radon.html] , x-rays [https://medlineplus.gov/xrays.html] , and gamma rays

What are the sources of radiation exposure?

Background radiation is all around us all the time. Most of it forms naturally from minerals. These radioactive minerals are in the ground, soil, water, and even our bodies. Background radiation can also come from outer space and the sun. Other sources are man-made, such as x-rays, radiation therapy [https://medlineplus.gov/radiationtherapy.html] to treat cancer, and electrical power lines.

What are the health effects of radiation exposure?

Radiation has been around us throughout our evolution. So our bodies are designed to deal with the low levels we're exposed to every day. But too much radiation can damage tissues by changing cell structure and damaging DNA. This can cause serious health problems, including cancer.

The amount of damage that exposure to radiation can cause depends on several factors, including

- The type of radiation
- The dose (amount) of radiation
- How you were exposed, such as through skin contact, swallowing or breathing it in, or having rays pass through your body
- Where the radiation concentrates in the body and how long it stays there
- How sensitive your body is to radiation. A fetus is most vulnerable to the effects of radiation. Infants, children, older adults, pregnant women, and people with compromised immune systems are more vulnerable to health effects than healthy adults.

Being exposed to a lot of radiation over a short period of time, such as from a radiation emergency [https://medlineplus.gov/radiationemergencies.html] , can cause skin burns [https://medlineplus.gov/burns.html] . It may also lead to acute radiation syndrome (ARS, or "radiation sickness"). The symptoms of ARS include headache and diarrhea. They usually start within hours. Those symptoms will go away and the person will seem healthy for a little while. But then they will get sick again. How soon they get sick again, which symptoms they have, and how sick they get depends on the amount of radiation they received. In some cases, ARS causes death in the following days or weeks.

Exposure to low levels of radiation in the environment does not cause immediate health effects. But it can slightly increase your overall risk of cancer.

What are the treatments for acute radiation sickness?

Before they start treatment, health care professionals need to figure out how much radiation your body absorbed. They will ask about your symptoms, do blood tests, and may use a device that measures radiation. They also try get more information about the exposure, such as what type of radiation it was, how far away you were from the source of the radiation, and how long you were exposed.

Treatment focuses on reducing and treating infections, preventing dehydration [https://medlineplus.gov/dehydration.html] , and treating injuries and burns. Some people may need treatments that help the bone marrow [https://medlineplus.gov/bonemarrowdiseases.html] recover its function. If you were exposed to certain types of radiation, your provider may give you a treatment that limits or removes the contamination that is inside your body. You may also get treatments for your symptoms.

How can radiation exposure be prevented?

There are steps you can take to prevent or reduce radiation exposure:

- If your health care provider recommends a test that uses radiation, ask about its risks and benefits. In some cases, you may be able to have a different test that does not use radiation. But if you do need a test that uses radiation, do some research into the local imaging facilities. Find one that monitors and uses techniques to reduce the doses they are giving patients.
- Reduce electromagnetic radiation [https://medlineplus.gov/electromagneticfields.html] exposure from your cell phone. At this time, scientific evidence has not found a link between cell phone use and health problems in humans. More research is needed to be sure. But if you still have concerns, you can reduce how much time you spend on your phone. You can also use speaker mode or a headset to place more distance between your head and the cell phone.
- If you live in a house, test the radon levels, and if you need to, get a radon reduction system.
- During a radiation emergency, get inside a building to take shelter. Stay inside, with all of the windows and doors shut. Stay tuned to and follow the advice of emergency responders and officials.

Environmental Protection Agency

Start Here

- Contamination vs. Exposure [https://emergency.cdc.gov/radiation/contamination.asp]
  (Centers for Disease Control and Prevention)
  Also in Spanish [https://emergency.cdc.gov/es/radiation/healtheffects.asp]

- Does the Product Emit Radiation? [https://www.fda.gov/medical-devices/classify-your-medical-device/does-product-emit-radiation]
  (Food and Drug Administration)

- Get the Facts about Radiation [https://newsinhealth.nih.gov/2012/10/looking-inside] NIH (National Institutes of Health)

- Radiation Basics [https://www.epa.gov/radiation/radiation-basics]
  (Environmental Protection Agency) - PDF

Prevention and Risk Factors

- Radiation Protection [https://www.epa.gov/radiation]
  (Environmental Protection Agency)

Treatments and Therapies

- DTPA (Diethylenetriamine pentaacetate) [https://emergency.cdc.gov/radiation/dtpa.asp]
  (Centers for Disease Control and Prevention)
  Also in Spanish [https://emergency.cdc.gov/es/radiation/dtpa.asp]

- Filgrastim (Neupogen) [https://www.cdc.gov/nceh/radiation/emergencies/neupogenfacts.htm]
  (Centers for Disease Control and Prevention)
  Also in Spanish [https://emergency.cdc.gov/es/radiation/neupogenfacts.asp]

- Frequently Asked Questions on Potassium Iodide (KI) [https://www.fda.gov/drugs/bioterrorism-and-drug-preparedness/frequently-asked-questions-potassium-iodide-ki] (Food and Drug Administration)

- Potassium Iodide ("KI"): Instructions to Make Potassium Iodide Solution for Use During a Nuclear Emergency (Liquid Form) [https://www.fda.gov/drugs/bioterrorism-and-drug-preparedness/potassium-iodide-ki] (Food and Drug Administration)

- Potassium Iodide (KI) [https://emergency.cdc.gov/radiation/ki.asp]
  (Centers for Disease Control and Prevention)

Also in Spanish [https://emergency.cdc.gov/es/radiation/ki.asp]

- Prussian Blue [https://www.cdc.gov/nceh/radiation/emergencies/prussianblue.htm] (Centers for Disease Control and Prevention)
  Also in Spanish [https://emergency.cdc.gov/es/radiation/prussianblue.asp]

Related Issues

- Airport Screening [http://hps.org/documents/airport_screening_fact_sheet.pdf] (Health Physics Society) - **PDF**
- Food Irradiation: What You Need to Know [https://www.fda.gov/food/buy-store-serve-safe-food/food-irradiation-what-you-need-know] (Food and Drug Administration)
  Also in Spanish [https://www.fda.gov/food/buy-store-serve-safe-food/la-irradiacion-de-alimentos-lo-que-usted-debe-saber]
- Non-Medical Sources of Man-Made Radiation [https://www.cancer.org/cancer/cancer-causes/radiation-exposure/x-rays-gamma-rays/other-man-made-sources.html] (American Cancer Society)
- Nuclear Radiation and the Thyroid [https://www.thyroid.org/wp-content/uploads/patients/brochures/NuclearRadiation_brochure.pdf] (American Thyroid Association) - **PDF**
  Also in Spanish [https://www.thyroid.org/wp-content/uploads/patients/brochures/espanol/radiacion_nuclear_y_la_glandula_tiroides.pdf]
- Sun and Other Types of Radiation [https://www.cancer.org/cancer/cancer-causes/radiation-exposure.html] (American Cancer Society)
  Also in Spanish [https://www.cancer.org/es/cancer/causas-del-cancer/sol-y-otras-formas-de-radiacion.html]

Specifics

- Accidents at Nuclear Power Plants and Cancer Risk [https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/nuclear-accidents-fact-sheet] NIH (National Cancer Institute)
  Also in Spanish [https://www.cancer.gov/espanol/cancer/causas-prevencion/riesgo/radiacion/hoja-informativa-accidentes-plantas-nucleares]
- Acute Radiation Syndrome [https://emergency.cdc.gov/radiation/ars.asp] (Centers for Disease Control and Prevention)
  Also in Spanish [https://emergency.cdc.gov/es/radiation/ars.asp]

- Cell Phones and Cancer Risk [https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/cell-phones-fact-sheet] NIH (National Cancer Institute)
  Also in Spanish [https://www.cancer.gov/espanol/cancer/causas-prevencion/riesgo/radiacion/hoja-informativa-telefonos-celulares]
- Consumer Products Containing Radioactive Materials [http://hps.org/documents/consumerproducts.pdf] (Health Physics Society) - **PDF**
- Frequently Asked Questions about Cell Phones and Your Health [https://www.cdc.gov/nceh/radiation/cell_phones._FAQ.html] (Centers for Disease Control and Prevention)
- Non-Ionizing Radiation Used in Microwave Ovens [https://www.epa.gov/radtown/non-ionizing-radiation-used-microwave-ovens] (Environmental Protection Agency)
- Radiation Exposure from Medical Exams and Procedures [http://hps.org/documents/Medical_Exposures_Fact_Sheet.pdf] (Health Physics Society) - **PDF**
- Radiation Exposure in X-Ray and CT Examinations [https://www.radiologyinfo.org/en/info.cfm?pg=safety-xray] (American College of Radiology, Radiological Society of North America)
  Also in Spanish [https://www.radiologyinfo.org/sp/info.cfm?pg=safety-xray]
- Radiation from Cardiac Imaging Tests [https://www.ahajournals.org/doi/10.1161/CIRCULATIONAHA.112.146043] (American Heart Association)
- Radionuclide Basics: Iodine [https://www.epa.gov/radiation/radionuclide-basics-iodine] (Environmental Protection Agency)
- Radionuclide Basics: Plutonium [https://www.epa.gov/radiation/radionuclide-basics-plutonium] (Environmental Protection Agency)
- TENORM (Technologically Enhanced Naturally Occurring Radioactive Materials) [https://www.epa.gov/radiation/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm] (Environmental Protection Agency, Office of Air and Radiation)

Clinical Trials

- ClinicalTrials.gov: Radiation Exposure [https://clinicaltrials.gov/search/open/condition=%22Radiation+Exposure%22] NIH (National Institutes of Health)

Journal Articles

References and abstracts from MEDLINE/PubMed (National Library of Medicine)

- Article: Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses. [https://www.ncbi.nlm.nih.gov/pubmed/32581288]
- Article: Ultraviolet Germicidal Irradiation to Decontaminate Filtering Face Piece Respirators During COVID-19... [https://www.ncbi.nlm.nih.gov/pubmed/32579801]
- Article: Pathogen reduction of SARS-CoV-2 virus in plasma and whole blood using... [https://www.ncbi.nlm.nih.gov/pubmed/32470046]
- Radiation Exposure -- see more articles [https://pubmed.ncbi.nlm.nih.gov/?term=radiation,ionizing[majr]+NOT+(X-rays[majr]+OR+food+irradiation[mh]+OR+radiotherapy[mh])+AND+english[la]+AND+humans+[mh]+NOT+(letter[pt]+OR+editorial[pt]+OR+case+reports[pt]+OR+comment[pt])+AND+%22last+1+Year%22[edat]]
- Radiation pollution -- see more articles [https://pubmed.ncbi.nlm.nih.gov/?term=radioactive+pollutants[majr]+NOT+radon[mh]+AND+english[la]+AND+humans[mh]+NOT+(letter[pt]+OR+editorial[pt]+OR+comment[pt])+AND+%22last+1+Year%22[edat]]

Find an Expert

- Centers for Disease Control and Prevention [https://www.cdc.gov/]
  Also in Spanish [https://www.cdc.gov/spanish/]
- National Center for Environmental Health [https://www.cdc.gov/nceh/]
  (Centers for Disease Control and Prevention)
- National Institute of Environmental Health Sciences [https://www.niehs.nih.gov/]
  NIH
  Also in Spanish [https://www.niehs.nih.gov/health/scied/teachers/educacion/]

Children

- What Parents Should Know about Medical Radiation Safety [https://www.imagegently.org/Portals/6/Parents/Image_Gently_8.5x11_Brochure.pdf] (Alliance for Radiation Safety in Pediatric Imaging) - **PDF**
- What You Should Know About Pediatric Nuclear Medicine and Radiation Safety

[https://www.imagegently.org/Portals/6/Nuclear%20Medicine/Parent%20Brochure%208th%20Grade.pdf] (Alliance for Radiation Safety in Pediatric Imaging) - PDF

Teenagers

- RadTown USA: Basic Information [https://www.epa.gov/radtown] (Environmental Protection Agency)

Women

- X-Rays, Pregnancy and You [https://www.fda.gov/radiation-emitting-products/medical-x-ray-imaging/x-rays-pregnancy-and-you] (Food and Drug Administration)

Patient Handouts

- Radiation sickness [https://medlineplus.gov/ency/article/000026.htm] (Medical Encyclopedia)
  Also in Spanish [https://medlineplus.gov/spanish/ency/article/000026.htm]

MEDICAL ENCYCLOPEDIA

Hyperbaric oxygen therapy [https://medlineplus.gov/ency/article/002375.htm]

Radiation sickness [https://medlineplus.gov/ency/article/000026.htm]

Related Health Topics

Electromagnetic Fields [https://medlineplus.gov/electromagneticfields.html]

Radiation Emergencies [https://medlineplus.gov/radiationemergencies.html]

Radiation Therapy [https://medlineplus.gov/radiationtherapy.html]

Radon [https://medlineplus.gov/radon.html]

Sun Exposure [https://medlineplus.gov/sunexposure.html]

National Institutes of Health

The primary NIH organization for research on *Radiation Exposure* is the National Institute of Environmental Health Sciences [http://www.niehs.nih.gov/]

Other Languages

Find health information in languages other than English [https://medlineplus.gov/languages/radiationexposure.html] on *Radiation Exposure*

Was this page helpful?

Yes No

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 197

[FRL–6427–5]

RIN 2060–AG14

Environmental Radiation Protection Standards for Yucca Mountain, Nevada

AGENCY: Environmental Protection Agency.

ACTION: Proposed rule.

SUMMARY: We, the Environmental Protection Agency (EPA), are proposing public health and safety standards for radioactive material stored or disposed of in the potential repository at Yucca Mountain, Nevada. Section 801 of the Energy Policy Act of 1992 (EnPA) directed the Administrator of EPA to develop these standards. The EnPA also required EPA to contract with the National Academy of Sciences (NAS) to conduct a study to provide findings and recommendations on reasonable standards for protection of the public health and safety. On August 1, 1995, NAS released its report (the NAS Report) entitled, "Technical Bases for Yucca Mountain Standards." We have taken the NAS Report into consideration as directed by the EnPA.

After we finalize these standards, the Nuclear Regulatory Commission (NRC or "the Commission") will incorporate them into its licensing regulations. The Department of Energy (DOE or "the Department") will be responsible for demonstrating compliance with these standards. The Commission will use its licensing regulations to determine whether the Department has demonstrated compliance with our standards prior to receiving the necessary licenses to store or dispose of radioactive material in Yucca Mountain.

DATES: *Comments.* We must receive your comments at the address given below on or before November 26, 1999 to assure their consideration.

Hearings. We will hold public hearings upon today's action in Amargosa Valley, Nevada, Las Vegas, Nevada, and Washington, DC. The dates will be announced in the **Federal Register** as soon as they are determined.

ADDRESSES: *Comments.* Send two copies of your comments to the Central Docket Section (6102), ATTN: Docket A–95–12, U.S. Environmental Protection Agency, 401 M Street, SW, Washington, D.C. 20460–0001.

Documents relevant to the rulemaking. Materials relevant to this rulemaking are contained in: (1) Docket No. A–95–12, located in Room M–1500 (first floor in Waterside Mall near the Washington Information Center), U.S. Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460–0001; (2) an information file in the Government Publications Section, Dickinson Library, University of Nevada-Las Vegas, 4504 Maryland Parkway, Las Vegas, Nevada 89154; and (3) an information file in the Public Library in Amargosa Valley, Nevada 89020.

Background documents for this action. We have prepared additional documents that provide more detailed technical background in support of these proposed standards. You may obtain copies of the draft background information document (BID), the draft economic impact evaluation, and the Executive Summary of the NAS Report by requesting them in writing from the Office of Radiation and Indoor Air (6602J), U.S. Environmental Protection Agency, Washington, DC 20460–0001. We have also placed these documents into the docket and information files. You may also find them on our Internet site for Yucca Mountain (see the *Additional Docket and Electronic Information* section later in this notice).

FOR FURTHER INFORMATION CONTACT: Ray Clark, Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, Washington, D.C. 20460–0001; telephone 202–564–9300.

SUPPLEMENTARY INFORMATION:

Who Will Be Regulated by These Standards?

The Department is the only entity directly regulated by these standards. To utilize the Yucca Mountain repository, DOE must obtain licensing approval from NRC. Thus, DOE will be subject to our standards which NRC will implement through its licensing proceedings. The NRC is only affected because, under the Energy Policy Act of 1992 (EnPA, Pub. L. 102–486), it must modify its licensing requirements, as necessary, to be consistent with our final standards.

Additional Docket and Electronic Information

When may I examine docket information? You may inspect the Washington, D.C. docket (phone 202–260–7548) on weekdays (8 a.m.–5:30 p.m.). As provided in 40 CFR part 2, the docket personnel may charge a reasonable fee for photocopying docket materials.

The information file located in the University of Nevada-Las Vegas, Government Publications Section (702–895–3409) may be inspected when classes are in session, Monday through Thursday (9 a.m.–8 p.m.), Friday (9 a.m.–6 p.m.), Saturday (9 a.m.–9 p.m.), and Sunday (11 a.m.–8 p.m.). However, since the hours vary based upon the academic calendar, you should call ahead to be certain of the time.

The information file in the Public Library in Amargosa Valley, Nevada (phone 775–372–5340) may be inspected Monday through Thursday (11 a.m.–7 p.m.) and Friday (9 a.m.–5 p.m.). The library is closed from 12:30 p.m.–1 p.m. each day. It is also closed Saturday and Sunday.

Can information be accessed by telephone or the Internet? Yes, we have established a toll-free information line that is accessible 24 hours per day. By dialing 800–331–9477, you can listen to a brief update describing our rulemaking activities for Yucca Mountain, leave a message requesting that your name and address be added to the Yucca Mountain mailing list, or request that an EPA staff person return your call. You can also find information on the World Wide Web at http://www.epa.gov/radiation/yucca.

Acronyms

There are many acronyms used in this notice. They are listed below for your reference and convenience.

ALARA—as low as reasonably achievable
BID—background information document
CAA—Clean Air Act
CEDE—committed effective dose equivalent
CG—critical group
DOE—U.S. Department of Energy
EIS—environmental impact statement
EnPA—Energy Policy Act of 1992
EPA—U.S. Environmental Protection Agency
GCD—greater confinement disposal
HLW—high-level radioactive waste
IAEA—International Atomic Energy Agency
ICRP—International Commission on Radiological Protection
LLW—low-level radioactive waste
MCL—maximum contaminant level
MCLG—maximum contaminant level goal
NAS—National Academy of Sciences
NCRP—National Council on Radiation Protection and Measurements
NEPA—National Environmental Policy Act
NESHAPs—National Emission Standards for Hazardous Air Pollutants
NID—negligible incremental dose
NIR—negligible incremental risk
NRC—U.S. Nuclear Regulatory Commission

NRDC—Natural Resources Defense Council
NTS—Nevada Test Site
NTTAA—National Technology Transfer and Advancement Act
NWPA—Nuclear Waste Policy Act of 1982
NWPAA—Nuclear Waste Policy Amendments Act of 1987
OMB—Office of Management and Budget
RCRA—Resource Conservation and Recovery Act
RME—reasonable maximum exposure
RMEI—reasonably maximally exposed individual
SDWA—Safe Drinking Water Act
SNF—spent nuclear fuel
TDS—total dissolved solids
UIC—underground injection control
UMRA—Unfunded Mandates Reform Act of 1995
USDW—underground source of drinking water
WIPP LWA—Waste Isolation Pilot Plant Land Withdrawal Act of 1992

Outline of Proposed Action

I. What Led up to Today's Action?

Spent nuclear fuel (SNF) and high-level radioactive waste (HLW) have been produced since the 1940s, mainly as a result of commercial power production and defense activities. Since then, the proper disposal of these wastes has been the responsibility of the Federal government. The Nuclear Waste Policy Act of 1982 (NWPA, Pub. L. 97–425) formalized the current Federal program for the disposal of SNF and HLW by:

(1) Making DOE responsible for siting, building, and operating an underground geologic repository for the disposal of SNF and HLW;

(2) Directing us to set generally applicable environmental radiation protection standards based upon authority established under other laws; and

(3) Requiring NRC to implement our standards by incorporating them into its licensing requirements for SNF and HLW repositories.

Those responsibilities are generally maintained under the EnPA. Thus, NRC will implement the standards that we are proposing today, and DOE will submit a license application to NRC. The Commission will then determine whether DOE has met the standards and whether to issue an operating license for Yucca Mountain. We anticipate that NRC will require compliance with all of the applicable provisions of 40 CFR part 197 prior to allowing receipt of radioactive material onto the Yucca Mountain site.

In 1985, we established generic standards for the management, storage, and disposal of SNF, HLW, and transuranic radioactive waste. These standards are found in 40 CFR part 191 (50 FR 38066, September 19, 1985). The term "generic" meant that the standards applied to any applicable facilities in the United States, including Yucca Mountain, Nevada. In 1987, the U.S. Court of Appeals for the First Circuit invalidated the disposal standards and remanded them to us (*NRDC* v. *EPA*, 824 F.2d 1258 (1st Cir. 1987)). Also in 1987, the Nuclear Waste Policy Amendments Act (NWPAA, Pub. L. 100–203) amended the NWPA by, among other actions, selecting Yucca Mountain, Nevada as the only potential site to be characterized.

In October 1992, the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA, Pub. L. 102–579) and the EnPA became law. The statutes changed our obligations concerning certain radiation standards. The WIPP LWA:

(1) Reinstated the 40 CFR part 191 disposal standards except those that were the specific subject of the remand by the First Circuit;

(2) Required us to issue standards to replace those that were the subject of judicial remand; and

(3) Exempted the Yucca Mountain site from the 40 CFR part 191 disposal standards. We issued the final disposal standards in 40 CFR part 191 on December 20, 1993 (58 FR 66398) to address the judicial remand.

The EnPA gave us the responsibility to set public health and safety radiation standards for Yucca Mountain. Specifically, section 801(a)(1) of the EnPA directed us to "promulgate, by rule, public health and safety standards for the protection of the public from releases from radioactive materials stored or disposed of in the repository at the Yucca Mountain site." The EnPA also directed us to contract with NAS to give us findings and recommendations on reasonable standards for protection of public health and safety. Moreover, the statute provided that our standards shall be the only such standards applicable to the Yucca Mountain site and are to be based upon and consistent with NAS' findings and recommendations. On August 1, 1995, NAS released its report, "Technical Bases for Yucca Mountain Standards" (the NAS Report).

II. Background Information

II.A. What Are the Sources of Radioactive Waste?

Radioactive wastes are the result of using nuclear fuel and other radioactive material. Today's action proposes standards pertaining to SNF, HLW, and other radioactive waste (these are collectively referred to after this as "radioactive material" or "waste") which may be stored or disposed of in the Yucca Mountain repository. (When storage or disposal are discussed in this notice in reference to Yucca Mountain, it is to be understood that no decision has been made regarding the acceptability of Yucca Mountain for storage or disposal. To save space and excessive repetition, the description of Yucca Mountain as a "potential" repository will not be used but is intended.) These standards do not apply to facilities other than those related to Yucca Mountain.

Once enough uranium or other fissionable material in nuclear reactor fuel has been consumed through nuclear reactions, it is no longer useful. The product is known as "spent" nuclear fuel (SNF). Sources of SNF include:

(1) Commercial nuclear power plants;

(2) Government-sponsored research and development programs in universities and industry;

(3) Experimental reactors, such as, liquid metal fast breeder reactors and high-temperature gas-cooled reactors;

(4) Federal Government-controlled, nuclear-weapons production reactors;

(5) Naval and other Department of Defense reactors; and

(6) U.S.-owned, foreign SNF.

Spent nuclear fuel can be dissolved in a chemical process called "reprocessing," which is used to recover desired radionuclides. Radionuclides which are not recovered become part of the acidic liquid wastes that DOE plans to convert into various types of solid materials. The highly radioactive liquid or solid wastes from reprocessing SNF are called HLW. If SNF is not reprocessed prior to disposal, it becomes the waste form without further modification. The only commercial reprocessing facility to operate in the United States, the Nuclear Fuel Services Plant in West Valley, New York, closed in 1972. Since that time, no commercial SNF has been reprocessed in the United States. In 1992, DOE decided to phase out reprocessing of its SNF which supported the defense nuclear weapons and propulsion programs.

Where are the wastes stored now? Today, most SNF is stored in water pools or above-ground in dry concrete or steel canisters at more than 70 commercial nuclear-power reactor sites across the Nation. High-level waste is stored underground in steel tanks at four Federal facilities in Idaho, Washington, South Carolina, and New York.

What types of wastes will be placed into Yucca Mountain? We anticipate that most of the waste in Yucca Mountain will be SNF and solidified HLW (in the rest of this notice, HLW will refer to solidified HLW unless otherwise noted). Under current NRC regulations (10 CFR 60.135), liquid HLW will have to be solidified, through processes such as vitrification (mixing the waste into glass), since non-solid waste forms would not be allowed to be stored or disposed of in Yucca Mountain. The Department estimates that by the year 2010, about 64,000 metric tons of SNF and 284,000 cubic meters (containing 450 million curies of radioactivity) of HLW in predisposal form and 2,600 cubic meters (containing 189 million curies) of the disposable form of HLW will be in storage (DOE/RW–0006, Rev. 12, December 1996).

We are aware that other radioactive materials might be stored or disposed of in the Yucca Mountain repository. These materials include highly radioactive low-level waste (LLW), known as greater-than-Class-C waste, and excess plutonium or other fissile materials resulting from the dismantlement of nuclear weapons. In the future, other types of radioactive materials could be identified for storage or disposal. Since the plans for the disposal of these materials have not been finalized, their impact upon the design and performance of the disposal system has not been analyzed by NRC or DOE. However, whatever types of radioactive materials are finally disposed of in Yucca Mountain, the disposal system must comply with these standards.

II.B. What Types of Health Effects Can Radiation Cause?

Ionizing radiation can cause a variety of health effects. These effects are classified as either "non-stochastic" or "stochastic." Non-stochastic effects are those for which the damage increases with increasing exposure, such as destruction of cells or reddening of the skin. They are seen in cases of exposures to large amounts of radiation. Stochastic effects are associated with long-term exposure to low levels of radiation. Their type or severity does not depend upon the amount of exposure. Instead, the chance that an effect, for example, cancer, will occur is assumed to increase with increasing exposure.

The three categories of stochastic effects are cancer, mutations, and teratogenic effects. Cancers caused by radiation are indistinguishable from those occurring from other causes. Cancers caused by radiation have been observed in humans. However, the risk of cancer at the exposure levels normally encountered by members of the public must be estimated using indirect evidence, that is, extrapolation from higher doses.[1]

Mutations, the second category of stochastic effects, are created in the reproductive cells of exposed individuals and are transmitted to their descendants. The severity of hereditary effects can range from inconsequential to fatal. Although hereditary effects have been observed in animal studies at relatively high doses, hereditary effects in humans exposed to relatively small amounts of radiation have not been confirmed statistically in epidemiological studies. Finally, we assume that at low levels of exposure, the probability of incurring either cancer or hereditary effects increases as the dose increases and that there is no lower threshold, that is, a linear, non-threshold, dose-response relationship (this is discussed below in more detail).

Teratogenic effects, the third category of stochastic effects, can occur following exposure of fetuses. We believe that the fetus is more sensitive than adults to the induction of cancer by radiation. The fetus also is subject to various radiation-induced, physical malformations such as small brain size (microencephaly), small head size (microcephaly), eye malformations and slow growth prior to birth. Recent studies have focused upon the apparently increased risk of severe mental retardation as measured by the intelligence quotient. These studies indicate that the sensitivity of the fetus is greatest during 8 to 15 weeks following conception, and continues, at a lower level, between 16 and 25 weeks.[2] Although we do not know exactly how mental retardation is related to dose, it is prudent to assume that there is a linear, non-threshold, dose-response relationship between these effects and the dose delivered to the fetus during the 8- to 15-week period.

The NAS published its reviews of human health risks from exposure to low levels of ionizing radiation in a

[1] The general term "dose" is used to mean the dose equivalent, effective dose equivalent, or committed effective dose equivalent, depending upon the surrounding text. When precision is necessary, the exact term is used.

[2] *Health Effects of Exposure to Low Levels of Ionizing Radiation*, National Academy Press, Washington, D.C., 1990.

series of reports between 1972 and 1990. However, scientists still do not agree upon how best to estimate the probability of cancer occurring as a result of the doses encountered by members of the public[3] because these effects must be estimated based upon the effects observed at higher doses (such as effects seen in the survivors of the Hiroshima and Nagasaki atomic bombs). The linear model for estimating effects has been endorsed by many organizations, including NAS, the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation, and the National Radiological Protection Board of the United Kingdom.

Over the past decade, the scientific community has performed an extensive reevaluation of the doses and effects in the Hiroshima and Nagasaki survivors. These studies have resulted in increased estimates (roughly threefold between 1972 and 1990) of the extrapolated risk of cancer arising from exposure to environmental levels of radiation, that is, background levels of radiation. Nonetheless, the estimated number of health effects induced by small incremental doses of radiation above natural background levels remains small compared with the total number of fatal cancers that occur from other causes. In addition, because cancers are the same as those resulting from other causes, identifying them in human epidemiological studies may never be possible. This difficulty in identifying stochastic radiation effects does not mean that such effects do not occur. However, there is the possibility that effects do not occur as a result of these small doses, that is, there might be an exposure level below which there is no additional risk above the risk that is posed by natural background radiation. Sufficient data to prove either possibility scientifically is lacking. As a result, we believe that the best approach is to assume that the risk of cancer increases linearly starting at zero dose. That is, any increase in exposure to ionizing radiation results in a constant and proportionate increase in the potential for developing cancer.

The NAS Report stated that radiation causes about five cancers for every severe hereditary disorder. Also, NAS concluded that nonfatal cancers are more common than fatal cancers. Despite this, the NAS cited an ICRP study which judged that non-fatal cancers contribute less to overall health impact than fatal cancers "because of their lesser severity in the affected individuals." (NAS Report pp. 37–39). Our risk estimates for exposure of the population to low-dose-rate radiation is based upon fatal cancers rather than all cancers.

For radiation-protection purposes, we estimate (using a linear, non-threshold, dose-response model) an average risk for a member of the U.S. population of 5.75 in 100 (5.75×10^{-2}) fatal cancers per sievert (Sv)[4] (5.75×10^{-4} fatal cancers per rem) delivered at low dose rates.[5] (For example, if 100,000 people randomly chosen from the U.S. population were each given a uniform dose of 1 millisievert (mSv) (0.1 rem) to the entire body at a low rate, approximately five to six people are assumed to die of cancer during their remaining lifetimes because of that exposure. This is in addition to the roughly 20,000 fatal cancers that would occur in the same population from other causes.) The risk of fatal childhood cancer, resulting from exposure while in the fetal stage, is about 3 in 100 (3×10^{-2}) per Sv (that is, 3×10^{-4} effects per rem). The risk of severe hereditary effects in offspring is estimated to be about 1×10^{-2} per Sv (1×10^{-4} effects per rem).[6] The risk of severe mental retardation from doses to a fetus is estimated to be greater per unit dose than the risk of cancer in the general population.[7] However, the period of increased sensitivity is much shorter. Hence, at a constant exposure rate, fatal cancer risk in the general population remains the dominant factor.

We note that there is, of course, uncertainty in our risk estimates. A recent uncertainty analysis published by the National Council on Radiation Protection and Measurements (NCRP Report 126) estimated that the actual risk of cancer from whole-body exposure to low doses of radiation could be between 1.5 times higher and 4.8 times lower (at the 90-percent confidence level) than our basic estimate of 5.75×10^{-2} per Sv (5.75×10^{-4} per rem). Further, existing epidemiological data does not rule out the existence of a threshold. If there is a threshold, exposures below that level would pose no additional risk above the risk that is posed by natural background radiation. The risks of genetic abnormalities and mental retardation are less well known than those for cancer and, thus, may include a greater degree of uncertainty. However, in spite of uncertainties in the data and its analysis, estimates of the risks from exposure to low levels of ionizing radiation are more clearly known than those for virtually any other environmental carcinogen.

II.C. What Are the Major Features of the Geology of Yucca Mountain and the Disposal System?

The geology. The Yucca Mountain site is located in southwestern Nevada approximately 90 miles northwest of Las Vegas. The eastern part of the site is on the Nevada Test Site, the northwestern part of the site is on the Nellis Air Force Range, and the southwestern part of the site is on Bureau of Land Management land. The area has a desert climate with topography typical of the Basin and Range province. See the BID for more information.

Yucca Mountain is made of layers of ashfalls from volcanic eruptions which happened more than 10 million years ago. The ash consolidated into a rock type called "tuff" which has varying degrees of compaction and fracturing depending upon the degree of "welding" caused by temperature and pressure when the ash was deposited. Regional geologic forces have tilted the tuff layers and formed Yucca Mountain's crest (Yucca Mountain's shape is actually a ridge rather than a peak). Below the tuff is carbonate rock. The carbonate rock was formed from sediments laid down at the bottom of ancient seas which existed in the area.

There are two general hydrologic zones within and below Yucca Mountain. The upper zone is called the "unsaturated zone" because the pore

[3] The risk of interest is not at or near zero dose, but that due to small increments of dose above the pre-existing background level. Background in the U.S. is typically about 3 millisievert (mSv), that is, 300 millirem (mrem), effective dose equivalent per year, or 0.2 Sv (20 rem) in a lifetime. Approximately two-thirds of this dose is due to radon, and the balance comes from cosmic, terrestrial, and internal sources of exposure.

[4] The traditional unit for dose equivalent has been the rem. The unit "sievert" (Sv), a unit in the International System of Units which was adopted in 1979 by the General Conference on Weights and Measures, is now in general use throughout the world. One sievert is equal to 100 rem. The prefix "milli" (m) means one-thousandth. The individual-protection limit being proposed today may be expressed in either unit.

[5] "Low dose rates" here refer to dose rates on the order of or less than those from background radiation.

[6] The risk of severe hereditary effects in the first two generations, for exposure of the reproductive part of the population (with both parents exposed), is estimated to be 5×10^{-3} per Sv (5×10^{-5} per rem). For all generations, the risk is estimated to be 1.2×10^{-2} per Sv (1.2×10^{-4} per rem). For exposure of the entire population, which includes individuals past the age of normal child-bearing, each estimate is reduced to 40% of the cited value.

[7] Assuming a linear, non-threshold dose response, estimated risk for mental retardation due to exposure during the 8th through 15th week of gestation is 4×10^{-1} per Sv (4×10^{-3} per rem); under the same assumption, the estimated risk from the 16th to 25th week is 1×10^{-1} per Sv (1×10^{-3} per rem).

spaces and fractures within the rock are not filled entirely with water. Below the unsaturated zone, beginning at the water table, is the "saturated zone" in which the pores and fractures are filled completely with water. Fractures in both zones could act as pathways which allow for faster contaminant transport than would the pores. The Department plans to build the repository in the unsaturated zone about 300 meters below the surface and about 300 to 500 meters above the current water table.

There are two major aquifers in the saturated zone under Yucca Mountain. The upper one is in tuff, while the lower one is in carbonate rock. Regional ground water in the vicinity of Yucca Mountain is believed to flow generally in a south-southwesterly direction. The aquifers are more fully discussed in the BID.

The disposal system. The NAS Report described the current conception of the potential disposal system as a system of engineered barriers for the disposal of radioactive waste located in the geologic setting of Yucca Mountain (NAS Report pp. 23–27). Entry into the repository for waste emplacement would be on gradually downward sloping ramps which enter the side of Yucca Mountain. The NWPAA limits the capacity of the repository to 70,000 metric tons of SNF and HLW. Current DOE plans project that about 90 percent (by mass) would be commercial SNF and 10 percent defense HLW. Within 100 years after starting to put waste in place, the repository would be sealed by backfilling the tunnels, closing the opening to each of the tunnels, and sealing the entrance ramps and shafts.

We expect the engineered barrier system to consist of at least the waste form (that is, SNF assemblies or borosilicate glass containing the HLW), internal stabilizers for the SNF assemblies, the waste packages holding the waste, and backfill in the space between the waste packages and adjacent host rock. Spent nuclear fuel assemblies are comprised of uranium oxide, fission products, fuel cladding, and support hardware, all of which will be radioactive. (see the *What are the Sources of Radioactive Waste?* section above.)

II.D. Background on and Summary of the NAS Report

Section 801(a)(2) of the EnPA directed us to contract with NAS to conduct a study to provide findings and recommendations on reasonable standards for protection of public health and safety. Section 801(a)(2) of the EnPA specifically called for NAS to address the following three issues:

(A) whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment (as that term is defined in the regulations contained in subpart B of part 191 of title 40, Code of Federal Regulations, as in effect on November 18, 1985) will provide a reasonable standard for protection of the health and safety of the general public;

(B) whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits; and

(C) whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years.

On August 1, 1995, NAS submitted to us its report entitled "Technical Bases for Yucca Mountain Standards." The NAS Report is available for review in the dockets and information file described earlier. You can order the Report from the National Academy Press by calling 800–624–6242 or on the World Wide Web at http://www.nap.edu/bookstore/isbn/0309052890.html#title.

II.D.1. What Were the NAS Findings and Recommendations?

The NAS Report provided a number of conclusions and recommendations. (The EnPA used the term "findings," however, the NAS Report used the term "conclusions.")

Conclusions. The conclusions in the Executive Summary of the NAS Report (pp. 1–14) were:

(a) "that an individual-risk standard would protect public health, given the particular characteristics of the site, provided that policy makers and the public are prepared to accept that very low radiation doses pose a negligibly small risk" [later termed "negligible incremental risk"]. This is the response to the issue identified in section 801(a)(2)(A) of the EnPA;

(b) that the Yucca Mountain-related "physical and geologic processes are sufficiently quantifiable and the related uncertainties sufficiently boundable that the performance can be assessed over time frames during which the geologic system is relatively stable or varies in a boundable manner;"

(c) "that it is not possible to predict on the basis of scientific analyses the societal factors required for an exposure scenario. Specifying exposure scenarios therefore requires a policy decision that is appropriately made in a rulemaking process conducted by EPA;"

(d) "that it is not reasonable to assume that a system for post-closure oversight of the repository can be developed, based on active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits." This is the response to the issue identified in section 801(a)(2)(B) of the EnPA;

(e) "that it is not possible to make scientifically supportable predictions of the probability that a repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years." This is the response to the issue identified in section 801(a)(2)(C) of the EnPA; and

(f) "that there is no scientific basis for incorporating the ALARA [as low as reasonably achievable] principle into the EPA standard or USNRC [U.S. Nuclear Regulatory Commission] regulations for the repository."

Recommendations. The recommendations in the Executive Summary of the NAS Report were:

(a) "the use of a standard that sets a limit on the risk to individuals of adverse health effects from releases from the repository;"

(b) "that the critical-group approach be used" (see the *Who Will Be Representative of the Exposed Population?* section later in this notice);

(c) "that compliance assessment be conducted for the time when the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment;" and,

(d) "that the estimated risk calculated from the assumed intrusion scenario be no greater than the risk limit adopted for the undisturbed-repository case because a repository that is suitable for safe long-term disposal should be able to continue to provide acceptable waste isolation after some type of intrusion."

Other Conclusions and Recommendations. There were other conclusions and recommendations in addition to those summarized in the Executive Summary. Most were related to or supported those presented in the Executive Summary.

II.D.2. How Has the Public Participated in Our Review of the NAS Report?

We are committed to providing ample opportunity for public participation in our Yucca Mountain rulemaking activities. We announced the first opportunity for public participation on September 11, 1995 in the **Federal**

Register (60 FR 47172) where we requested comments upon the NAS Report and announced the times and locations of three public meetings. Along with the general request for public comments, we asked five questions:

(1) did the Report sufficiently answer the questions posed in the EnPA;

(2) was there sufficient rationale to support the NAS' findings and conclusions;

(3) do provisions other than those found in NAS' findings and conclusions need to be included in the EPA standards;

(4) are any of NAS' findings or conclusions inappropriate or inaccurate regarding Yucca Mountain; and

(5) would the cost of imposing the findings and recommendations be justifiable when compared with the benefits provided?

We held the public meetings to inform the public of our role, to outline the issues associated with setting standards for Yucca Mountain, and to seek comments upon the NAS Report. The meetings were held on September 20, 1995, in Amargosa Valley, Nevada; on September 21, 1995, in Las Vegas, Nevada; and on September 27, 1995, in Washington, DC. We also have established several other information sources and given directions, in the **ADDRESSES** and *Additional Docket and Electronic Information* sections earlier in this notice, on how to access them.

II.D.3. What Were the Public Comments on the NAS Report?

We received comments regarding the NAS Report both orally and in writing at the public meetings and in response to the September 11, 1995, **Federal Register** notice, respectively. All written comments are in the docket and information files. The oral comments were summarized in a separate document, copies of which are also in the docket and information files.

Some commenters believed that the NAS inadequately supported its conclusion that there is no scientific basis for including the "as low as reasonably achievable" (ALARA) principle and subsystem requirements in the standards and, therefore, that we should include them in the proposed standards. The ALARA principle is a radiation-protection concept which states that exposures to radiation should be kept as low as can be done taking into account the costs and benefits of exposure reduction methods. "Subsystem requirements" refers to regulation of individual components of the overall disposal system. Other comments indicated that there was inadequate rationale to support NAS' concept of negligible incremental risk (NIR). The NIR concept is based upon an NCRP concept known as "negligible incremental dose" (NID, discussed in more detail later in this notice) which was described by NAS "as a level of effective dose that can, for radiation protection purposes, be dismissed from consideration" (NAS Report pp. 59–60). Commenters also stated that they did not support the NAS" rejection of a collective-dose standard. Comments were divided upon requiring quantitative or qualitative assessment of human intrusion.

With regard to the three questions posed in the EnPA: (1) There were mixed responses upon whether a standard to protect individuals could adequately protect the general public; (2) there was nearly unanimous agreement that active institutional controls cannot prevent a breach of the repository; and (3) there was nearly unanimous agreement that it is impossible to predict the probability of future human intrusion into the repository.

Commenters also expressed views related to a number of other issues. The majority favored:

(1) A standard expressed in terms of dose;

(2) The highest level of protection possible;

(3) Measuring compliance at the time of peak risk of the maximally exposed individual;

(4) A reference biosphere to be specified by EPA;

(5) Including other local sources of man-made radiation in determining an acceptable level of protection;

(6) Protection equal to that specified for WIPP, that is, that in 40 CFR part 191 (WIPP is a geologic disposal system in New Mexico for defense-related transuranic waste but, unlike Yucca Mountain, WIPP is subject to our generic radioactive-waste standards codified at 40 CFR part 191; see also 61 FR 5224, February 9, 1996);

(7) Using a collective-dose limit to restrict exposure to the general population while ignoring the NIR concept;

(8) Including assurance requirements; and

(9) Including ground water protection requirements.

We have taken into consideration all comments received during preparation of these proposed standards. If you submitted comments in response to the September 11, 1995, **Federal Register** notice or at the September 1995 public hearings, you should submit additional comments in response to today's notice to convey any concerns or views about this proposal.

III. What Are We Proposing Today?

We are proposing, and requesting comment upon, public health and safety standards governing the storage and disposal of SNF, HLW, and other radioactive material in the repository at Yucca Mountain, Nevada. We are also announcing a public comment period and public hearings to gather comments upon the proposal.

As noted earlier, section 801(a)(1) of the EnPA gave us rulemaking authority to set "public health and safety standards for the protection of the public from releases from radioactive materials stored or disposed of in the repository at the Yucca Mountain site." The statute also directed us to develop standards "based upon and consistent with the findings and recommendations of the National Academy of Sciences." Section 801(a)(2) of the EnPA directed us to contract with NAS to conduct a study to provide findings and recommendations on reasonable standards for protection of the public health and safety. Because the EnPA called for us to act "based upon and consistent with" the NAS findings, a major issue in this rulemaking is whether we are bound to follow the NAS determinations without exception or whether we have discretionary decision-making authority.

As a practical matter, the difficulty of this issue is reduced because some of the findings and recommendations in the NAS Report are expressed in a non-binding manner. In other words, NAS stated its findings and recommendations as starting points for the rulemaking process or recognized those that involve public policy issues that are more properly addressed in this public rulemaking proceeding. However, the Report also contains some findings and recommendations stated in relatively definite terms. It is these issues that most squarely present the question of whether we are to treat the views of NAS as binding.

Whether the EnPA binds us to following exactly the NAS findings and recommendations is a question that warrants close attention at this stage of the rulemaking because it affects the scope of our rulemaking. If we are required to follow every view expressed in the NAS Report, any such issue would be treated as addressed conclusively by NAS. We would not need to entertain public comment upon the affected issues since the outcome would be predetermined.

We believe that the EnPA does not bind us absolutely to follow the NAS Report. Instead, we have used the NAS Report as the starting point for this rulemaking. Today's proposal is based upon and consistent with the findings and recommendations of NAS. We have developed this proposal guided by the findings and recommendations of NAS because of the special role given NAS by Congress and the scientific expertise of NAS. However, the entirety of our proposed standards for the Yucca Mountain disposal system is the subject of this rulemaking. We do not intend to treat the views expressed by NAS as necessarily dictating the outcome of this rulemaking, thereby foreclosing public scrutiny of important issues. For the reasons described below, we believe this proposed interpretation of the EnPA is consistent with the statute and prudent in that it avoids potential Constitutional issues. Further, this proposed interpretation supports an important EPA policy objective—ensuring an opportunity for public input upon all aspects of the issues presented in this rulemaking.

Section 801(a)(2) of the EnPA required a study by NAS that provides "findings and recommendations on reasonable standards for protection of the public health and safety." While this section of the EnPA calls for NAS to address three specific issues, Congress did not place any restrictions upon other issues NAS could address. The report of the Congressional conferees underscored that "the National Academy of Sciences would not be precluded from addressing additional questions or issues related to the appropriate standards for radiation protection at Yucca Mountain beyond those that are specified." (H.R. Rep. No. 1018, 102nd Cong., 2d Sess. 391 (1992)). Thus, given the potentially unlimited scope of the NAS inquiry under the statute, NAS could have provided findings and recommendations that would dictate literally all aspects of the public health and safety standards for Yucca Mountain, rendering our function a ministerial one.

Section 801(a)(1) of the EnPA plainly gave EPA the authority to issue, by rulemaking, public health and safety standards for Yucca Mountain. If at the same time that Congress gave NAS the authority to provide findings and recommendations on any issues related to the Yucca Mountain public health and safety standards, Congress also intended that NAS' findings and recommendations be binding upon us, then Congress would have effectively delegated to NAS a standard-setting authority that overrides our delegated rulemaking authority. Carried to its logical conclusion, under this view of the statute, NAS would have authority to establish the public health and safety standards, and to do so without a public rulemaking process. Then the direction for EPA to set standards "by rule" would be unnecessary or relatively meaningless. This tension in the statute can be reasonably resolved by interpreting the NAS' findings and recommendations as non-binding, but highly influential, expert guidance to inform our rulemaking.

Thus, we do not believe the statute forces our rulemaking to adopt mechanically the NAS' recommendations as standards. If it did, the statutory provisions would allow us to consider only those issues that NAS did not address. Further, the provisions calling for us to use standard rulemaking procedures in issuing the standards would be unnecessary to reach results that NAS already established.

The report of the conferees also indicates that Congress did not intend to limit our rulemaking discretion. The Conference Report provides that Congress intended NAS to provide "expert scientific guidance" on the issues involved in our rulemaking and that Congress did not intend for NAS to establish the specific standards:

> The Conferees do not intend for the National Academy of Sciences, in making its recommendations, to establish specific standards for protection of the public but rather to provide expert scientific guidance on the issues involved in establishing those standards. Under the provisions of section 801, the authority and responsibility to establish the standards, pursuant to rulemaking, would remain with the Administrator, as is the case under existing law. The provisions of section 801 are not intended to limit the Administrator's discretion in the exercise of his authority related to public health and safety issues. (H.R. Rep. No. 1018 at p. 391)

Our proposed interpretation of the EnPA as not limiting the issues for consideration in this rulemaking is consistent with the views we expressed to Congress during deliberations over the legislation. The Chairman of the Senate Subcommittee on Nuclear Regulation requested our views of the bill reported out of conference. The Deputy Administrator of EPA indicated that the NAS Report would provide helpful input. Moreover, EPA's Deputy Administrator pointed to the language, cited above, stating the intent of the conferees not to limit our rulemaking discretion and assured Congress that any standards for radioactive materials that we ultimately issue would be the subject of public comment and involvement and would fully protect human health and the environment. (138 Cong. Rec. S33,955 (daily ed. October 8, 1992)).

Our proposed interpretation also is consistent with the role that both NAS and Congress understood NAS would fulfill. During the Congressional deliberations over the legislation, NAS informed Congress that while it would conduct the study, it would not assume a standard-setting role because that is properly the responsibility of government officials. (138 Cong. Rec. S33,953 (October 8, 1992)).

Our proposed interpretation of the NAS Report also avoids implicating potentially significant Constitutional issues. Construing the EnPA as delegating to NAS the responsibility to determine the health and safety standards at Yucca Mountain may violate the Appointments Clause of the Constitution (Art. II, sec. 2, cl. 2), which imposes restrictions against giving Federal governmental authority to persons not appointed in compliance with that Clause. In addition, the Constitution places restrictions arising under the separation of powers doctrine upon the delegation of governmental authority to persons not part of the Federal government. We are not concluding, at this time, that an alternative interpretation would necessarily run afoul of Constitutional limits. However, we believe it is reasonable both to assume that Congress intended to avoid these issues when it adopted section 801 of the EnPA and to interpret the EnPA accordingly.

In summary, we do not believe we must, in this rulemaking, adopt all of the positions advanced by NAS. At the same time, the statute does give NAS a special role. As noted, the NAS' findings and recommendations have been the starting point for this rulemaking and our proposal is consonant with those findings and recommendations. In fact, the NAS Report influenced us heavily during the development of this proposed rule. We have included many of the findings and recommendations in whole in today's proposal, and we intend to continue to weigh the NAS Report heavily throughout the course of this rulemaking. We will tend to give greatest weight to the judgments of NAS about issues having a strong scientific component, the area where NAS has its greatest expertise. In addition, we will reach final determinations that are congruent with the NAS analysis whenever we can do so without departing from the Congressional delegation of authority to us to promulgate, by rule, public health and safety standards for protection of the public, which we believe requires the consideration of public comment and our own expertise and discretion.

We request public comment upon how we should view and weigh the NAS' findings and recommendations in this rulemaking. Public commenters should also address this issue in the context of the specific issues presented in this rulemaking. Commenters should indicate whether we have given proper consideration to the NAS' findings and recommendations, whether we should give them more or less weight, and what the resulting outcome should be.

The following sections describe our proposed public health and safety standards for Yucca Mountain and the considerations which underlie the set of standards we are proposing today. The next section addresses the storage portion of the proposed standards. All of the other sections pertain to the disposal portion of the standards.

III.A. What Is the Proposed Standard for Storage of the Waste? (Proposed Subpart A)

Section 801(a)(1) of the EnPA calls for EPA's public health and safety standards to apply to radioactive materials "stored or disposed of in the repository at the Yucca Mountain site." (The repository is the mined portion of the facility constructed underground within the Yucca Mountain site. Hereafter, the term "repository" refers to the Yucca Mountain repository.) The EnPA differentiates between waste that is "stored" and waste that is "disposed," although it indicates that we must issue standards that apply to both types of activity. Congress was not clear regarding its intended use of the word "stored" in this context. Also, NAS did not address the issue of storage (see proposed §§ 197.2 and 197.12 for our proposed definitions of "storage" and "disposal"). The Yucca Mountain repository currently is conceived to be a disposal facility, not a storage facility, but that could change. Therefore, we propose to interpret this language as directing us to develop standards that apply to waste that DOE either stores or disposes of in the Yucca Mountain repository. The public health and safety standards we issue under section 801 of the EnPA would, therefore, apply to waste inside of the repository, whether it is there for storage or disposal.

The Department will also handle and might store radioactive material aboveground (that is, outside the repository). Those activities are covered by our previously promulgated standards for management and storage, codified at subpart A of 40 CFR part 191. The 40 CFR part 191 standards require that DOE manage and store SNF, HLW, and transuranic radioactive wastes at a site, such as Yucca Mountain, in a manner that provides a reasonable expectation that the annual dose equivalent to any member of the public in the general environment will not exceed 25 millirem (mrem) to the whole body. This is the standard which DOE must meet for WIPP and the greater confinement disposal (GCD) facility. (The GCD facility is a group of 120-feet deep boreholes located within the Nevada Test Site (NTS) which contains disposed transuranic wastes.)

The storage standards in 40 CFR 191.03(a) are stated in terms of an older dose-calculation method and are set at an annual whole-body-dose limit of 25 mrem/yr. The proposed storage standards for Yucca Mountain use a modern dose-calculation method known as "committed effective dose equivalent" (CEDE).[8] Even though today's proposal uses the modern method of dose calculation, we believe that the proposed dose level essentially maintains a similar risk level as in 40 CFR 191.03(a) at the time of its promulgation (see the discussion of the different dose-calculation methods in the *What Should the Level of Protection Be?* section later in this notice). The difference between these dose calculation procedures presents a problem in combining the doses for regulatory purposes. However, we have begun a rulemaking to amend both 40 CFR Parts 190 and 191. That rulemaking would update these limits to the CEDE methodology. We anticipate that we will finalize the amendments to parts 190 and 191 prior to the finalization of this rulemaking. If that does not occur, we would need to address the calculation of doses under the two methods in another fashion. For example, we could require that the doses occurring as a result of activities outside the repository be converted into annual CEDE for purposes of determining compliance with the storage standard. We request comments upon such an approach.

Section 801 of the EnPA specifically provides that the standards that we issue shall be the only "such standards" that apply at Yucca Mountain. Thus, the statute provides that the EnPA is the exclusive authority for "such standards" and, in turn, replaces our generally applicable standards for radiation protection to the extent that section 801 requires site-specific standards. Otherwise, our generic standards are not affected. As noted, we propose to interpret the scope of section 801 as applying to both storage and disposal of waste in the repository. Thus, waste inside the repository would be subject to the standards proposed in today's notice. Our generic standards in subpart A of 40 CFR part 191 will apply to waste outside of the repository.

Using this interpretation, we have considered the differences between the conditions covered by the storage standards in 40 CFR 191.03(a) and the conditions which could affect storage in the Yucca Mountain repository. The most significant difference is that the storage in Yucca Mountain would be underground whereas most storage covered under 40 CFR part 191 is aboveground. Otherwise, the technical situations we anticipate under both the existing generic standards and the proposed Yucca Mountain standards are essentially the same. Also, one of our goals in issuing 40 CFR parts 190 and 191 was to bring the entire uranium fuel cycle under consistent EPA standards. Therefore, we are proposing that the part 197 standards continue the coverage of the uranium fuel cycle because SNF, a large part of the waste planned for emplacement in Yucca Mountain, is part of that fuel cycle. Therefore, we are proposing to extend a similar level of protection as in the 1985 version of subpart A of 40 CFR part 191. In other words, under the part 197 storage standards, exposures of members of the public from waste storage inside the repository would be combined with exposures occurring as a result of storage outside the repository but within the Yucca Mountain site. The total dose could be no greater than 150 microsieverts (μSv) (15 mrem) CEDE per year (CEDE/yr).

Our application of subpart A of 40 CFR part 191 to storage activities outside of the repository at the Yucca Mountain site is supported by the WIPP LWA. Section 8 of the WIPP LWA excludes Yucca Mountain from our generic disposal standards but not from the generic management and storage standards found in subpart A of 40 CFR part 191. If we finalize the proposed interpretation of section 801 of the EnPA as applying to radioactive material stored or disposed of in the repository, we would apply subpart A of 40 CFR part 191 to the storage activities outside of the repository at the site without further public notice.

[8] The term "committed effective dose" in this rulemaking has the same meaning as the term "committed effective dose equivalent" which was used prior to the publication of ICRP Publication No. 60. It is used here since the term is less complicated and more compact. Also, the use of "committed effective dose" is consistent with subpart B of 40 CFR part 191 (58 FR 66398, 66402, December 20, 1993).

We request comment upon our proposed interpretation that section 801 of the EnPA directs us to develop new standards that apply only to radioactive materials stored in the repository. We also request public comment upon whether we should instead construe section 801 of the EnPA as providing for the establishment of new storage standards, rather than applying the existing storage standards in 40 CFR part 191 to storage, or handling, of radioactive materials at the Yucca Mountain site prior to their movement into the repository. If we decide, based upon the alternative interpretation of section 801, to promulgate new storage standards for the site, we anticipate that we would adopt standards essentially the same as those in 40 CFR 191.03(a). Thus, we request public comment upon whether we should develop and adopt in this rulemaking, under section 801 of the EnPA, new standards for management and storage activities at the site, and request comments upon the adoption of such standards based upon those in 40 CFR 191.03(a).

III.B. What Is the Standard for Protection of Individuals? (Proposed §§ 197.20 and 197.25)

III.B.1. Should the Limit Be on Dose or Risk?

Although a standard for limiting exposure of people to radiation can take many forms, NAS narrowed its final considerations to risk and dose, that is, a risk-based or dose—based standard. The numeric level of the proposed standard for protecting individual members of the public from radioactive materials disposed of in the Yucca Mountain disposal system is addressed in the *What Should the Level of Protection Be?* section later in this notice. The discussion here explains why we selected a dose-based standard rather than a risk-based standard, as recommended by NAS.

Two forms of radiation exposure can occur depending upon the location of the source relative to the body '' internal and external. Internal exposures occur when a person inhales or ingests contaminated air, food, water, or soil. External exposures occur because a person is near a radionuclide which is emitting X-rays, gamma rays, beta particles, or neutrons. ''Dose'' is a measure of the amount of radiation received by individuals resulting from exposure to radionuclides. ''Risk'' is the probability of an individual incurring an adverse health effect from exposure to radiation. The NAS defined ''risk'' as the product of two parameters: (1) the probability of an individual receiving a dose, and (2) the probability of incurring a health effect because of that dose (NAS Report p. 42). This rulemaking takes both of these factors into account. (The probability of an individual receiving a dose is part of the performance assessment and is discussed in the *What Are the Requirements for Performance Assessments and Determinations of Compliance?* section later in this notice.) As mentioned in the previous section, these standards state radiation risk estimates as the probability of an individual developing a fatal cancer, since fatal cancers are the greatest harm to individuals from low-dose-rate radiation (NAS pp. 37–39).

Section 801(a)(1) of the EnPA directed that our standards for Yucca Mountain ''shall prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository....'' At the same time, the EnPA calls for us to issue our standards ''based upon and consistent with'' the findings and recommendations of NAS. The NAS recommended that we adopt a standard expressed as risk rather than the dose standard that Congress prescribed. The NAS offered two reasons for its recommendation. First, a risk-based standard is advantageous relative to a dose-based standard because it ''would not have to be revised in subsequent rulemakings if advances in scientific knowledge reveal that the dose-response relationship is different from that envisaged today'' (NAS Report p. 64). Second, a standard in the form of risk more readily enables the public to comprehend and compare the standard with human-health risks from other sources.

We have reviewed and evaluated the merits of a risk-based standard as recommended by NAS. However, we are proposing a dose-based standard for the following reasons. First, both national and international radiation protection guidelines developed by bodies of non-governmental radiation experts, such as ICRP and NCRP, generally have recommended that radiation standards be established in terms of dose. Also, national and international radiation standards, including the individual-protection requirements in 40 CFR part 191, are established almost solely in terms of dose or concentration, not risk. Therefore, a risk-based standard will not allow a convenient comparison with the numerous existing radiation guidelines and standards that are stated in terms of dose.

Second, we have an established methodology for calculating dose that is described in Federal Guidance Reports Nos. 11 and 12 (Federal Guidance). The development of this methodology was a combined effort of many Federal agencies involved in radiation protection and has become Federal policy. The guidance provides a consistent methodology for calculating doses for regulatory purposes. By contrast, there is currently no Federal Guidance Report, in final form, for calculating risk from radiation exposure.

Third, we have based the proposed dose-based standard upon the risk of developing a fatal cancer as a result of that level of exposure based upon a linear, non-threshold, dose-response relationship. We would establish a risk-based standard in the same manner. Thus, a risk-based standard, like a dose-based standard, depends upon current knowledge and assumptions about the chance of developing fatal cancer from a particular exposure level. Dose and risk are closely related; one can be converted to the other simply by using the appropriate factor. Therefore, both dose- and risk-based standards are based upon scientific assumptions that could change and no matter how it is expressed, the standard is based upon risk.

Finally, section 801(a)(1) of the EnPA specifically calls for a dose-based standard. Most commenters supported this by asking for a dose-based standard rather than a risk-based standard.

Accordingly, we are proposing a standard expressed as a limit on dose. We are requesting comments upon the proposed form of the standard, including whether the standard should be expressed as risk.

III.B.2. What Should the Level of Protection Be?

As noted previously, section 801(a)(1) of the EnPA calls for our Yucca Mountain standards to ''prescribe the maximum annual effective dose equivalent to individual members of the public from releases of radioactive materials.'' Development of the individual-protection standard requires us to evaluate and specify several factors. These factors include the level of protection, who the standards should protect, and how long the standards should provide protection. Determining the appropriate dose level is ultimately a question of both science and public policy. The NAS stated in its Report: ''The level of protection established by a standard is a statement of the level of the risk that is acceptable to society. Whether posed as ''How safe is safe enough?'' or as ''What is an acceptable level?", the question is not solvable by science" (NAS Report p. 49). We seek to find answers to these questions for the Yucca Mountain disposal system through this rulemaking.

We considered the NAS findings and recommendations in our determination of the CEDE level that would be adequately protective of human health. We also reviewed established EPA standards and guidance, other Federal agencies' actions for both radiation and non-radiation-related actions, and other countries' regulations. In addition, we evaluated guidance on dose limits provided by National and international, non-governmental, advisory groups of radiation experts.

The NAS recommended a range of risk levels that we could use as a reasonable starting point in this rulemaking (NAS Report p. 5). The range of annual risk of fatal cancer suggested by NAS was 1 chance in 100,000 (1×10^{-5}) to 1 chance in 1,000,000 (1×10^{-6}) (this corresponds to a range of 20 to 2 mrem CEDE/yr). The NAS based its recommendation upon its review and evaluation of our actions, other Federal actions, guidelines developed by National and international groups, and regulations of other countries. For these standards, we are proposing a limit of 150 μSv (15 mrem) CEDE/yr. This limit corresponds approximately to an annual risk of 7 chances in 1,000,000 (7×10^{-6})—within the range that NAS recommended as a starting point for consideration.

Table 1 below lists the dose limits of other current EPA and NRC regulations (adapted from NAS Report p. 50). Today's proposed standard of 150 μSv (15 mrem) CEDE/yr is within the range of these established standards. Further, it is consistent with the individual-protection standard at 40 CFR 191.15 in our generic disposal standards which limits the annual CEDE to 150 μSv (15 mrem)/yr.

TABLE 1.—CURRENT EPA AND NRC DOSE LIMITS ON VARIOUS ENVIRONMENTAL CONCERNS

Environmental concern	Limit*
Low-Level Waste (10 CFR part 61)	250 μSv (25 mrem)/yr
License Termination (10 CFR part 20)	25 mrem TEDE**/yr
Uranium Fuel Cycle (40 CFR part 190)	25 mrem/yr
Generic Standard for Management and Storage of SNF and HLW (40 CFR 191.03).	25 mrem/yr
Generic Individual-Dose Standard for Disposal of SNF and HLW (40 CFR 191.15).	150 μSv (15 mrem) CEDE/yr
National Emission Standards for Hazardous Air Pollutants (40 CFR part 61, subparts H and I).	10 mrem CEDE/yr
SNF and HLW Disposal Limit for Underground Sources of Drinking Water (40 CFR 191.24).	4 mrem/yr for man-made beta- and photon-emitting radionuclides

*Unless otherwise noted, only whole-body dose limits are listed; there may also be other requirements for any particular environmental concern. The 25-mrem/yr, whole-body-dose limit established in 1985 is essentially equivalent to the risk associated with today's dose rate of 150 μSv (15 mrem) CEDE/yr (58 FR 66402, December 20, 1993).

**TEDE (total effective dose equivalent) is NRC's term for CEDE. This regulation was not included in the NAS Report.

We note that, except for 40 CFR 191.15, 40 CFR part 61, and 10 CFR part 20, the dose limits in Table 1 are stated in terms of an old dose system. For example, the annual limits in 40 CFR 191.03(a) are 25 mrem for the whole body, 75 mrem for the thyroid, or 25 mrem for any other organ (only the whole-body limit is listed in Table 1). We established these dose levels in 1985 (50 FR 38085, September 19, 1985) under a different system for calculating doses than the more recent rulemakings that use the CEDE concept. We estimate that the 25-mrem/yr, whole-body-dose limit established in 1985 is essentially equivalent to the risk associated with today's proposed limit of 150 μSv (15 mrem) CEDE/yr (58 FR 66398, 66402, December 20, 1993).

In addition, the proposed 150-μSv (15 mrem)-CEDE/yr limit in today's proposal is consistent with other current standards. For example, our limits on radiation exposure through the air is part of the set of limits for pollutant releases known as the National Emission Standards for Hazardous Air Pollutants (NESHAPs, 40 CFR part 61). Since our NESHAPs limit of 10 mrem/yr covers radionuclide releases into only the air, the 150 μSv (15 mrem) CEDE/yr standard being proposed for 40 CFR part 197 is consistent with the NESHAPs limit because it applies to all potential pathways, that is, the dose limit is higher but includes other pathways in the analysis.

In summary, based upon our review of the guidance, regulations, and standards cited above, and the NAS Report, we are proposing a standard of 150 μSv (15 mrem) CEDE/yr for the Yucca Mountain disposal system. We request comment upon the reasonableness of this level of protection.

III.B.3. What Factors Can Lead to Radiation Exposure?

Protection of the public from exposure to radioactive pollutants requires knowledge and understanding of three factors: the source of the radiation, the pathways leading to exposure, and the recipients of the radiation. This section provides a discussion of the source of radiation and pathways of exposure. The following two sections discuss the recipients of the dose. The development of standards to protect public health and safety from radionuclides released from waste disposed of in the Yucca Mountain disposal system must include consideration of the sources of radiation and pathways which could lead to exposure of humans. The mechanisms of exposure are the basis of an analysis called the performance assessment. The performance assessment is the quantitative analysis of the projected behavior of the disposal system.

Source. The waste disposed of in Yucca Mountain will contain many different radionuclides including unconsumed uranium, fission products (for example, cesium-137 and strontium-90), and transuranic elements (for example, plutonium and americium).

The inventory of radionuclides over time will depend upon the type and amount of radionuclides originally disposed of in the disposal system, the half-lives of the radionuclides, and the amount of any radionuclides formed from the decay of parent radionuclides (see the BID). In the time frame of tens- to hundreds-of-thousands of years, most radionuclides initially present in SNF and HLW will decay to essentially no radioactivity. Therefore, the waste will eventually have radiologic characteristics similar to a large uranium ore body (see the BID).

To delay the movement of radionuclides into the biosphere, DOE plans to use multiple barriers. These barriers would be man-made (engineered) and natural based upon the design of, and conditions in and around, the disposal system.

Engineered barriers must be designed to delay release of radionuclides from the repository. For example, an engineered barrier could be the waste form. The Department plans to convert liquid HLW derived from reprocessing of SNF into a solid by entraining the radionuclides into a matrix of borosilicate glass; NRC will likely consider this an engineered barrier. The molten glass then would be poured into and hardened in a second man-made barrier, a metal container (see the BID). In addition, it is possible to have other man-made barriers in the repository to serve as part of the disposal system (see the BID).

Natural barriers at Yucca Mountain also could slow the movement of radionuclides into the accessible environment. For instance, the Department plans to construct the repository in a layer of tuff located above the water table. The relative dryness of the tuff around the repository would limit the amount of water which comes into contact with the waste. It also would retard the future movement of radionuclides from the waste into the underlying aquifer. Any radioactive material that dissolved into infiltrating water, originating as surface precipitation, still would have to be moved to the saturated zone. Minerals, such as zeolites, contained within the tuff beneath the repository could act as molecular filters and ion-exchange agents for some of the released radionuclides, thereby slowing their movement. Such minerals also could limit the amount of water that contacts the waste and could help retard the movement of radionuclides from the waste to the water table. This mechanism would be most effective if flow was predominantly through the pores in the rock, also known as the matrix (see the BID).

Pathways. Once radionuclides have left the waste packages, they could be carried by water or air and reach the public. Upon release from the waste packages, most radionuclides will be carried by ground water away from the repository. However, those in a gaseous form, such as carbon-14 (^{14}C) in the form of carbon dioxide, will be carried by air moving through the mountain.

Movement via water. Radionuclides will not be moved into the water table instantaneously. The length of time it takes depends partly upon how much the water moves via fractures or through the matrix of the rock. Once radionuclides reach the saturated zone, they would move away from the disposal system in the direction of ground water flow.

There are currently no perennial rivers or lakes adjacent to Yucca Mountain to further transport contaminants. Therefore, based upon current knowledge and conditions, ground water and its usage will likely be the main pathway leading to exposure of humans. Current knowledge suggests that the two major ways that people would use the contaminated ground water are: (1) drinking and domestic uses; and (2) agricultural uses (see the BID). In other words, radionuclides that reach the public could deliver a dose if an individual: (1) Drinks contaminated ground water or uses it directly for other household uses; (2) drinks other liquids containing contaminated water; (3) eats food products processed using contaminated water; (4) eats vegetables or meat raised using contaminated water, or (5) is otherwise exposed as a result of immersion in contaminated water or air or inhalation of wind-driven particulates left following the evaporation of the water.

Movement via air. Some radionuclides could be carried by moving air. The largest known source of potential movement by air in Yucca Mountain is carbon dioxide containing ^{14}C. Airborne radionuclides might move through the tuff overlying the repository and exit into the atmosphere following release from the waste package. Once the radioactive gas enters the atmosphere, it would disperse. This dispersion would probably be global and, therefore, become greatly diluted. The major pathway for exposure of people by ^{14}C is the uptake of radioactive carbon dioxide by plants that humans subsequently eat (see the BID).

III.B.4. Who Will Be Representative of the Exposed Population?

To determine whether the Yucca Mountain disposal system complies with the standard, it will be necessary for DOE to calculate the dose to some individual or group of individuals exposed to releases from the repository and compare the calculated dose with the limit established in the standard. The standard must specify, therefore, the individual or group of individuals for whom the dose calculation is to be made.

The NAS definition of critical group. The NAS Report recommended that we base the standards for protection of individuals upon risk incurred by a critical group (CG). The CG would be the group of people which, based upon cautious, but reasonable, assumptions, has the highest risk of incurring health effects due to releases from the disposal system. The ICRP introduced the concept of a CG in order to account for the variation of dose which may occur in a population due to differences in age, size, metabolism, habits, and environment. In other words, the ICRP recommends the use of a group of people because individuals might have personal traits which make them much more or less vulnerable to releases of radiation than the average within a small group of the most highly exposed individuals. The ICRP defines the CG as a relatively homogeneous group of people whose location and habits are such that they represent those individuals expected to receive the highest doses as a result of the discharge of radionuclides. The NAS adapted the CG concept to a risk framework for the development of an individual-risk standard and recommended the following description of the CG (NAS Report p. 53):

> The critical group for risk should be representative of those individuals in the population who, based on cautious, but reasonable, assumptions, have the highest risk resulting from repository releases. The group should be small enough to be relatively homogeneous with respect to diet and other aspects of behavior that affect risks. The critical group includes the individuals at maximum risk and is homogeneous with respect to risk. A group can be considered homogeneous if the distribution of individual risk within the group lies within a total range of a factor of ten and the ratio of the mean of individual risks in the group to the standard is less than or equal to one-tenth. If the ratio of the mean group risk to the standard is greater than or equal to one, the range of risk within the group must be within a factor of 3 for the group to be considered homogeneous. For groups with ratios of mean group risk to the standard between one-tenth and one, homogeneity requires a range of risk interpolated between these limits.

The NAS also recommended that the CG risk calculated for purposes of comparison with the risk limit established in the standard is the average of the risks of all the members in the group. Using the average risk avoids the problem of the outcome being unduly influenced by unusual habits of individuals within the group.

The NAS indicated that in order to select a CG, the person or persons likely to be at highest risk from among the larger, exposed population must be specified. To accomplish this, one must make assumptions about the nature of human activities, lifestyles, and pathways that affect the level of exposure. The set of circumstances that affects the dose received, such as where people live, what they eat and drink, and other lifestyle characteristics, is a very important part of the exposure scenario. Many human behavior factors important to assessing repository performance vary over periods that are short in comparison with the compliance period proposed for these standards. The past several centuries have seen radical changes in human technology and behavior, many of which were not reasonably predictable. Given this potential for rapid change, we believe that it is not possible to know what patterns of human activity and changes in human biology might occur thousands of years from now. For the purpose of compliance with the standard, therefore, we are proposing that it is appropriate to use many of the current characteristics of members of the public in the vicinity of Yucca Mountain in the compliance assessments required by these standards (see the *What Should Be Assumed About the Future Biosphere? section later in this notice).*

The NAS Report presented two illustrative approaches for formulating an exposure scenario for determining compliance. The NAS also clearly stated that there might be other methods to reach the same objective (NAS Report p. 100). One approach, described in Appendix C of the NAS Report, *A Probabilistic Critical Group,* used statistical methods and probabilities to characterize a CG. The second, *The Subsistence-Farmer Critical Group,* described in Appendix D, identified a subsistence farmer as a principal representative of the CG.

The NAS probabilistic critical group. Appendix C of the NAS Report described a ''probabilistic critical group.'' This section describes the contents of Appendix C of the NAS Report.

The NAS probabilistic CG approach would require use of a theoretical population distribution which we would, or require DOE to, develop by using a mathematical method known as ''Monte Carlo.'' The Monte Carlo method is a mechanism to randomly select values of parameters which have a range of possible values. The parameters would be present-day environmental parameters, including soil quality, land slope, growing season, depth to the aquifer, and population distribution and lifestyles. The individuals who comprise the CG may represent a variety of economic lifestyles and activities. The analysis would then use the variability of those parameters in the region around Yucca Mountain to arrive at the theoretical population for the calculation of radiation exposure. This theoretical population would then, according to NAS, be combined with Monte Carlo simulations of the distribution of contaminated ground water in time and space (NAS Report p. 148). According to NAS, each simulation would generate a plume path which could be overlain on a map of potential farm density or water use to determine a potential exposure area. Each of these potential plume paths is known as a ''realization.'' Values for parameters, including well depths, rates of water use, food sources, and consumption rates, are determined by sampling from the parameter-value distributions. For each plume realization of the contamination in the aquifer, the results of the exposure simulations are combined to give a spatial distribution of maximum exposures for the locations likely to be inhabited. This approach would use a large number of simulations of plume realizations to identify critical subgroups with the highest risk. It would then be used to calculate the arithmetic average of the risk of all critical subgroups over all plume realizations to estimate the risk for the CG. In determining compliance, the Commission would compare this estimate with the risk limit in the standard.

We considered proposing the probabilistic CG approach but are not doing so for the following reasons. First, there is no relevant experience in applying the probabilistic CG approach. Second, the approach is very complex and difficult to implement in a manner that assures it would meet the requirements of defining a CG. Third, we are concerned that this approach does not appear to identify clearly who is being protected. Finally, a significant majority of the comments that we have received upon the NAS Report opposes the probabilistic CG approach.

The NAS subsistence-farmer critical group. The approach in Appendix D of the NAS Report specified one or more subsistence farmers as the CG. It made assumptions designed to define the farmer at maximum risk to be included in the CG. This section describes the contents of Appendix D of the NAS Report.

The subsistence-farmer CG is a definable, highly exposed segment of the larger, exposed population. The subsistence farmer would be assumed to: (1) be a person with eating habits and response to doses of radiation that would be average for present-day people and (2) obtain all potable water and grow all of his or her own food using water withdrawn from the aquifer contaminated with radionuclides from the disposal system. The water used by this CG would be withdrawn at a location downgradient from and outside the footprint of the repository at the point of maximum potential concentration of ground water contamination, provided that no natural geologic features preclude drilling for water at that location. (The footprint of the repository is the circumscription of the outermost, original emplacement locations of the waste.)

Concentrations of radionuclides in the extracted ground water may be smaller than in undisturbed ground water due to pumping; this possibility could be used when evaluating exposures (NAS Report p. 155). As a result of uncertainty, there will be probabilistic distributions of radionuclide concentrations, as they vary in time and space in the aquifer outside the repository footprint, which are the input variables needed to estimate the risk. The radionuclide distributions in the aquifers, in turn, depend upon the performance of the components of the natural and engineered barrier systems. Projections of their performance also contain uncertainty and likely will be subject to probabilistic assessment. Any assessment of the potential doses from the repository, therefore, must consider the probability of processes and events that influence eventual concentrations of radionuclides in aquifers supplying water to the CG.

Overall, the ''expected'' risk for the average member of this CG would be about one-half that of the most-exposed subsistence farmer (NAS Report p. 158). This average risk to the members of the CG would be compared with the standard selected for compliance.

We considered proposing that the protected individual(s) be the subsistence-farmer CG. The CG concept has been utilized within the U.S. in various ways. The NRC uses the CG concept in assessing compliance with NRC standards for radionuclide releases from nuclear facilities. For example, the Commission uses the CG concept in: (1) licensing actions involving dose calculations under 10 CFR part 40, appendix A; (2) its radiological criteria for license termination of all NRC-licensed facilities at 10 CFR part 20, subpart E; and (3) its draft guidance for LLW disposal under 10 CFR part 61. The State of Washington recently implemented the CG concept in actions relating to U.S. Ecology's LLW site at Hanford, and the State of Texas endorses CG in its decommissioning standards. Also, a great deal of international guidance exists that discusses the use of CG. The ICRP endorses CG, and has recommended the CG concept in numerous documents, both recent and dating back as far as 1977. Canada, Sweden, Switzerland, and the United Kingdom are among those individual nations that have adopted the CG methodology for radioactive waste storage and disposal.

We prefer an approach to exposure assessment that is consistent with other Agency programs (*Guidance on Risk Characterization for Risk Managers and Risk Assessors,* Deputy Administrator F. Henry Habicht II, February 26, 1992) and which we believe provides a level of protection substantially equivalent to that which would be achieved by the CG concept.

Our proposal for the protection of individuals. Most of our programs use an approach for the development of exposure scenarios that involves determining the high-end range of doses or exposures. Conceptually, this range is that above the 90th percentile of the entire (either measured or estimated) distribution of potential doses within the exposed population. Conversely, the NESHAPs program for radionuclides and the individual-protection requirements in the generic SNF and HLW disposal standards at 40 CFR 191.15 require calculation of the individual dose for a person assumed to reside at a location where that person would receive the highest dose. However, other Agency programs use a different approach to protect individuals by using "reasonable, maximum exposure" (RME) conditions. The National Contingency Plan describes an approach to be used for the RME scenario to protect individuals as "a product of factors, such as concentration and exposure frequency and duration, that are an appropriate mix of values that reflect averages and 95th percentile distributions" (55 FR 8666, 8710, March 8, 1990). In the past, we have defined "reasonable maximum" to mean potential exposures that are likely to occur. The method for calculating the RME is to estimate the high-end range of possible exposures by identifying the factors which have the greatest effect upon the size of the dose, and using maximum or nearly maximum values for one or a few of these factors, leaving the others at their average values (57 FR 22888, 22922, May 29, 1992). In this approach, we select a hypothetical individual who would be representative of the most highly exposed individuals. We call this individual the reasonably maximally exposed individual (RMEI). To be effective, the RMEI approach must avoid incompatible combinations of parameter values, such as, low body weight used in combination with high intakes.

Thus, we intend for this procedure to project doses that are within a reasonably expected range rather than projecting the most extreme case. However, the procedure is also meant to identify an individual dose which is well above the average dose in the exposed population. The ultimate goal and purpose is to estimate a level of exposure that is protective of the vast majority of individuals at a site, but is still within a reasonable range of potential exposures.

For the preceding reasons, we are proposing the RMEI concept as our preferred approach instead of the CG approach. The United States and other countries have used the concept of a hypothetical individual to represent future populations in radioactive-waste management programs. This is consistent with widespread practice, current and historical, of estimating dose and risk to highly exposed individuals even when the exposure habits of future people cannot be specified or accurately calculated, as in this case where doses must be projected for very long periods. The approach is straightforward and relatively simple to understand. We believe that this approach provides protection similar to that afforded by the NAS recommendation to use a CG. The RMEI model uses a series of assumptions about the lifestyle of a hypothetical individual. The desired degree of conservatism can be built into the model through choices of assumed values of RME parameters. However, these values would be within certain limits since we are proposing to require the use of Yucca Mountain-specific characteristics in choosing those parameters and their values. In subpart B of 40 CFR part 197, we propose a framework of assumptions for NRC to incorporate into its implementing regulations.

Our proposed RMEI would be representative of a future population group termed "rural-residential." The CEDE received by this RMEI would be calculated by DOE using cautious, but reasonable, exposure parameters and parameter-value ranges. The projected CEDE would be used by NRC in the determination of compliance with the proposed standards. We believe that the results obtained by using this approach would be similar to those which would be obtained by using the subsistence-farmer CG approach put forth in Appendix D of the NAS Report. In both cases, the objective is to determine the magnitude of the potential exposure using reasonable, not extreme, assumptions. Under the proposed standards, the RMEI will have food and water intake rates, diet, and physiology like that of individuals currently living in the downgradient direction of flow of the ground water passing under Yucca Mountain. The Department will perform the dose calculation to estimate exposure resulting from releases from the waste into the accessible environment based upon the assumption of present-day conditions in the vicinity of Yucca Mountain. Presently, we expect the ground water pathway to be the most significant pathway for exposure from radionuclides that are transported from the repository. Our initial evaluation of potential exposure pathways from the disposal system to the RMEI suggests that the dominant fraction of the dose incurred by the RMEI likely will be from ingestion of food irrigated with contaminated water (see the BID). It is possible, however, that another exposure pathway will be determined by DOE and NRC to be more significant for radiation exposure. Consequently, DOE and NRC must consider and evaluate all potentially significant exposure pathways in the performance assessment. As a result of the performance assessment, there will be a distribution of the highest potential doses incurred by the RMEI. We are proposing that the mean or median value (whichever is higher) of that distribution be used by NRC to determine compliance with the individual-protection standard. We request comments upon this method of determining compliance with the individual-protection standard.

We are also requesting comments upon the alternative of adopting the CG approach rather than the RMEI. Comments supporting the CG approach should address the level of detail EPA's rule should include on the parameters of the CG.

Exposure scenario for the RMEI. A major part of the exposure scenario is the location of the RMEI. In preparing to propose a location for the RMEI, we collected and evaluated information on the natural geologic and hydrologic features, such as topography, geologic structure, aquifer depth, aquifer quality, and the quantity of ground water, that may preclude drilling for water at a specific location. Based upon these factors and the current understanding of ground water flow in the area of Yucca

Mountain, it appears that an individual could reside anywhere along the projected radionuclide flow path extending from Forty-Mile Wash, approximately five kilometers (km) from the proposed repository location, to the southwestern part of the Town of Amargosa Valley, Nevada, where the ground water is close to the land surface and where most of the farming in the area is done. However, an individual's ability to reside at any particular point along that path depends upon that individual's purpose and available resources. To explore these variations, we developed the four scenarios described below. We present our evaluation of factors associated with these scenarios more fully in the BID. We welcome comment upon the appropriateness of each of these scenarios and upon our preferred scenario. In developing scenarios, we assumed that the level of technology and economic considerations affecting population distributions and life styles in the future are the same as today (for more detail, see the *What Should Be Assumed about the Future Biosphere?* section below).

The RMEI in the first scenario is a subsistence (low technology) farmer. Such an individual would have continuous exposure to radionuclides in water, air, and soil which are arriving through all exposure pathways. The RMEI's location and habits would be generally consistent with historical locations of Native Americans and early settlements in Amargosa Valley and influenced heavily by easy access to water, that is, where the water table is near the surface (approximately 30–40 km away from the disposal system). In addition, all of the RMEI's water and food would come from contaminated sources. We did not choose this option because we believe that such a scenario is overly conservative given the site-specific characteristics of the area and reasonable consideration of the lifestyles of individuals in that area.

In the second scenario, we considered using a commercial farmer as the RMEI. We evaluated economic factors and current and potential future technologies which could be economically viable. There are areas in the vicinity of Yucca Mountain which are currently being farmed commercially or could be economically farmed based upon reasonable assumptions, current technology, and experience in other arid parts of the western United States. The exposure pathways in this scenario would be the same as those used for the subsistence-farmer scenario. We did not choose this as our preferred scenario since we believe that commercial farming would not be representative of the general population and would not be likely in areas other than where there is currently such farming, approximately 30 kilometers from the disposal system.

The third scenario, selected as our preferred approach, involves a rural-residential RMEI. We assume that the rural-residential RMEI is exposed through the same general pathways as the subsistence farmer. However, this RMEI would not be a full-time farmer but would do personal gardening and earn income from other sources of work in the area. We assume further that all of the drinking water (two liters per day) and some of the food consumed by the RMEI is from the local area. The consumption of two liters per day of drinking water is a high value since people consume water from outside sources, such as commercial products. Similarly, we assume that local food production will use radioactively contaminated water coming from the disposal system. We believe this lifestyle is similar to that of most people living in Amargosa Valley today.

The fourth scenario which we considered is domestic use of an underground source of drinking water (USDW) by a community living near the repository site. A USDW is essentially an aquifer which is large enough to supply or could supply a public water system (the full definition is in 40 CFR 144.3). Based upon current water usage in the arid western United States, a public water supply inside of the current NTS could exist since a community would have greater resources to access and recover water than would most individuals. Such a community water supply would have characteristics similar to DOE's water wells J–12 and J–13. These wells have supplied water needs (including human consumption) since the early 1960s for the Federal government. While we consider such a scenario possible, it could be less protective than the rural-residential scenario because it would not protect individuals from the ingestion of contaminated home-grown food. Also, we consider this scenario less representative of current conditions for most people in the vicinity of Yucca Mountain.

Location of the RMEI. The location of the RMEI is a basic part of the exposure scenario. We considered locations within a region occupying an area bordering Forty-Mile Wash, within a few kilometers of the repository site, to the southwestern border of the Town of Amargosa Valley. This region, which we believe is hydrologically downgradient from Yucca Mountain, can be considered as three general subareas.

The first subarea occupies the land south from near Yucca Mountain to the vicinity of U.S. Route 95. This subarea has deep ground water (up to about 300 meters) which is accessed by Federally owned wells used for DOE activities associated with Yucca Mountain and the NTS. This land is currently under government control and ownership. In addition, the likelihood of small or economically viable agricultural activities in this area is questionable when the depth to the water table is taken into consideration.

The next subarea borders the first and extends several kilometers south of U.S. Route 95. The northern portion of the Town of Amargosa Valley, including the businesses at the intersection of U.S. Route 95 and Nevada State Route 373 (Lathrop Wells), is included in this subarea. This subarea currently includes about 15 residents and no agricultural activities, although abandoned irrigation wells exist (see the BID). The depth to water in this area ranges from slightly more than 100 to about 60 meters. The U.S. Natural Resource Conservation Service has designated the types of soils in this area as suitable for rangeland and wildlife habitat.

The third subarea borders the second and covers the remainder of the Town of Amargosa Valley. This subarea is the closest downgradient location to Yucca Mountain with perennial agricultural activity. The depth to ground water is relatively shallow—approximately 50 to 15 meters. The agriculture consists of both personal gardens and commercial activities. The commercial agriculture is a mainstay of the local economy. Commercial farms produce crops, livestock, and dairy products for either local consumption or for transport out of the region. Most of the residents of the Town of Amargosa Valley are within this subarea, as are the community center, school, clinic, library, post office, and sheriff's office. The population consists of all age groups.

Based upon these considerations of the subareas, we propose that the intersection of U.S. Route 95 and Nevada State Route 373, known as Lathrop Wells, is a likely location for the RMEI. In this example, we do not consider it probable that the rural-residential RMEI would occupy locations significantly north of U.S. Route 95. We make this assumption mainly because the rough terrain and increasing depth to ground water nearer to Yucca Mountain would likely discourage settlement by individuals because access to water is more difficult than it would be a few kilometers farther south. Also, there are currently several residents and businesses near this location whose source of water is the underlying aquifer (which we understand flows from under Yucca Mountain). Therefore, we believe that it is reasonable to assume that individuals could reside near this intersection in the future.

Farming occurs today farther south, in the southwestern portion of the Town of Amargosa Valley in an area near the California border and west of Nevada State Route 373. However, soil conditions in the vicinity of Lathrop Wells are similar to those in southwestern Amargosa Valley. Therefore, it should be feasible for the RMEI to grow some of his or her own food, including a grazing cow, using a fraction of the water recovered but not used for household purposes. Larger-scale food production at Lathrop Wells is unlikely because of the cost of recovering sufficient water. To supplement the gardening and grazing, we propose that it is also reasonable to assume that the RMEI would obtain much of his or her food from the local area.

Finally, we believe that a rural-residential RMEI near Lathrop Wells would be among the most highly exposed individuals in the downgradient direction from Yucca Mountain. We believe that this is true even though individuals residing closer to the repository (where the ground water is at a greater depth) could be consuming higher concentrations of radionuclides in their drinking water. Because of the significant cost of finding and withdrawing the ground water, we further believe that individuals living nearer the repository are unlikely to withdraw water from the significantly greater depth and in the much larger quantities needed for farming activities. Based upon our analyses of potential pathways of exposure, discussed above, we believe that irrigation would be the most likely pathway for most of the dose from the most soluble, least retarded radionuclides (such as technetium-99 and iodine-129). The percentage of the dose that results from irrigation would depend upon the assumptions about the fraction of all food assumed to be consumed by the RMEI from gardening or other crops grown using contaminated water. We also are proposing that protection of a rural-residential RMEI would be protective of the general population (see the *How Will the General Population Be Protected?* section below).

Our identification of Lathrop Wells as a potential location of the RMEI is based upon a review of available, site-specific information. Of course, DOE and NRC must consider other, more appropriate locations based upon additional data which DOE or others may develop later, but the selection of that other location must be based upon the same considerations used for this example. For example, if DOE subsequently determines that the direction of ground water flow is different than we have assumed, DOE and NRC must choose the location, at the same distance from the center of the repository footprint as the original point of compliance, where the highest radionuclide concentrations occur.

As stated earlier, the method of calculating the RME is to select average values for most parameters except one or a few which are set at their maximum, that is, high-end, values. We believe that the Lathrop Wells location and a consumption rate of two liters per day of drinking water from the plume of contamination represent high-end values for two of these factors. The Commission may identify additional parameters for which to assign high-end values in projecting the dose to the RMEI. To the extent possible, NRC should use site-specific information for any remaining factors. For example, NRC should use the most accurate projections of the amount of contaminated food that would be ingested in the future. Projections might be based upon surveys which indicate the percentage of the total diet of Amargosa Valley residents which is from food grown in the Amargosa Valley area.

We particularly request comment upon whether:

(1) Based upon the above criteria, there is now sufficient information for us to adequately support a choice for the RMEI location in the final rule or should we leave that determination to NRC in their licensing process based upon our criteria;

(2) Another location in one of the three subareas identified previously should be the location of the RMEI; and

(3) Lathrop Wells and an ingestion rate of two liters per day of drinking water are appropriate high-end values for parameters to be used to project the RME. We also request comment upon the potential approaches and assumptions for the exposure scenario to be used for calculating the dose incurred by the RMEI.

III.B.5. How Will the General Population be Protected?

In section 801(a)(2)(A) of the EnPA, Congress asked whether an individual-protection standard could also protect the general population. In response, the NAS concluded that an individual-protection standard could provide such protection for the case of the proposed Yucca Mountain repository. The NAS premised this conclusion upon the condition that the public and policymakers would accept the idea that extremely small individual radiation doses spread out over large populations pose a risk that is negligible (NAS Report p. 57). The NAS refers to this concept as "negligible incremental risk" (NAS Report p. 59). Earlier, we described our proposed individual-protection standard for the RMEI which would establish the highest allowable radiation dose. This section of the notice raises another question—should we also adopt a standard to limit the possible widespread exposure of whole populations to extremely small individual doses?

In discussing the feasibility of protecting the general population from releases of radionuclides from Yucca Mountain, NAS considered the potential for the release of gaseous radionuclides. The NAS Report explained how the release of carbon dioxide gas containing ^{14}C from the Yucca Mountain disposal system might expose a large population:

> Global populations might be affected because radionuclide releases from a repository can in theory be diffused throughout a very large and dispersed population. In the case of Yucca Mountain, the likely pathway leading to widely dispersed radionuclides is via the atmosphere beginning with release of carbon dioxide gas containing the carbon-14 (^{14}C) radioactive isotope which might escape from the waste canisters. (NAS Report p. 7)

On page 61 of its Report, NAS estimated that the average dose to members of the global population, based upon this scenario, to be 0.003 μSv/year (0.0003 mrem/yr) and equated that to an annual risk of fatal cancer of 1.5 in 10 billion (1.5×10^{-10}).

The NAS relied upon the recommendations of the NCRP in its report titled "Limitation of Exposure to Ionizing Radiation" (NCRP Report No. 116) to support their claim that such doses are negligibly small. In this report, the NCRP stated that a radiation dose of less than 10 μSv (1 mrem)/yr for any source or practice would represent a "negligible incremental dose." The NCRP endorsed the assumption that there is some radiation risk for every radiation exposure. Further, they explained that there are great uncertainties in trying to understand the meaning of radiation effects upon populations, especially when these effects are calculated by summing extremely small individual doses among huge populations. Agreeing with this concept, the NAS preferred to use risk instead of dose. The NAS then estimated the risk level associated with the NCRP's NID level of 10 μSv/yr and adopted the term "negligible incremental risk." The NAS then proposed this NIR level as the starting point for a process to establish a risk level for individuals that would be "negligible."

For different reasons, we provisionally agree with the NAS that an individual-risk standard can adequately protect the general population near Yucca Mountain. Our agreement is based upon the particular characteristics of the Yucca Mountain site. We emphasize that our view relates to the specific circumstances associated only with Yucca Mountain. We are not proposing to adopt either an NID or NIR level. We are concerned that such an approach is not appropriate in all circumstances. Again, our proposed determination that an individual-risk standard is adequate to protect both the local and general population is based upon considerations unique to the Yucca Mountain site—it is not a general policy judgment by us upon other uses of the concept of NID or NIR.

We considered the NAS suggestion to adopt a general NIR level but have not done so because of reservations regarding the reasoning and analysis employed by NAS. As noted above, NAS referred to the NID level of 10 μSv (1 mrem)/yr per source or practice recommended by the NCRP. The International Atomic Energy Agency (IAEA) has made similar recommendations regarding exemptions in its Safety Series No. 89, "Principles for the Exemption of Radiation Sources and Practices from Regulatory Control." The IAEA has recommended that individual doses not exceed 10 μSv (1 mrem)/yr from each exempt practice. The IAEA's recommendations relate to criteria for exempting whole sources or practices, such as waste disposal or recycling generally, not whether radiation doses from a portion of a given practice, such as the release of gases from a specific geologic repository, may be considered negligible. Finally, the IAEA's recommendations intend their exemption to be for sources and practices "which are inherently safe." It is not clear that the low individual doses or risks projected from gaseous releases from the Yucca Mountain repository should be considered on their own as a "source" or "practice" or that such a source or practice should be considered inherently safe. Also, we believe it to be inappropriate to not calculate a radiation dose merely because the dose rate from a particular source is small.

Further, we are not sure it is appropriate to apply the NIR concept to consideration of population dose. A recent NCRP report questions the application of the negligible incremental dose (NID) concept to consideration of population doses. According to NCRP Report No. 121: "A concept such as the NID (Negligible Incremental Dose) provides a legitimate lower limit below which action to further reduce individual dose is unwarranted, but it is not necessarily a legitimate cut-off dose level for the calculation of collective dose. Collective dose addresses societal risk while the NID and related concepts address individual risk." Based upon this, we think it would be inappropriate to use the negligible incremental dose or risk concept to evaluate whether an individual-protection standard adequately protects the general population.

Although we do not advocate use of the NID concept, we acknowledge that the extremely low levels of individual risk and dose cited by NAS as being associated with the release of ^{14}C from Yucca Mountain are many orders of magnitude below the levels at which we have regulated in other circumstances. For example, we used the following policies under the pre-1990 Clean Air Act (CAA) hazardous air pollution control program: (1) provide public health protection for the greatest number of persons possible based upon a lifetime (70 years) risk level no higher than approximately 1 x 10^{-6} for an individual, and (2) limit the maximum, individual-lifetime, estimated risk to no higher than 1 in 10,000 (1 x 10^{-4}) (54 FR 51654, 51655, December 15, 1989). Even though we adopted this approach in a different policy context, it provides insight into how we have dealt with similar risk-management issues in a regulatory context. In 1990, Congress amended the CAA to require us to develop technology-based standards to reduce emissions. At the same time, Congress authorized us to delete categories of sources from regulation if no source in that category could cause a lifetime risk of cancer exceeding 1 x 10^{-6} for the most-exposed individual in the population. The risk over an individual's lifetime from exposure to gaseous ^{14}C released from the Yucca Mountain repository, as estimated by NAS, would be about 100 times lower than 10^{-6}. This particular risk level is extremely low and well below the risk level that we generally regulate.

The disposal standards in 40 CFR part 191 include release limits (or containment requirements) to protect populations and an individual-protection standard. We rejected adopting only an individual-protection standard in those standards because of a concern that an individual-dose limitation alone might encourage selection of disposal sites that relied upon dilution of radionuclides at the expense of increased overall population exposures. Specifically, we were concerned that, in the absence of release limits, "disposal sites near bodies of surface water or large sources of ground water might be preferred—which the Agency believes is an inappropriate policy that would usually increase overall population exposures" (50 FR 38066, 38078, September 19, 1985). For example, it is possible to have a site that could meet the 150 μSv (15 mrem)−CEDE/yr individual-protection standard while still having large numbers of people being exposed to radiation levels just below the standard. This scenario could result in significant numbers of calculated health effects for each generation exposed and very large numbers of calculated health effects over the regulatory period. We believe that the policy embodied in the generic 40 CFR part 191 disposal standards is sound. The provisions in 40 CFR part 191, which could apply to a variety of potential disposal sites, should discourage reliance upon dilution of radionuclides in the general environment as a disposal method.

However, the potential for large-scale dilution of radionuclides, through ground water and into surface water, as modeled in the supporting analyses for 40 CFR part 191, does not exist at Yucca Mountain, thereby minimizing the need for the kind of population-protection requirements found in 40 CFR part 191. Rather, DOE plans to locate the Yucca Mountain repository in an unsaturated rock formation with limited amounts of infiltrating water passing through it and into the underlying tuff aquifer. ("Unsaturated" means that the rock could absorb more water than it is holding.) That aquifer is, in turn, within a ground water system which discharges into arid areas having high evaporation rates and very little surface water. In other words, we believe that the characteristics of the saturated zone under Yucca Mountain are such that dilution from other sources will be limited and the aquifer does not discharge into any large bodies of surface water. Therefore, our basis for inclusion of a population-protection requirement in 40 CFR part 191 does not appear to apply to the development of site-specific standards for Yucca Mountain.

In addition, we based the release limits in 40 CFR part 191 partly upon technology and partly upon risk levels which we believed to be acceptably small. The technology basis for the release limits was based upon assessments of repository performance of several generic disposal systems, including one located in tuff. In finalizing 40 CFR part 191, we stated:

[T]he rule cannot be interpreted as setting precedents for ''acceptable risk'' levels to future generations that should not be exceeded regardless of the circumstances. Instead, because of a number of unique circumstances, the Agency has been able to develop standards for the management and disposal of these wastes that are both reasonably achievable . . . and that limit risks to levels that the Agency believes are clearly acceptably small. (50 FR 38066, 38070, September 19, 1985)

We developed these standards during the siting process mandated by the NWPA in the 1980s. The inclusion of release limits pointed to the importance of considering population doses during site selection. We established the standards at a level that appeared to be reasonably achievable for several types of rocks or geologic media and which would keep risks to future populations acceptably small. The assessments we performed in support of these generally applicable standards, however, did not include a gaseous-release pathway similar to that described by NAS for ^{14}C because no one foresaw the potential importance of that pathway at that time. In fact, according to the generic analyses we performed in support of 40 CFR part 191, the unsaturated site in tuff was generally more protective, in terms of limiting total releases, than the other geologic media we evaluated.

For these reasons, we do not believe that these generic analyses and conclusions supporting the development of release limits in 40 CFR part 191 are appropriate for judging the need for population-risk limits or the acceptability of population risks from releases from wastes in the Yucca Mountain disposal system. We are proposing to find that the individual-protection standard is sufficient to protect public health based upon the unique characteristics of the area around the Yucca Mountain site.

In summary, we are proposing to adopt an individual-protection standard for Yucca Mountain that will limit the annual radiation dose incurred by the RMEI to 150 μSv (15 mrem) CEDE. At the same time, we are not proposing to adopt a separate limit on radiation releases for the purpose of protecting the general population, but we are recommending that collective dose be estimated and considered (see the following paragraph). We based this decision upon several factors. The first factor is the NAS projection of extremely small doses to individuals resulting from air releases from Yucca Mountain. That dose level is well below the risk corresponding to our proposed individual-protection standard for Yucca Mountain. It is also well below the level that we have regulated in the past through other regulations. Further, while we decline to establish a general NIR level, we do agree with NAS that estimating the number of health effects resulting from a 0.0003 mrem/yr dose rate, in addition to the dose rate from background radiation, in the general population is uncertain and controversial. The second major factor is that, based upon current and site-specific conditions near Yucca Mountain, there is not likely to be great dilution resulting in exposure of a large population. In addition, we are proposing additional ground water protection standards that would establish specific limits to protect users of ground water and ground water as a resource. Finally, we are still proposing to require that all of the pathways, including air and ground water, would be analyzed by DOE and considered by NRC under the individual-protection standard. We request comment upon this approach. Commenters who disagree with this approach should specifically address why it is inappropriate for the Yucca Mountain disposal system and make suggestions about how we might reasonably address this issue.

While we are not proposing to adopt additional regulatory requirements for collective exposures of the general population from releases from the Yucca Mountain disposal system, we urge DOE to examine design alternatives for the disposal system, for the purpose of reducing potential risk to the general population, in the National Environmental Policy Act (NEPA) process for Yucca Mountain. We received public comments, in response to our request for comments regarding the NAS Report, noting that DOE had already proposed, in its Notice of Intent to prepare a NEPA-prescribed environmental impact statement (EIS) for Yucca Mountain, to evaluate technical alternatives (60 FR 40167, August 7, 1995). In other words, DOE has previously proposed to evaluate technical alternatives as part of its waste containment and isolation strategy for Yucca Mountain (DOE, ''Strategy for Waste Containment and Isolation for the Yucca Mountain Site,'' Preliminary Review Draft, October 9, 1995). Thus, we recommend that DOE incorporate these or similar considerations into its NEPA process to assess the effectiveness of design alternatives to mitigate population exposures.

The following language provides context to the approach we consider appropriate for calculating population exposure in the NEPA process. We recommend that DOE calculate the collective dose without truncation and with full consideration of the appropriate factors. This recommendation is supported by a recent NCRP report upon the principles and application of a collective dose in radiation protection (NCRP Report No. 121). The NCRP advocated the use of collective dose for optimization of protection and provided guidance on future exposures from long-lived radionuclides, the situation that will likely exist at Yucca Mountain:

The most reasonable risk assessment that can be made for such situations is to calculate potential individual doses for a range of scenarios in order to: (1) evaluate protective measures and (2) to try to place some boundaries on estimates of future individual risks. For the few very long-lived radionuclides that are metabolically regulated in the body and more or less uniformly distributed within the biosphere (e.g., ^{14}C and ^{129}I), future average individual doses may be estimated from total quantities in the environment. . . . (NCRP Report No. 121, pp. 57–58)

III.B.6. What Should Be Assumed About the Future Biosphere?

We propose to require DOE and NRC to use the biosphere assumptions described in this section in all analyses of repository performance, including the performance assessment for determining compliance with the individual-protection standard, the assessment for determining compliance with the ground water standards, and the human-intrusion analysis. Projecting biosphere conditions necessitates making assumptions, many of which are very uncertain and may not be boundable. The NAS stated:

In view of the almost unlimited possible future states of society and of the significance of these states to future risk and dose, . . . we have recommended that a particular set of assumptions be used about the biosphere (including, for example, how and where people get their food and water) for compliance calculations . . . we recommend the use of assumptions that reflect current technologies and living patterns. (NAS Report p. 122)

The NAS also stated:

. . . unlike our conclusion about the earth science and geologic . . . factors described [earlier], we believe that it is not possible to predict on the basis of scientific analyses the societal factors that must be specified in a far-future exposure scenario. . . . Any particular scenario about the future of human society near Yucca Mountain . . . should not be interpreted as reflecting conditions that eventually will occur. Although we recognize the burden on regulators to avoid regulations that are arbitrary, we know of no scientific method for identifying these [exposure] scenarios. (NAS Report p. 96)

We agree with the NAS on this point and propose that speculation concerning some characteristics of the future should not be the focus of the compliance determination process. Instead, we believe that it would be more appropriate to assume that those characteristics will be the same as they are today. No one should interpret this assumption so literally that only current residences and lifestyles of individuals living in the area on the day of promulgation of this part can be considered. Rather, we intend that, based upon current knowledge, DOE and NRC may use those characteristics in combinations in a cautious, but reasonable, manner as input into the Yucca Mountain performance projections. Future characteristics which NRC and DOE may assume to be the same as they are today include the level of human knowledge and technical capability (including medical), human physiology and nutritional needs, general lifestyles of the population, and potential pathways through the biosphere leading to radiation exposure of humans. Also, we propose that it is inappropriate to speculate upon extreme changes in the number of residents, but that consideration should be given to changes in population near the location of the RMEI.

In concert with the NAS Report, we also propose not to allow the assumption that conditions in the future will be the same as present conditions for geologic, hydrologic, and climatic conditions. We are proposing this because we believe the parameter values in the performance assessment which relate to these conditions can be reasonably bounded. We propose to require that these conditions be varied within reasonable bounds over the compliance period and request comment upon this proposed approach.

III.B.7. How Far Into the Future Is It Reasonable To Project Disposal System Performance?

The NAS recommended that the time over which compliance should be assessed, that is, the compliance period, should be "the time when the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment" (NAS Report p. 7). The NAS stated that it based this recommendation upon technical, not policy, considerations. However, we believe the selection of the compliance period necessarily involves both technical and policy considerations. For example, NAS stated that we might choose to establish similar policies for managing risks "from disposal of both long-lived hazardous nonradioactive materials and radioactive materials" (NAS Report p. 56). As NAS recognized, we must consider, in this rulemaking, both the technical and policy issues associated with establishing the appropriate compliance period for the performance assessment of the Yucca Mountain disposal system.

We request public comment upon two alternatives for the compliance period for the individual-protection standard. One alternative is to adopt a compliance period that is the time to peak dose within the period of geologic stability. The second alternative is to adopt a time period during which the repository must meet the disposal standards. For the reasons described below, we believe that the second alternative is preferable. Therefore, we are proposing that the peak dose within 10,000 years after disposal must comply with the individual-protection standard. Also, the EPA-preferred approach would require calculation of the peak dose within the period of geologic stability. It does not, however, apply a quantitative limit after 10,000 years. The intent of examining disposal system performance after 10,000 years is to estimate the long-term performance of the disposal system to see if dramatic changes in the performance of the disposal system could be anticipated. We would require DOE to include the results and bases of the additional analysis in the EIS for Yucca Mountain as an indicator of the future performance of the disposal system. This analysis also would serve as another source of information for decisionmakers in making both design and licensing decisions. However, NRC is not to use the additional analysis in determining compliance with proposed § 197.20.

The principal tool used to assess compliance with the individual-protection standard is a quantitative performance assessment. This method relies upon modeling of the potential processes and events leading to releases of radionuclides from the disposal system, subsequent radionuclide transport, and consequences upon health. To consider compliance for any length of time, several facets of knowledge and technical capability are necessary. First, the scientific understanding of the relevant, potential processes and events leading to releases must be sufficient to allow a quantitative estimate of projected repository performance. Second, adequate analytical methods and numerical tools must exist to incorporate this understanding into a quantitative assessment of compliance. Third, scientific understanding, data, and analytical methods must be adequately developed to allow evaluation of performance with sufficient robustness to judge compliance with reasonable expectation over the regulatory period. Finally, the analyses must be able to produce estimated results in a form capable of comparison with the standards.

The NAS evaluated these requirements for Yucca Mountain and concluded that those aspects of disposal system and waste behavior that depend upon physical and geologic properties can be estimated within reasonable limits of uncertainty. Also, NAS believed that these properties and processes are sufficiently understood and boundable over the long periods at issue to make such calculations possible and meaningful. The NAS acknowledged that these factors cannot be calculated precisely, but concluded that there is a substantial scientific basis for making such calculations. The NAS concluded that by taking uncertainties and natural variabilities into account, it would be possible to estimate, for example, the concentration of radionuclides in ground water at different locations and the times of gaseous releases. Second, NAS concluded that the mathematical and numerical tools necessary to evaluate repository performance are available or could be developed as part of the standard-setting or compliance-determination processes. Third, NAS concluded that: "So long as the geologic regime remains relatively stable, it should be possible to assess the maximum risks with reasonable assurance" (NAS Report p. 69). The NAS used the term "geologic stability" to describe the situation where geologic processes, such as earthquakes and erosion, that could affect the performance assessment of the Yucca Mountain site are active (not static) and are expected to occur. Based upon the use of the terms "stable" and "boundable" throughout the NAS Report, one can infer that NAS applied the term "geologic stability" or "stable" to the situation where the rate of processes and numeric range of individual physical properties could be bounded with reasonable certainty. The subsequent use of the term ''stable'' will not imply static conditions or processes. Rather, it will describe the properties and processes that can be bounded. Finally, NAS found that the established procedures of risk analysis should enable the results of each performance simulation of the disposal system to be combined into a single estimate for comparison with the standard.

Time to peak dose within the period of geologic stability. The NAS recommended that the compliance period for the Yucca Mountain disposal system be the time to peak risk within the long-term stability of the geologic environment. Since the time to peak risk is generally the time to peak dose, subsequent discussion of the NAS findings will refer to the time to peak dose. The ''peak dose'' is the mean value of the range of the highest potential annual doses, as determined by the performance assessment, incurred by the RMEI within the compliance period. The NAS based its recommendation to use the time to peak dose upon its review of:

(1) The technical analyses supporting 40 CFR part 191;

(2) Information derived from current performance assessments of the Yucca Mountain disposal system; and (3) The geologic and physical processes that could affect the release and transport of radionuclides to the biosphere.

The 40 CFR part 191 standards contain a compliance period of 10,000 years. There were three reasons that we set this time frame:

(1) After that time, there is concern that the uncertainties in compliance assessment become unacceptably large (50 FR 38066, 38076, September 19, 1985);

(2) There are likely to be no exceptionally large geologic changes during that time (47 FR 58196, 58199, December 29, 1982); and

(3) Using time frames of less than 10,000 years does not allow for valid comparisons among potential sites. For example, for 1,000 years, all of the generic sites analyzed appeared to contain the waste approximately equally because of long ground water travel times at well-selected sites (47 FR 58196, 58199, December 29, 1982).

One purpose of geologic disposal is to provide long-term barriers to the movement of radionuclides into the biosphere (NAS Report p. 19). As described earlier, the Department plans to locate the Yucca Mountain repository in tuff about 300 meters above the local water table. When nongaseous radionuclides are released from the waste packages, they most likely will be transported by rain water that moves from the surface both horizontally within individual tuff layers and vertically downward, through fractures in the tuff layers, toward the underlying aquifer. Once the radionuclides reach the aquifer, they will be carried away from the repository in the direction of ground water flow. The most probable route for exposing humans to radiation resulting from releases from the Yucca Mountain disposal system is via withdrawal of contaminated water for local use. In the case of Yucca Mountain, DOE estimates that most radionuclides would not reach currently populated areas within 10,000 years (see the BID).

While this finding alone seems to indicate that the compliance period for Yucca Mountain should be longer than 10,000 years to be protective, NAS concluded that the need to consider the exposures when they are calculated to occur must be weighed against the problem of cumulative uncertainty. As noted above, exposures could occur over tens-to hundreds-of-thousands of years. However, as the compliance period is extended to such lengths, uncertainty increases and the resulting projected doses are increasingly meaningless from a policy perspective. The NAS stated that there are significant uncertainties in a performance assessment and that the overall uncertainty increases with time. Even so, NAS found that, ''. . . there is no scientific basis for limiting the time period of the individual-risk standard to 10,000 years or any other value'' (NAS Report p. 55). Estimates by NRC and DOE related to the Yucca Mountain disposal system have indicated wide differences in estimates of the time that radionuclides may take to reach the biosphere and cause the peak dose to occur (see the BID). However, while the results have indicated that the time to peak dose may vary anywhere from a few tens-of-thousands to hundreds-of-thousands of years, the estimated values of the peak doses, while separated in time, are similar in magnitude (see the BID). These estimates differ because the analysts used different assumptions and conceptual models for flow and transport of radionuclides through the Yucca Mountain unsaturated zone. We believe that this situation will exist independently of the compliance-period issue. The NAS also stated that data and analyses of some of the factors that are uncertain at one time might be more certain at a later time. For example, there is uncertainty as to how many waste packages might fail in the near term. However, at some later time in the distant future, the uncertainty is very small because when enough time has passed, all of the packages will fail (NAS Report p. 72). Also, NAS stated that many of the uncertainties in parameter values describing the geologic system are not due to the length of time but rather to the difficulty in estimating values of site characteristics which vary across the site. We believe that these difficulties are always present and that analysts must consider them in the compliance assessment for any period chosen (NAS Report p.72).

As NAS noted, evaluating compliance with the 40 CFR part 197 standards depends upon being able to:

(1) Understand and model radionuclide-transport processes and the processes and events that might lead to transport;

(2) Use appropriate analytical methods to determine the levels of human exposure;

(3) Quantify or bound the probabilities of the processes and events, including the related uncertainties; and

(4) State the results in a form capable of being compared with the standards.

The NAS reviewed how radionuclides might enter the biosphere in order to determine the feasibility of evaluating them in a compliance assessment. In addition, to determine whether the modifying processes should also be evaluated in a compliance assessment, NAS analyzed the geologic and physical processes that could modify the properties of the contaminant-containing media and processes by which radionuclides are moved.

The radionuclide-transport processes evaluated by NAS included:

(1) Release from the waste form;

(2) Transport from canisters into the near-field (near the waste canisters) unsaturated zone;

(3) Gas-phase transport from the unsaturated zone into the atmosphere around Yucca Mountain;

(4) Atmospheric circulation leading to dispersal of gaseous radionuclides in the global atmosphere;

(5) Aqueous-phase transport from the unsaturated zone to the water table; and

(6) Transport of radionuclides through the saturated zone beneath the repository to other locations from which water may be extracted by humans or ultimately reach the surface at a discharge area (NAS Report pp. 85–90).

The NAS concluded that these processes are ''sufficiently quantifiable and the uncertainties are sufficiently boundable that they can be included in performance assessments that extend over time frames corresponding to those over which the geologic system is relatively stable or varies in a boundable manner'' (NAS Report p. 85). The NAS concluded that the ''geologic record suggests that this time frame is on the order of about one million years'' (NAS Report pp. 9 and 85). Likewise, NAS concluded that the probabilities and consequences of these processes and events that could modify the way in which radionuclides are moved in the vicinity of Yucca Mountain, including climate change, seismic activity, and volcanic eruptions, ''are sufficiently boundable so that these factors can be included in performance assessments that extend over periods on the order of about one million years'' (NAS Report p. 91).

Thus, NAS recommended, on a technical basis, that the compliance period for the protection of the individual should extend to the time of the peak dose during the period in which geologic processes are stable or boundable. This would require determining compliance and licensing the disposal system on the basis of projections of performance over tens- to hundreds-of-thousands of years into the future. We believe that such an approach is not practical for Yucca Mountain.

As noted earlier, NAS concluded that ''there is no scientific basis for limiting the time period of the individual-risk standard to 10,000 years or any other value.'' Nevertheless, there is still considerable uncertainty as to whether current modeling capability allows development and validation of computer models that will provide sufficiently meaningful projections over a time frame up to tens-of-thousands to hundreds-of-thousands of years. Simply because such models can provide projections for those time periods does not mean those projections are either meaningful for decisionmakers or accurate. Furthermore, we are not aware of a policy basis that we could use to determine the level of proof or confidence necessary to determine compliance based upon projections of hundreds-of-thousands of years into the future. While NAS indicated that analyses of the performance of the Yucca Mountain disposal system dealing with the far future can be bounded, a large and cumulative amount of uncertainty is associated with those numerical projections. Setting a strict numerical standard at a level of risk acceptable today for the period of geologic stability would tend to ignore this cumulative uncertainty. For example, if the performance assessment indicates that the peak dose occurs 600,000 years in the future at an annual CEDE that has an uncertainty range of 0.1 mrem to 10,000 mrem, does that indicate that the disposal system is safe or unsafe and should NRC license it or not? In light of the cumulative uncertainty for calculations over an extremely long time, it may be more appropriate to consider, in a regulatory decisionmaking, assessments of disposal system performance over such time in a qualitative manner. We request comments upon the reasonableness of adopting the NAS-recommended compliance period or some other approach in lieu of the 10,000-year compliance period which we favor and describe below. We also seek comment upon whether the NAS-recommended compliance period can be implemented in a reasonable manner and how that could be done.

A 10,000-year compliance period (proposed § 197.20). As noted earlier, the selection of the compliance period for the individual-protection standard involves both technical and policy considerations. It is our responsibility to weigh both during this rulemaking. In addition to the technical guidance provided in the NAS Report, we have considered several policy and technical factors that NAS did not fully address.

First, as suggested by NAS, we evaluated the policies for managing risks from the disposal of both long-lived, hazardous, nonradioactive materials and radioactive materials. Second, we evaluated consistency with both 40 CFR part 191 and the issue of consistent time periods for the protection of ground water resources and public health. Third, we considered the issue of uncertainty in predicting dose over the very long periods contemplated in the alternative of peak dose within the period of geologic stability. Finally, we reviewed the feasibility of implementing the alternative of peak risk within the period of geologic stability, as recommended by NAS. As a result of these considerations, we are proposing a 10,000-year compliance period with a quantitative limit and a requirement to calculate the peak dose, using performance assessments, if the peak dose occurs after 10,000 years. Under our proposal, the performance assessment results for the post-10,000-year period must be made part of the public record by DOE including it in the EIS for Yucca Mountain.

In its discussion of the policy issues associated with the selection of the time period for compliance, NAS suggested that we might choose to establish consistent risk-management policies for long-lived, hazardous, nonradioactive materials and radioactive materials. We previously addressed the 10,000-year compliance period in the regulation of hazardous waste subject to land-disposal restrictions. Land disposal, as defined in 40 CFR 268.2(c), includes, but is not limited to, any placement of hazardous waste in land-based units such as landfills, surface impoundments, and injection wells. Facilities may seek an exemption by demonstrating that there will be no migration of hazardous constituents from the disposal unit for as long as the waste remains hazardous (40 CFR 268.6). We have interpreted the phrase ''for as long as the waste remains hazardous'' to mean that the no-migration demonstration shows that hazardous constituents will not exceed acceptable concentration levels for as long as the constituents retain the potential to harm human health and the environment. This period may include not only the operating phase of the facility, but also what may be an extensive period after facility closure. With respect to injection wells, we have specifically required a demonstration that the injected fluid will not migrate within 10,000 years (40 CFR 148.20(a)). We chose the 10,000-year performance period referenced in our guidance upon no-migration petitions, in part, to be equal to time periods cited in draft or final DOE, NRC, and EPA regulations (10 CFR 960, 10 CFR 60, or 40 CFR 191, respectively) governing siting, licensing, and releases from HLW disposal systems. With respect to other land-based units regulated under the Resource Conservation and Recovery Act (RCRA) hazardous-waste regulations, we concluded that the compliance period is specific to the waste and site under consideration. For example, for the WIPP no-migration petition, we found that ''it is not particularly useful to extend this model beyond 10,000 years into the future.* * * [However, t]he agency does believe * * * that modeling over a 10,000-year period provides a useful tool in assessing the long-term stability of the repository and the potential for migration of hazardous constituents'' (55 FR 13068, 13073, April 6, 1990).

Second, the individual-protection requirements in 40 CFR part 191 (58 FR 66398, 66414, December 20, 1993) have a compliance period of 10,000 years. The part 191 standards apply to the same types of waste and type of disposal system as proposed for Yucca Mountain. However, as we explained in the *What Led up to Today's Action?* section earlier in this notice, by statute the part 191 requirements do not apply to Yucca Mountain. If we finally adopt the 10,000-year compliance period, it would require the same compliance period for the Yucca Mountain disposal system as for other disposal systems subject to 40 CFR part 191. Such a requirement would be consistent with 40 CFR part 191, which we deem appropriate since both sets of standards apply to the same types of waste.

Third, we are concerned that there might be large uncertainty in projecting human exposure due to releases from the repository over extremely long periods. We agree with the NAS conclusion that it is possible to evaluate the performance of the Yucca Mountain disposal system and the lithosphere within certain bounds for relatively long periods. However, we believe that NAS might not have fully addressed two aspects of uncertainty.

One of the aspects of uncertainty relates to the impact of long-term natural changes in climate and its effect upon choosing an appropriate RMEI. For extremely long periods, major changes in the global climate, for example, a transition to a glacial climate, could occur (see the BID). However, over the next 10,000 years, the biosphere in the Yucca Mountain area will probably remain, in general, similar to present-day conditions due to the rain-shadow effect of the Sierra Nevada Mountains, which lie to the west of Yucca Mountain (see the BID). For the longer periods contemplated for the alternative of time to peak dose, the global climate regime is virtually certain to pass through several glacial-interglacial cycles, with the majority of time spent in the glacial state (NAS Report p. 91). These longer periods would require the specification of exposure scenarios that would not be based upon current knowledge or cautious, but reasonable, assumptions, but rather upon potentially arbitrary assumptions. The NAS indicated that it knew of no scientific basis for identifying such scenarios (NAS Report p. 96). It is for these reasons that such extremely long-term calculations are useful only as indicators, rather than accurate predictors, of the long-term performance of the Yucca Mountain disposal system (IAEA TECDOC–767, 1994).

The other aspect of uncertainty concerns the range of possible biosphere conditions and human behavior. It is necessary to make certain assumptions regarding the biosphere, even for the 10,000-year alternative, because the period of 10,000 years represents a very long compliance period for current-day assessments to project performance. For example, it is twice as long as recorded human history (see the *What Should Be Assumed About the Future Biosphere?* section earlier in this notice). For periods approaching the 1,000,000 years that NAS contemplated under the peak-dose alternative, even human evolutionary changes become possible. Thus, reliable modeling of human exposure may be untenable and regulation to the time of peak dose within the period of geologic stability could become arbitrary.

Fourth, many international geologic disposal programs use a 10,000-year regulatory compliance period as a requirement.

Finally, an additional complication associated with the time to peak dose within the period of geologic stability is that it could lead to a period of regulation that has never been implemented in a national or international radiation regulatory program. Focusing upon a 10,000-year compliance period forces more emphasis upon those features over which man can exert some control, such as repository design and engineered barriers. It is unlikely that over much longer time frames that any engineered barrier will be effective. Those features, the geologic barriers, and their interactions define the waste isolation capability of the disposal system. By focusing upon an analysis of the features that man can influence or dictate at the site, it may be possible to influence the timing and magnitude of the peak dose, even over times longer than 10,000 years.

Thus, we request comment upon our proposal of a 10,000-year compliance period to judge compliance with proposed § 197.20 and our proposal to require consideration of the peak dose, using performance assessments, if it occurs after 10,000 years. Again, after 10,000 years, we would not require the calculated level to comply with a specific numerical standard but we would require its consideration as an indicator of longer-term performance and be included in the EIS for Yucca Mountain.

We also request comment upon the appropriateness of a 10,000-year compliance period for the individual-protection standard. Commenters should address the issues that we should consider in determining the appropriate compliance period. We also specifically request comments upon whether the NAS' recommendation of the time to peak dose within the period of geologic stability can be implemented reasonably and, if so, how that could be done.

III.C. What Are the Requirements for Performance Assessments and Determinations of Compliance? (Proposed §§ 197.20, 197.25, and 197.35)

III.C.1. What Limits Are there on Factors Included in the Performance Assessments?

The Commission is responsible for deciding whether or not to license the Yucca Mountain disposal system. It must make that decision based largely upon whether DOE has demonstrated compliance with our standards in 40 CFR part 197. Under the proposed 40 CFR part 197, the quantitative analysis underlying that decision will be a performance assessment (the proposed definition of ''performance assessment'' is in § 197.12). We are proposing that performance assessments be a requirement of licensing. The EnPA requires that the Commission modify its technical requirements for licensing the disposal system to be consistent with our final 40 CFR part 197 standards. Therefore, our standards would require DOE to complete a performance assessment prior to applying for a license and would require NRC to determine, taking into consideration that performance assessment, whether the disposal system's projected performance complies with § 197.20.

We also are proposing, consistent with the performance assessment requirements in 40 CFR part 191:

(1) To exclude from performance assessments those natural processes and events whose likelihood of occurrence is so small that they are very unlikely;

(2) That such performance assessments need not include categories of processes or events that DOE and NRC estimate to have less than a 1 in 10,000 (1×10^{-4}) chance of occurring during the 10,000 years after disposal. Probabilities below this level are associated with events such as the appearance of new volcanoes outside of known areas of volcanic activity or a cataclysmic meteor impact in the area of the repository. We believe there is little or no benefit to public health or the environment from trying to regulate the effects of such very unlikely events; and

(3) That the performance assessment need not evaluate, in detail, the releases from processes, events, and sequences of processes and events estimated to have a likelihood of occurrence greater than 1×10^{-4} of occurring during the 10,000 years following disposal, if there is a reasonable expectation that the time to, or the magnitude of, the peak dose would not be changed significantly by such omissions. As necessary, the Commission may provide specific

guidance upon scenario selection and characterization to assure that processes or events are not excluded inappropriately.

A related issue upon which we request comment is if there is a period of the geologic record which we should require DOE and NRC to use to calculate the probability of processes and events occurring. The probability of a geologic event, such as an earthquake, occurring in the future typically comes from evidence of previous events which is preserved in, and can be dated by using, the geologic record. We believe that the geologic record is best preserved in the relatively recent past.

We are also proposing to require that DOE and NRC use quantitative assessments to determine compliance with the human-intrusion and ground water protection standards (see the *What Is the Standard for Human Intrusion?* and *How Will Ground Water Be Protected?* Sections later in this notice). The human-intrusion analysis would require a separate assessment of the effects of human intrusion upon the resilience of the Yucca Mountain disposal system. Following the recommendation of NAS, we intend the analysis to be an assessment of the disposal system's isolation capability following a single, stylized, human intrusion. The analysis required to determine compliance with the ground water protection standards applies only to undisturbed performance.

We are proposing to allow the exclusion of unlikely natural events from both the ground water and human-intrusion assessments. The approach for the ground water protection requirements is consistent with subpart C of 40 CFR part 191, "Environmental Standards for Ground-Water Protection" while the approach for the human-intrusion assessment is consistent with the NAS recommendation (see the *What Is the Standard for Human Intrusion?* section later in this notice). We request public comment upon whether this approach is appropriate for Yucca Mountain.

III.C.2. Is Expert Opinion Allowed?

The quantitative requirements in proposed subpart B of part 197 require:

(1) Evaluation of processes, events, and sequences of processes and events leading to radionuclide releases from the disposal system;

(2) Estimation of the resulting doses or radionuclide concentrations; and

(3) Estimation of the likelihood of the resulting doses or radionuclide concentrations.

The likelihood of the processes, events, and sequences of processes and events occurring should be estimated by DOE and NRC based upon current scientific knowledge of previous occurrences. However, it is likely that there will be processes, events, and sequences of processes and events which have not occurred or occurred too infrequently to be statistically significant. This situation will require the use of expert opinion, for example, scientific and engineering expertise, to arrive at cautious, but reasonable, estimates of the probability of future occurrence. Also, there likely will be many other areas where DOE could use expert opinion, for example, when there are multiple models applicable to the performance assessment or human-intrusion analysis, or significant uncertainties in the variation of parameter values.

There are two commonly used methods for the gathering of expert opinion, namely, expert judgment and expert elicitation. Expert judgment is typically obtained informally from one or more individuals and is noted by the person(s) seeking the judgment in documentation used to support the activity. In contrast, expert elicitation is a formal, structured, and thoroughly documented process. Whether it is appropriate to conduct an expert elicitation depends upon the issue under consideration.

We have considered setting guidelines for the use of expert elicitation. The type of guidelines we considered could include one or all of the following requirements when expert elicitation is used: (1) the Commission needs to consider the source and use of the information so gathered; (2) we would expect the Commission to assure that, to the extent possible, experts with both expertise appropriate for the subject matter and independence from DOE will be on the expert elicitation panel consulted to judge the validity and adequacy of the model(s) or value(s) for use in a compliance assessment; and (3) when DOE presents information to the expert elicitation panel, it should do so in a public meeting, and qualified experts, such as representatives of the State, should be given an opportunity to present information.

If we were to set any requirement, we would have to consider whether NRC may allow DOE to use expert elicitations, which did not follow these rules but were completed prior to the effective date of part 197, for the purpose of determining compliance with the provisions of part 197. We believe that it would probably be an unnecessary use of time and resources to require such work to be repeated or not be used if the Commission judges them to be acceptable.

We request comment upon whether it is appropriate for us to set guidelines for the use of expert opinion in this standard and, if so, what those guidelines should be.

III.C.3. What Level of Expectation Is Required for NRC To Determine Compliance?

While the provisions in this rule establish minimum requirements for implementation of the disposal standards, NRC may establish requirements that are more stringent. As mentioned in the previous section, we are proposing the concept of "reasonable expectation" to reflect our intent regarding the level of "proof" necessary for NRC to determine whether the projected performance of the Yucca Mountain disposal system complies with the standards (see proposed §§ 197.20, 197.25, and 197.35). We intend for this term to convey our position and intent that unequivocal numerical proof of compliance is neither necessary nor likely to be obtainable. The NRC has used a similar qualitative test, "reasonable assurance," for many years in its regulations. However, the NRC regulations are focused upon engineered systems with relatively short lifetimes, for example, nuclear power reactors. We believe that for very long-term projections, involving the interaction of natural systems with the engineered system and the uncertainties associated with the long time periods involved, a different approach may be more appropriate.

Therefore, we are proposing to require that the test of disposal system compliance be a "reasonable expectation" that the standards will be met. In carrying out performance assessments under a "reasonable expectation" approach, all parameters that significantly affect performance would be identified and included in the assessments. The distribution of values for these parameters would be made to the limits of confidence possible for the expected conditions in the natural and engineered barriers and the inherent uncertainties involved in estimating those values. Selecting parameter values for quantitative performance assessments would focus upon the full range of defensible and reasonable parameter distributions rather than focusing only upon the tails of the distributions as is more commonly done under the "reasonable assurance" approach. The "reasonable expectation" approach also would not exclude important parameters from the assessments because they are difficult to quantify to a high degree of confidence. Some parameters, such as corrosion rates for metal container components, may be quantified with a high degree of accuracy and precision. Others, such as the amount of water entering a waste emplacement drift and dripping onto a waste package, cannot be quantified with a high degree of accuracy and precision, but are very important to a realistic assessment of performance. Overestimating or underestimating the values of parameters, or ignoring the positive effects upon performance for other processes and parameters because they cannot be precisely estimated, would essentially result in the performance assessments actually being analyses of extreme performance scenarios. These extreme assessments have a high probability of being unrealistic or of such low probability that they would not represent the range of likely performance for the disposal system.

We note that if the compliance period for the individual-protection standard extended to the time of peak dose within the period of geologic stability (which NAS estimated to be one million years for the Yucca Mountain site), this test would allow for decreasing confidence in the numerical results of the performance assessments as the compliance period increases beyond 10,000 years. For example, this means that the weight of evidence necessary, based upon reasonable expectation, for a compliance period of 10,000 years would be greater than that required for a compliance period of hundreds of thousands of years.

III.D. Are There Qualitative Requirements To Help assure Protection?

In addition to the quantitative limits in the standards, we considered several qualitative principles called "assurance requirements." We considered including such requirements because of the uncertainties that exist in projecting the effects of releases from radioactive waste over long periods. The intent for such assurance requirements would be to add confidence that the Yucca Mountain disposal system will achieve the level of protection proposed in the quantitative standards. This is the same approach that we require in 40 CFR part 191 and would provide similar protection regarding Yucca Mountain. The NAS also recognized the need for protection beyond that provided by the disposal system when it addressed institutional controls in its Report (NAS Report p. 11).

The assurance requirements we considered included the use of passive and active institutional controls, monitoring, the use of multiple barriers to isolate waste, and the ability to locate and remove the waste after disposal. In 40 CFR part 191, there is a sixth assurance requirement, 40 CFR 191.14(e), which we consider to be inappropriate for the Yucca site. The purpose of that requirement is to avoid sites where there are resources that might increase the likelihood of human intrusion. Congress specifically designated the Yucca Mountain site for characterization, so avoiding sites close to resources is not relevant in this instance. Further, the EnPA specifically dictates that we establish standards for the Yucca Mountain site so the intent of influencing site selection does not apply here.

We recognize that no one can accurately project the increase of protection brought by these assurance requirements. Under 40 CFR part 191, which we promulgated under the authority of the Atomic Energy Act of 1954, as amended (42 U.S.C. 2022), NRC is exempted from the assurance requirements because it included equivalent provisions in 10 CFR part 60, the NRC regulations which implement 40 CFR part 191. The EnPA requires NRC to modify its technical requirements and criteria to be consistent with our standards for Yucca Mountain. We request comment upon whether it is appropriate for us to establish assurance requirements in 40 CFR part 197, and if so, what those requirements should be.

III.E. What Is the Standard for Human Intrusion? (Proposed § 197.25)

Previous standards and regulations for radioactive waste disposal, for example, 40 CFR part 191 for SNF and HLW and 10 CFR part 61 for LLW, included consideration of inadvertent human intrusion which could affect the release rate from, and the resultant quantity of radionuclides leaving, a disposal system.

In section 801(a)(2)(B) of the EnPA, Congress inquired about whether active institutional controls could effectively stop human intrusion into the Yucca Mountain disposal system (see Background on and Summary of the NAS Report section earlier in this notice). In its Report, NAS concluded that the answer to this question was "no" (NAS Report p. 11). The NAS reasoned that an answer of "yes" would require assumptions that active institutional controls will endure and that future generations are willing to dedicate resources for this purpose for a period longer than recorded human history. In support of its opinion, NAS stated, "that there is no scientific basis for making projections over the long term of either the social [or] institutional...status of future societies' (NAS Report p. 106).

It was NAS' opinion that human intrusion is plausible at Yucca Mountain and that the standards should, therefore, include consideration of the effects of human intrusion. In order to assess the effects of human intrusion, one must determine the probability of its occurrence sometime in the future and the consequences of that intrusion. Whether it is possible to predict the probability or frequency of human intrusion in a scientifically supportable manner was the third and final question posed by Congress in the EnPA (section 801(a)(2)(C)). The NAS concluded "that there is no technical basis for predicting either the nature or the frequency of occurrence of intrusions' and that although accurate prediction of the frequency of human intrusion is not possible, calculations can project potential consequences of assumed human-intrusion events (NAS Report p. 106). The NAS thus recommended that we assume that an intrusion will occur and that we specify an intrusion scenario for DOE and NRC to use to evaluate the "resilience" of the repository. The NAS stated: "The key performance issue is whether repository performance would be substantially degraded as a consequence of an inadvertent intrusion...." (NAS Report p. 121).

In following that recommendation, we are proposing a single-borehole intrusion scenario based upon Yucca Mountain-specific conditions. The intended purpose of analyzing this scenario "...is to examine the site-and design-related aspects of repository performance under an assumed intrusion scenario to inform a qualitative judgment" (NAS Report p. 111). The assessment would result in a calculated RMEI dose arriving through the pathway created by the assumed borehole (with no other releases included). Consistent with the NAS Report, we also are proposing "that the conditional risk as a result of the assumed intrusion scenario should be no greater than the risk levels that would be acceptable for the undisturbed-repository case" (NAS Report p. 113). We are proposing to interpret the NAS" term "undisturbed" to mean that the Yucca Mountain disposal system is not disturbed by human intrusion but could be disturbed by other processes or events which are likely to occur.

We also are proposing that the human-intrusion analysis of repository performance use the same methods and RME characteristics for the performance assessment as those required for the individual-protection standard, with two exceptions. Those exceptions are that the human-intrusion analysis would exclude unlikely natural events and that the analysis would only address the releases occurring through the borehole (see the *What Are the Requirements for Performance Assessments and Determinations of Compliance?* section earlier in this notice).

Concerning intentional intrusion, NAS concluded that: "We also considered intentional intrusion...but concluded that it makes no sense...to try to protect against the risks arising from the conscious activities of future human societies'' (NAS Report p. 114). We agree with this conclusion and propose to find it acceptable to exclude long-term or deliberate, as opposed to acute and inadvertent, human disturbance of the disposal system from the human-intrusion analysis on the theory that society could retain at least some general knowledge of the disposal system and, therefore, would know that such actions could be dangerous. The proposed human-intrusion scenario, therefore, includes only an acute, inadvertent intrusion.

Description of the proposed human-intrusion scenario. To develop an appropriate scenario, we reviewed information about known resources and geologic characteristics of the Yucca Mountain site associated with past and current drilling for resources in the area surrounding Yucca Mountain that could have an effect upon the type of proposed human-intrusion scenario (see the BID). Based upon this examination, we are proposing to adopt the NAS-suggested starting point for a human-intrusion scenario. That scenario is a single, stylized intrusion through the repository to the underlying aquifer based upon current drilling practices. The proposed scenario presumes that the intrusion occurs because of exploratory drilling for water. There are a number of reasons why people in the future could be drilling within the repository area, e.g., archeological pursuits, mineral exploration, or geological investigations. However, we believe that drilling for water is, for regulatory purposes, the best example of an intrusion scenario. The choice of exploratory drilling for water is not a prediction that this type of intrusion will occur or that it will occur on the surface slopes overlying the repository but it is necessary to fulfill the NAS' consideration that a borehole "of specified diameter [is] drilled from the surface through a canister of waste to the underlying aquifer'' (NAS Report p. 111). Exploratory drilling for water, using current technology, essentially fixes the diameter of the borehole and drilling from the surface necessarily places the drill rig somewhere above the repository, but not necessarily on the crest of Yucca Mountain. For purposes of determining compliance with the human-intrusion standard, DOE must calculate the CEDE incurred by the RMEI using only releases through the pathway created by the assumed borehole (with no other releases included).

Under our proposal, NRC would specify when the intrusion would occur based upon the earliest time that current technology and practices could lead to waste package penetration. However, it must not occur sooner than the cessation of active institutional controls (see the *Are There Qualitative Requirements To Help Assure Protection?* section earlier in this notice). In general, we believe that the time frame for the drilling intrusion should be within the period that a small percentage of the waste packages have failed but before significant migration of radionuclides from the engineered barrier system has occurred since, based upon our understanding of drilling practices, this would be about the earliest time that impact with a waste package would not be recognized by a driller. Our review of information about drilling and experiences of drillers indicates that special efforts, for example, changing to a specialized drill bit, would likely be necessary to penetrate intact, nondegraded waste packages of the type DOE plans to use. As stated earlier, NRC would determine the timing as part of the licensing process. The Department's waste-package performance estimates indicate that a waste package would be recognizable to a driller for at least thousands of years (see the BID).

This is consistent with NAS' example scenario (NAS Report pp. 111–112). It requires evaluation of a single, nearly vertical borehole from the surface that breaches the repository, passes through a degraded waste package, and reaches the water table. We also are proposing that careful sealing of the borehole does not occur, but that natural processes gradually modify the transport characteristics within the borehole. In determining compliance, we are proposing that it is appropriate to assume that the result is no more severe than the creation of a ground water flow path from the crest of Yucca Mountain through the repository and into the ground water table. By proposing this single-borehole, single-waste-package scenario, we are not suggesting that other forms or types of human intrusion, or that intrusion as a result of a resource other than water, will not occur. For example, we know of different drilling techniques such as slanted, horizontal, and robotic which, in theory, could result in more penetrated waste packages. However, we do not believe that more complex scenarios would provide more information about the resilience of the repository than would the proposed scenario.

We also considered use of a human-intrusion scenario consistent with that required in EPA's criteria for certifying WIPP (40 CFR part 194). These criteria required DOE to identify the rate of resource drilling in the area surrounding the WIPP for the past 100 years (approximately the period of recorded history for drilling events in the area). DOE was required to then use this drilling rate in its performance assessment to determine the number of intrusions into the repository over the 10,000-year regulatory period. We considered this approach appropriate for the WIPP facility given the considerable amount of drilling in the vicinity of the site. We chose not to propose this approach for the Yucca Mountain facility given the recommendation in the NAS Report. We request comment upon the reasonableness of the proposed human-intrusion scenario, and whether an approach similar to that used for WIPP is more appropriate.

As noted earlier, we are proposing to use the same RME descriptors for this analysis and scenario as in the assessment for compliance with the individual-protection standard. While one could postulate that an individual occupies a location above the repository footprint in the future and is impacted by radioactive material brought to the surface during an intrusion event, the level of exposure of such an individual would be independent of whether the repository performs acceptably when breached by human intrusion in the manner prescribed in the proposed scenario. Movement of waste to the surface as a result of human intrusion is an acute action with the resulting exposure being a direct consequence of that action. Thus, we propose to interpret the NAS-recommended test of "resilience'' to be a longer-term test as measured by exposures caused by releases which occur gradually through the borehole, not suddenly as with direct removal. In addition, the effects of direct removal depend upon the specific parameters involved with the drilling and not upon the containment characteristics of the disposal system. We also are proposing that the test of the resilience of the repository system be the dose incurred by the same RMEI as determined for the individual-protection standard. This is consistent with the NAS' recommendation.

We request comment upon how much the human-intrusion analysis will add to protection of public health. Also, given current drilling practice in the vicinity of Yucca Mountain, we seek comment upon whether our proposed, stylized, human-intrusion scenario is reasonable.

Time frame for the analysis. We are considering two approaches to determine how far into the future that the human-intrusion analyses will be required to project doses. In the first approach, which is proposed in §§ 197.25 and 197.26, we would require the peak dose during the first 10,000 years, as a result of human intrusion, to be less than 150 µSv/yr (15 mrem/yr). In the second approach, DOE would calculate the earliest time that the engineered barrier system would degrade sufficiently that current drilling techniques could lead to complete waste package penetration without recognition by the drillers. If that intrusion can happen within 10,000 years, then DOE must do an analysis which projects the peak dose that would occur as a result of the intrusion within 10,000 years. That dose would have to be less than 150 µSv/yr (15 mrem/yr) for the site to be licensed, considering reasonable expectation. If the undetected intrusion could not occur until after 10,000 years, then DOE would still do the analysis, however the results would not be part of the licensing process but would be included in the Yucca Mountain EIS. This approach mirrors the way that the 10,000-year and post-10,000-year analyses are proposed in the individual-protection standard. This approach has the advantage of encouraging DOE to use a robust engineered design. We request comment upon the appropriateness of using either of these alternatives.

III.F. How Will Ground Water Be Protected? (Proposed § 197.35)

Ground water is a valuable resource with many potential uses. Our proposed ground water protection standards would protect ground water that is being used or might be used as drinking water by restricting potential future contamination. Water from the aquifer which flows beneath Yucca Mountain is currently being used as a source of drinking water 20 to 30 km south of Yucca Mountain in the communities directly protected by the individual-protection standard. It is also a potential source of drinking water for more distant communities and, theoretically, could supply drinking water for several hundred thousand people. For these reasons, we believe it is a resource that needs to be protected. Therefore, we are proposing to protect the ground water to the same level as the maximum contaminant levels (MCLs) for radionuclides which we have established under the authority of the Safe Drinking Water Act (SDWA). This is also consistent with our policy for ground water protection as stated in "Protecting the Nation's Ground Water: EPA's Strategy for the 1990s" ("the Strategy," EPA 21Z–1020, July 1991). In addition to drinking water, ground water may be a source of radiation exposure when used for irrigation, stock watering, food preparation, showering, or when incorporated into various industrial processes. Ground water contamination is also of concern to us because of potential adverse impacts upon ecosystems, particularly sensitive or endangered ecosystems.

Today's proposal utilizes the current MCLs, but the MCLs might change in the final rule. The Agency recognizes that the current MCLs are based upon the best scientific knowledge regarding the relationship between radiation exposure and risk that existed in 1975 when the MCLs were developed. Scientific understanding has evolved since 1975 and we are working to update the existing MCLs based upon a number of factors, including: the current understanding of the risk of developing a fatal cancer from exposure to radiation; pertinent risk management factors, e.g., information about treatment technologies and analytical methods; and applicable statutory requirements. Particularly relevant statutory requirements, in this context, are the requirements that MCLs be set as closely as feasible to the Maximum Contaminant Level Goal (MCLG) (SDWA section 1412(b)(4)(B)) and that revised drinking water regulations provide for equivalent or greater human health protection than the regulations they replace (SDWA section 1412(b)(9)). The Agency's preliminary efforts indicate that, for the radionuclides of concern at Yucca Mountain, the concentration values for those MCLs are probably not likely to change significantly. However, if those revisions to the MCLs are finalized prior to finalization of the part 197 standards, we plan to adopt those MCLs into the final part 197 standards. If part 197 is finalized first, the MCLs being proposed today would be maintained. We believe that this approach is necessary to provide stability for NRC and DOE in the licensing process. The uncertainty involved in not knowing when a change would occur and what form that change would take could delay the licensing proceeding. We request public comment upon this approach. If you do not consider the proposed approach appropriate, please provide an alternative and rationale.

In July 1991, we issued the Strategy cited above in order to guide future EPA and State activities in ground water protection and cleanup. The Strategy presents an effective approach for protecting the Nation's ground water resources. Our policies, programs, and resource allocations reflect this approach. It guides EPA, State and local governments, and other parties in carrying out ground water protection programs. In addition, our "Final Comprehensive State Ground-Water Protection Program Guidance" provides guidance to States for establishing a coordinated approach to their ground water protection.

The key element of our ground water protection strategy is the overall goal of preventing adverse effects upon human health and the environment by protecting the environmental integrity of the Nation's ground water resources. We believe that it is important to protect ground water to ensure that the Nation's currently used and potential USDWs are preserved for present and future generations. Also, we believe that it is important to protect ground water to ensure that where it interacts with surface water it does not interfere with the attainment of surface-water-quality standards. These standards are necessary to protect human health and the integrity of ecosystems.

Our Strategy also recognizes, however, that our efforts to protect ground water must take into consideration the use, value, and vulnerability of the resource, as well as social and economic values. In carrying out our programs, we use MCLs, established under the SDWA, as reference points for water-resource protection efforts when the ground water in question is a potential source of drinking water. Pursuant to section 1412 of the SDWA, we issued the National Primary Drinking Water Regulations for contaminants in drinking water which may cause an adverse effect upon the health of persons and which are known or anticipated to occur in public water systems (see 40 CFR parts 141 and 142). These regulations specify either MCLs or treatment techniques and contain "criteria and procedures to assure a supply of drinking water which dependably complies'' with such MCLs (see SDWA § 1401). The relevant MCLs, for water containing less than 10,000 milligrams per liter (mg/L) of total dissolved solids (TDS) and assuming an ingestion rate of 2 L of water per day, are:

(1) 5 picocuries per liter (pCi/L) for combined radium-226 and radium-228;

(2) 15 pCi/L for gross alpha; and

(3) 4 mrem/yr for combined beta particle and photon radiation from man-made radionuclides.

We employ MCLs to protect ground water in numerous regulatory programs. This approach is reflected in our regulations pertaining to hazardous-waste disposal (40 CFR part 264), municipal-waste disposal (40 CFR parts 257 and 258), underground injection control (UIC) (40 CFR parts 144, 146, and 148), generic SNF, HLW, and transuranic radioactive waste disposal (40 CFR part 191), and uranium mill tailings disposal (40 CFR part 192). These Agency programs have demonstrated that such protection is scientifically and technically achievable, within the constraints applied in each of these regulations (''Progress In Ground Water Protection and Restoration,'' EPA 440/6–90–001).

Most ground water in the United States moves slowly, in the range of five to 50 feet per year. This means that a large amount of a contaminant can enter an aquifer and remain undetected until it affects a water well or surface-water body. Contaminants in ground water, unlike those in other environmental media like air or surface water, can move with relatively little mixing or dispersion, so concentrations can remain relatively high. Moreover, because ground water is below the Earth's surface and ''out of sight,'' its contamination is far more difficult to monitor or remove than is contamination in air, surface water, or soil. These plumes of contaminants move slowly through aquifers and may be present for many years, sometimes for decades or longer, potentially making the resource unusable for extended periods of time. Because an individual plume may underlie only a small part of the land surface, it can be difficult to detect by aquiferwide or regional monitoring. In addition, for periods spanning thousands of years, monitoring is unlikely to continue, avoidance of the contamination may be difficult, and the area affected may become large. These factors are part of the reason that our policy emphasizes prevention of ground water pollution.

Regarding this rulemaking, NAS clearly identified the ground water pathway as one of the significant pathways of exposure in the vicinity of the Yucca Mountain site (NAS Report pp. 52 and 81). The NAS also recognized that ground water modeling for the Yucca Mountain site is complex, involving both fracture and matrix flow and, as a result, that there is uncertainty regarding which model or models to use in the analysis:

> Because of the fractured nature of the tuff aquifer below Yucca Mountain, some uncertainty exists regarding the appropriate mathematical and numerical models required to simulate advective transport....[E]ven with residual uncertainties, it should be possible to generate quantitative (possibly bounding) estimates of radionuclide travel times and spatial distributions and concentrations of plumes accessible to a potential critical group. (NAS Report p. 90)

The basis of NRC's determination of compliance with the ground-water protection standards will be DOE projections in the license application of potential future contaminant concentrations that will inevitably contain uncertainty. An important cause of uncertainty, as recognized above by NAS, is the choice of conceptual site models. To illustrate, the conceptual models used for Yucca Mountain can differ fundamentally, that is, water can be presumed to flow through either pores in the rock or conduits through the rock, such as discrete fractures or a network of fractures that may act as preferential pathways for faster ground water flow, or a combination of the two. To further complicate the situation, any of these flow scenarios, with the possible exception of flow through conduits, can occur at Yucca Mountain whether the rock is completely saturated with water or not.

We believe that adequate data and the choice of models will be critical to any compliance calculation or determination. The NAS has examined the use of ground-water flow and contaminant-transport models in regulatory applications (''Ground Water Models: Scientific and Regulatory Applications,'' 1990). In that report, NAS concluded that data inadequacy is an impediment to the use of unsaturated fracture flow models for Yucca Mountain. However, NAS noted that data inadequacy was also an impediment to using models that assume the pores in the rock are either saturated or unsaturated or that assume flow through fractures that are completely filled with water. However, despite the recognition of the importance of the choice of the site conceptual model, the Agency believes that the need for sufficient quantity, types, and quality of data to adequately analyze the site, because of its hydrogeologic complexity, is even more important. In other words, the complexity of the ground water flow system requires adequate site characterization to justify the choice of the conceptual flow model.

The choice of modeling approaches to address the ground water system in the area of Yucca Mountain, based upon the conceptual model of the site developed from site characterization activities, is important to characterize contaminant migration, particularly the mixing of water, contaminated with radionuclides from breached waste packages, with uncontaminated water. The extent of the dilution afforded by mixing contaminated water with other ground water moving through the rocks below the repository but above the water table and the dispersion of the plume of contamination within the saturated zone as the ground water system carries radionuclides downgradient are critical elements of the dose assessments.

At one end of a spectrum of approaches to modeling the site ground water system is the assumption that the system can be modeled based upon flow through pores over the area of total system assessments (tens of square kilometers). At the other extreme is the assumption that radionuclides are carried through fast-flow, fracture pathways in the unsaturated zone separately from uncontaminated ground water also passing through the repository footprint. Those radionuclides then are assumed to be carried through the saturated zone in fractures that allow little or no dispersion within, or mixing with, uncontaminated water in the saturated zone. This is essentially ''pipe flow'' from the repository to the receptor. Although the flow of ground water at the site is influenced strongly by fractures, which should be reflected in the models, we believe that it is unreasonable to assume that no mixing with uncontaminated ground water would occur along the radionuclide travel paths. We request comment upon this approach, including consideration of the practical limitations on characterizing the flow system over several or tens of square kilometers.

Our intention is to develop ground water protection standards that are implementable by NRC. In this regard, NAS indicated that quantitative estimates of ground water contamination should be possible (NAS Report p. 90). We are proposing to require DOE to project the level of radioactive contamination it expects to be in the representative volume of ground water. The representative volume could be calculated to be in any aquifer which contains less than 10,000 mg/L of TDS and is downgradient from Yucca Mountain. By proposing this method, we intend to avoid requiring DOE and NRC to project the contamination in a small, possibly unrepresentative amount of water since we believe that this is not practical (see the discussion of ''representative volume of ground water'' immediately below). For example, we do not intend that NRC must consider whether a few gallons of water in a single fracture would exceed the standards. Thus, we are proposing to allow use of a larger volume of water which must, on average, meet the standards. This larger volume, the ''representative volume,'' is discussed below.

Since the intended purpose of the engineered and natural barriers of the geologic repository is to contain radionuclides and minimize their movement into the general environment, we anticipate that radionuclide releases from the repository will not occur for long periods of time. With this in mind, we believe that ground water protection for the Yucca Mountain site should focus upon the protection of the ground water as a resource for future human use. It is the general premise of this proposal that the individual-protection standard would adequately protect those few current residents closest to the repository. The proposed ground water standards are directed to protecting the aquifer as a resource for current users, and a potential resource for larger numbers of future users either near the repository or for communities farther away comprised of as many as several hundred thousand people. To implement this conceptual approach and develop an approach for compliance determinations, we believe that the ground water standards currently used, the MCLs, should apply to public water supplies downgradient from the repository in aquifers at risk of contamination from repository releases. Applying the MCLs assures that the level of protection currently required for public water supplies elsewhere in the Nation is also maintained for future communities using the water supply downgradient from the Yucca Mountain repository.

To implement the standards in § 197.35, we are proposing that DOE use the concept of a ''representative volume'' of ground water in which DOE and NRC would project the concentration of radionuclides released from the Yucca Mountain disposal system for comparison against the MCLs. The representative volume will be the volume of water that would supply the annual water demands of a defined hypothetical community that could exist in the future at the point of compliance for the ground water protection standards. We believe that community size and water demand estimates should reflect the current, general lifestyles and demographics of the area, but not be rigidly constrained by current activities since any potential contamination would occur far into the future. In the area south of Yucca Mountain, the ground water is currently used for domestic purposes, commercial agriculture (for example, dairy cattle, feed crops, other crops, and fish farming), residential gardening, commercial, and municipal uses. The water resources, as reflected by estimates of current usage and aquifer yields, indicate that there is theoretically enough water to support communities of hundreds to thousands of people at the four alternative proposed locations for the point of compliance. This sets an upper bound on the size of the hypothetical community and its water demand. On the other hand, the SDWA defines the minimum size for a public water system as a system with 15 service connections or, regularly supplying at least 25 people.

For the four alternative proposed downgradient distances for the point of compliance (approximately 5, 18, 20, and 30 km from the repository), current populations vary from hundreds of persons around 30 km, to about 10 people residing at 18–20 km, to no residents at 5 km. Current projections of population growth in the area indicate increases at both the 20– and 30–km locations. Based upon current water usage, lifestyles, projections of population increases, and the potential number of people that could be supported by available ground water, there is a range of annual ground water volumes that could correspond to possible future public water system uses. While we believe that, ideally, the representative volume should be fully consistent with the protection objectives of the ground water protection strategy, we also recognize the unique features of this proposal. The extraordinary 10,000-year compliance period introduces unresolvable uncertainties that make this situation fundamentally different from the situations of clean-up or foreseeable, near-term potential contamination to which the strategy ordinarily applies. We therefore request comment upon a proposed representative ground water volume and upon possible alternatives for the size of the representative volume of ground water. These alternatives are based upon variations in possible lifestyles for residents downgradient from the repository and upon current and near-term projections of population growth and land use in the area.

The proposed representative volume is based upon a small farming community of 25 people and 255 acres of alfalfa cultivation, the current economic base in the Amargosa Valley. This approach assumes a community whose water needs include an agricultural component comparable to present water usage in the vicinity of the repository. The size of the average area of alfalfa cultivation, 255 acres, is based upon site-specific information for the nine alfalfa-growing operations which range in size from about 65 acres to about 800 acres. Using a water demand for alfalfa farming in Amargosa Valley of 5 acre-feet per acre per year, we estimate the water demand for the average operation to be 1275 acre-feet per year. As discussed below, it is appropriate to add 10 acre-feet per year for domestic uses resulting in 1285 acre-feet per year.

We request comment upon whether this approach is the most appropriate representative volume of ground water, or whether other values within the ranges discussed below are more appropriate. We believe that there may be significant technical, policy, or practical obstacles with the use of either very small or very large water volumes.

We considered using volumes of 10 and 120 acre-feet per year. Although the character of ground water movement in the saturated zone makes it progressively more difficult to model smaller volume flow, we are interested in comment upon the use of and whether, or how, it would be practical and feasible, using scientifically defensible methods, for the Commission to determine compliance with an alternative which specifies smaller representative volumes, such as 10 acre-feet and 120 acre-feet per year. A volume of 10 acre-feet would be representative of the annual water use of a non-farming family of four with average domestic water usage, including a garden. This is also the lower bound for the amount of water that would be used through 15 connections serving at least 25 persons in a public water supply, as defined in the SDWA. As mentioned in earlier discussions regarding the nature of ground water flow in fractured rocks, modeling the flow of ground water and the movement of contaminants involves significant uncertainties in the exact quantitative relationship between ground water movement in fractures versus its movement in the rock pore spaces. Modeling these processes, of necessity, requires simplifying assumptions and approximations that lower the level of confidence that can be attached to estimating contaminant concentrations in progressively smaller volumes of ground water. From our understanding of the complexity of the flow system at Yucca Mountain and the surrounding area, and the uncertainties involved in modeling it, a small representative volume such as 10 acre-feet would be difficult to model with a sufficient degree of certainty for regulatory confidence. The Agency, of course, wants the size of the representative volume used in compliance calculations to be scientifically defensible in order to provide the public a reasonable certainty of their accuracy.

An annual water demand of 120 acre-feet assumes a community of 150 persons and is based upon current water use data for the area. This population estimate is based upon recent population increases in the area and 20-year projections of land use at the 20-km location, as described in county planning documents. In such a scenario, it would be important for commenters to look at whether it is appropriate to assume this community would have an agriculture component, or whether a primarily residential community is more appropriate.

We also considered using a volume of 4,000 acre-feet which would be representative of the estimated perennial yield of the Jackass Flats hydrographic sub-basin in which the proposed Yucca Mountain repository is located. This volume represents the annual sustainable quantity of water which could be removed from this sub-basin without significantly decreasing the subsequent water yield and quality in the future. This volume is not directly linked to any specific use, but rather is included as representative of the volume of the water resource for potential future, large-scale, sustainable ground water use.

As already stated, we believe that there may be significant technical, policy, or practical obstacles that preclude the use of such a large volume. Releases from the repository will migrate downward and into the saturated zone where the contaminated ground water will move generally southward. The Jackass Flats sub-basin covers a large area, most of which is east of the repository site and not in the path of ground water flow from the repository. The Agency did not include this alternative in the rule since the use of 4,000 acre-feet would result in a contaminant estimate based upon dilution by a large volume of unaffected water. We are requesting comment upon the use of 4,000 acre-feet as the basis for the Commission to determine compliance with an alternative which specifies this volume as representative of the ground water resource.

To implement these options, the Department would project the radionuclide concentration in the representative volume or the resultant doses, for the option selected, and compare them against the appropriate MCLs. For these calculations, the movement of radionuclides released from the repository must be calculated as they move downgradient toward the compliance point. For the purpose of demonstrating compliance with the ground water protection standards, we intend for DOE and NRC to use the performance assessments to determine compliance with the individual-protection standard to calculate the concentration of radionuclides in the ground water.

There are two basic approaches between which DOE must choose for calculating the concentrations of radionuclides at the point of compliance. The Department may perform this analysis by determining how much contamination is in: (1) a "well-capture zone"; or (2) a "slice of the plume." (These approaches are explained immediately below.) For either approach, the volume of water used in the calculations is equal to the representative volume, i.e., the annual water demand for the proposed future group using the ground water.

The "well-capture zone" is the volume from which a water supply well, pumping at a defined rate, is withdrawing water from an aquifer. The dimensions of the well-capture zone are determined by the pumping rate in combination with aquifer characteristics assumed for calculations, such as hydraulic conductivity, gradient, and the screened interval. If this approach is used, DOE must assume that the:

(1) Well has characteristics consistent with public water supply wells in Amargosa Valley, for example, well bore size and length of the screened interval;

(2) Screened interval is centered at the highest concentration in the plume of contamination at the point of compliance; and

(3) Pumping rate is set to produce an annual withdrawal equal to the representative volume.

To include an appropriate measure of conservatism in the compliance calculations for the well withdrawal approach, we are proposing that, for the purpose of the analysis, DOE should assume that the community water demand would be supplied from one pumping well located in the center of any projected plume of contamination originating in the repository. Conservatism is achieved by requiring that the entire water demand is withdrawn from one well intercepting the center of the plume of contamination so that the highest radionuclide concentrations in the plume are included in the volume used for the compliance calculations.

The "slice of the plume" is a cross-section of the plume of contamination centered at the point of compliance with sufficient thickness parallel to the prevalent flow of the plume such that it contains the representative volume. If DOE uses this approach, it must:

(1) Propose to NRC, for its approval, where the edge of the plume of contamination occurs, for example, where the concentration of radionuclides reaches 0.1% of the level of the highest concentration at the point of compliance;

(2) Assume that the slice of the plume is perpendicular to the prevalent direction of flow of the aquifer; and

(3) Set the volume of ground water contained within the slice of the plume equal to the representative volume.

In both alternatives, we are proposing that DOE must determine the physical dimensions and orientation of the representative volume during the licensing process, subject to approval by the Commission. Factors that would go into determining the orientation of the representative volume would include hydrologic characteristics of the aquifer and the well.

Under our proposal, the Department must demonstrate compliance with the proposed ground water protection standards (§ 197.35) assuming undisturbed performance of the disposal system. The term "undisturbed performance" means that human intrusion or the occurrence of unlikely, disruptive, natural processes and events do not disturb the disposal system. This approach recognizes that human behavior is difficult to predict and, if human intrusion occurs, that individuals may be exposed to radiation doses that would be more attributable to human actions than to the quality of repository siting and design (NAS Report p. 11). The requirement that DOE project performance for comparison with the ground water protection standards based upon undisturbed-performance scenarios is consistent with our generally applicable standards for SNF, HLW, and transuranic waste in 40 CFR part 191 (58 FR 66402, December 20, 1993; 50 FR 38073 and 38078, September 19, 1985).

We also are proposing to require that DOE combine certain estimated releases from the Yucca Mountain disposal system with the pre-existing naturally occurring or man-made radionuclides to determine the concentration in the representative volume (see Table 1 in the *What Should the Level of Protection Be?* section earlier in this notice for particular cases). This means that the releases of radionuclides from radioactive material in the Yucca Mountain disposal system must not be allowed to cause the projected level of radioactivity at the point of compliance to exceed the limits in § 197.35 with reasonable expectation.

We request public comment upon these approaches. Comments also are requested upon whether it is desirable and appropriate for us to provide more quantitative requirements for the proposed representative volume in the final standards. If so, please provide specifics.

III.F.1. Is the Storage or Disposal of Radioactive Material in the Yucca Mountain Repository Underground Injection?

We first addressed the issue of whether the disposal of radioactive waste in geologic repositories might be considered a form of underground injection in a rulemaking to amend 40 CFR part 191. In the preamble to the final amendments (58 FR 66398), we stated that it was unnecessary to address whether the disposal of radioactive waste in a geologic repository covered under 40 CFR part 191 constitutes underground injection under the SDWA since the ground water protection requirements in 40 CFR part 191 conformed with the MCLs. We also noted that in *NRDC* v. *EPA*, 824 F.2d at 1270–71, the First Circuit Court of Appeals itself did not resolve the underground injection issue. The Court stated only that disposal in geologic repositories would "likely" constitute underground injection. Also, in the preamble to the 40 CFR part 191 amendments, we reviewed the SDWA, its legislative history, and the regulations governing the UIC program. We concluded that the underground disposal of containerized radioactive waste in geologic repositories subject to 40 CFR part 191 does not constitute underground injection within the meaning of the SDWA or our regulations governing the UIC program (58 FR 66398, 66408–66411, December 20, 1993). Similarly, in the present rulemaking, we propose to find that the storage or disposal of containerized radioactive waste in Yucca Mountain does not constitute underground injection.

Section 1421 of the SDWA defines "underground injection" as "the subsurface emplacement of fluids by well injection." 42 U.S.C. 300h(d)(1). The statute defines neither "fluids" nor "well injection." Moreover, neither the statute nor the legislative history directly addresses whether the underground storage or disposal of containerized radioactive waste constitutes the "subsurface emplacement of fluids by well injection." Even though the legislative history states, "[t]he definition of 'underground injection' is intended to be broad enough to cover any contaminant which may be put below ground level and which flows or moves, whether the contaminant is in semi-solid, liquid, sludge, or any other form or state," (H.R. Rep. No. 1185, 93d Cong., 2d Sess. 31 (1974)), it does not specifically address whether the underground storage or disposal of containerized radioactive waste in a geologic repository, such as Yucca Mountain, constitutes the "subsurface emplacement of fluids by well injection."

In this rulemaking, we are proposing to conclude that the underground storage or disposal of containerized radioactive waste in the Yucca Mountain repository does not constitute underground injection both because the materials to be emplaced are not "fluids" and because the mode of emplacement of these materials is not "well injection." We do not consider the type of containerized radioactive wastes covered under today's proposal to be "fluids." Instead, DOE plans for the wastes to consist entirely of solid materials and to be enclosed in thick metal waste packages. We do not believe that the SDWA's reference to "subsurface emplacement of fluids" was intended to address the subsurface storage or disposal of solid, containerized materials. As noted above, neither the statute nor the legislative history specifically address the subsurface emplacement of containerized materials or solids. On the other hand, the legislative history does address the injection of liquid materials that flow or move at the time they are emplaced into the ground. For example, in floor debate, Sen. Domenici stated that "the [UIC] regulations would cover all types of injection wells from industrial and nuclear disposal wells, oil and gas injection wells, solution mining wells or any hole in the ground designed for the purpose of injecting water or other fluids below the surface" (see 126 Cong. Rec. 30189, November 19, 1980, remarks of Sen. Domenici). Indeed, in amending the SDWA in 1985, Congress stated "underground injection is the process of forcing liquids underground through a well." H.R. Rep. No. 168, 99th Cong., 1st Sess. 30 (1985). Moreover, it is clear from the legislative history of the SDWA that Congress intended to ratify EPA's policy regarding deep-well injection contained in Administrator's Decision Statement #5, entitled "Subsurface Emplacement of Fluids," (39 FR 12922, April 2, 1974, H.R. Rep. No. 1185, 93rd Cong., 2d Sess. 31–32 (1974)). Administrator's Decision Statement #5 contains parameters for well injection including, among other things, data requirements for volume, rate, and injection pressure of the fluid; degree of fluid saturation; and formation and fluid pressure (39 FR 12923, April 9, 1974). Like the legislative history itself, the policy does not mention the subsurface emplacement of containerized radioactive wastes, but it does address the injection of noncontainerized liquids as an object of regulatory concern.

The legislative history of the SDWA indicates that Congress was concerned about contamination of ground water from a variety of sources of noncontainerized liquids and sludges. Quoting from a U.S. Department of Health, Education and Welfare report entitled "Human Health and the Environment—Some Research Needs," Representative Rogers noted in floor debate that ground water pollution was rapidly increasing from sources including ". . . waste water sludges and effluents . . . mine drainage, subsurface disposal of oil-field brines, seepage from septic tanks and storage transmission facilities, and individual on-site waste-water disposal systems." (123 Cong. Rec. 22460 (July 12, 1977)). Later in 1985, Congress made clear its intent that there would be early detection of fluid migration into or in the direction of a USDW (H.R. Rep. No. 168, 99th Cong., 1st Sess. 30 (1985)). Again, there is no mention that Congress intended that the SDWA cover the subsurface emplacement of containerized radioactive wastes.

Reflecting this statutory approach, our UIC regulations similarly do not treat containerized radioactive wastes as fluids or liquids for the purpose of control under the UIC program. Our regulations at 40 CFR 146.3 define "fluid" as "material or substance which flows or moves whether in a semisolid, liquid, sludge, gas, or any other form or state." In adopting this regulatory definition of fluid, we did not consider the emplacement of containerized radioactive wastes into geologic repositories to be fluids subject to the UIC regulations. There is no mention of this activity in the preambles to the proposed or final UIC regulations. On the contrary, the fluids regulated by our UIC program include: (1) Brines from oil and gas production; (2) hazardous and industrial waste waters; (3) liquid hydrocarbons (gasoline, crude petroleum, and others); (4) solution mining fluids from uranium, sulfur, and salt solution mining; and (5) sewage and treated effluent (40 CFR 144.6). All of these materials can flow or move at the time they are emplaced into the ground. There is no indication of any intention to cover containerized materials as fluids under the UIC regulations.

Finally, we have never interpreted our UIC regulations to include the subsurface emplacement of containerized wastes or solid materials that do not flow or move. As explained in greater detail below, we have stated instead that placement of containerized hazardous waste in geologic repositories such as underground salt formations, mines, or caves, is regulated under Subtitle C of the RCRA hazardous waste program. Subtitle D of RCRA regulates the disposal of containerized, nonhazardous wastes pursuant to the regulatory provisions at 40 CFR 257.1. Today's proposed standards for Yucca Mountain regulate the emplacement and disposal of containerized radioactive wastes including SNF and HLW.

In *NRDC* v. *EPA*, 824 F.2d 1258, the First Circuit was concerned that radiation itself might be considered a fluid within the meaning of the SDWA and EPA's UIC regulations (40 CFR 146.3). We believe that radiation itself does not meet the UIC regulatory or statutory definition of "fluid." Radioactivity is a specific characteristic of the radionuclides in the waste but does not define the form of the waste. Also, radioactivity results in the emission of ionizing radiation in the form of electromagnetic energy or subatomic particles. Electromagnetic radiation is a form of energy, not a "material or substance." Hence, it is not a "fluid." Subatomic particles, such as alpha and beta particles, will be absorbed in either the waste or the container and, therefore, not travel beyond the container, or will travel very short distances, perhaps a few inches. In any event, as set forth above, we believe that since the activity at the Yucca Mountain repository will consist of the emplacement of containers of radioactive wastes underground, this activity is emplacement of solid materials, not "fluids." Even though these materials might eventually disintegrate or dissolve and release some radiation, liquids, or gases, the activity in question still consists of emplacement of containers and solid materials that will not flow or move at the time of emplacement underground.

Moreover, we do not consider the emplacement into the Yucca Mountain repository of containerized and solid wastes that do not flow or move to be subsurface emplacement "by well injection." At the Yucca Mountain repository as currently conceived, a rail car will be used to carry the containerized waste into the repository. The waste containers then will be emplaced in drifts mined into the geologic formation. Once enough containers are accumulated, each drift will be closed. Closure of the disposal system will occur when all of the openings into the repository have been backfilled and all entrance ramps sealed.

Our UIC regulations define "well injection" as "subsurface emplacement of fluids through a bored, drilled or driven well; or through a dug well, where the depth of the dug well is greater than the largest surface dimension" (40 CFR 146.3). The regulations define a "well" as "a bored, drilled or driven shaft, or a dug hole, whose depth is greater than the largest surface dimension" (Id.). Although movement of the materials underground in the Yucca Mountain repository will involve waste handling, it will be drifts, that is, tunnels, through which containerized solid materials are transported and emplaced, not "wells" into which fluids are being "injected" within the meaning and intent of the SDWA or our UIC regulations. In addition, the overall configuration of the repository is far different from that of a "drilled," "driven," or "dug" injection well.

We noted in the preamble to the proposed UIC rules setting forth the definitions of "well" and "well injection" that the definitions cover not only "conventional" deep wells, but also drilled, bored, and driven wells. Dug wells and non-residential septic tanks also fall under the term. We further stated, however, that "although the definition is broad, it is not without limitation." (44 FR 23738, 23740, April 20, 1979) For example, we stated that the term does not cover simple depressions in the land or single-family domestic cesspools or septic systems, nor does it cover surface impoundments (Id.). Although we had been concerned initially about whether the UIC regulations should impose conditions upon surface impoundments, generally referred to as "pits, ponds, and lagoons," since they pose a threat to ground water, we noted that standards to control such contamination are under the RCRA hazardous-waste management program (44 FR 23740, April 20, 1979). Thus, we recognized that there are some disposal practices that might contaminate ground water that would not be covered under the UIC program.

Similarly, we do not believe that the UIC program should cover emplacement of containerized waste by way of a drift. Such emplacement is in no way similar to the pressurized or gravity-driven flow of fluids, liquids, or sludges injected into a well that has been the traditional focus of the UIC program (for example, 41 FR 36726, 36732, August 31, 1976). Even Class-V wells, a general category of injection wells, are not used for the disposal of containerized waste. Class V covers the subsurface emplacement of fluids, usually by gravity-driven flow, into the injection well. Although Class-V wells include some types of wells that traditionally might not be thought of as injection wells, for example, septic systems, all of the well types involve the emplacement of noncontainerized fluids into drilled, bored, dug, or driven wells, typically through gravity-driven flow rather than pressurized flow.

We specifically addressed the status of containerized waste under RCRA and SDWA in the preamble to the final rule promulgating standards for miscellaneous units used for the disposal of hazardous wastes under subpart X of the RCRA regulations (40 CFR part 264). In the preamble to the final rule, we stated: "Placement of containerized hazardous waste or bulk non-liquid hazardous waste in geologic repositories such as underground salt formations, mines, or caves, either for the purpose of disposal or long-term retrievable storage, is included under subpart X" (52 FR 46946, 46952, December 10, 1987).

We promulgated the subpart X regulations to address hazardous-waste management technologies not covered under 40 CFR part 264 (RCRA regulations for the disposal of hazardous waste) or 40 CFR part 146 (UIC program technical criteria and standards). As we indicated in the preamble to the subpart X regulations, the 40 CFR part 146 technical standards do not address practices other than the injection of noncontainerized liquids, slurries, and sludges, and do not fully address some potential disposal or storage practices that may fall under our regulatory definition of well injection (52 FR 46946, 46953, December 10, 1987). In the subpart X rule, we provided that, to the extent that miscellaneous disposal practices subject to subpart X might be underground injection, a subpart X permit would constitute a UIC permit for well injection of hazardous waste for which current 40 CFR part 146 technical standards are not generally appropriate. We stated, however, that we were not "specifying that these miscellaneous management practices constitute underground injection" (Id.).

Thus, we have never expressed an intent that the disposal of containerized waste, including containerized radioactive waste, in geologic repositories is an activity covered by the UIC program. Instead, injection wells have been described as "facilities [within] which wastes, in a fluid (usually liquid) state, are injected into the land under a pressure head greater than the pressure head of the ground water into or above which they are injected for the purpose of disposal. Discharge to the ground water is either direct or by direct seepage of leachate from the well outlet (46 FR 11126, 11137–38, February 5, 1981).

Moreover, we have never intended for the regulatory criteria and standards applicable to underground injection, contained in 40 CFR parts 144 and 146, to apply to a geologic repository such as Yucca Mountain. The concepts of area of review, pressure buildup and pressure monitoring, restrictions upon injection pressure, other operating requirements, and mechanical-integrity testing of injection wells, that are included in the 40 CFR part 146 regulations, are meaningless as applied to Yucca Mountain. Further, as noted above, the Yucca Mountain disposal system will have mined containment areas in which humans operate mechanical equipment to emplace waste packaged in containers surrounded by both engineered and natural barriers designed to isolate such waste from the environment. The UIC regulations are directed at injection of fluids by pressure or gravity flow where they are then in direct contact with the natural, underground media; this activity is far different, from an engineering perspective, than the subsurface emplacement of containerized wastes planned for Yucca Mountain.

Finally, as explained below, we are proposing specific ground water protection standards, in addition to other public health and safety standards, to protect ground water resources in the vicinity of Yucca Mountain. We believe these standards are adequate to protect public health and the environment from the radiation exposure resulting from releases following the emplacement of these containerized radioactive wastes into the Yucca Mountain disposal system. Thus, it is not necessary to expand the scope of the UIC program to cover this activity.

III.F.2. Does the Class-IV Well Ban Apply?

Today's action provides protection, with one possible exception, substantively similar to the SDWA through the proposed adoption of the MCLs to protect ground water resources in the vicinity of Yucca Mountain (proposed § 197.35). The possible exception relates to the provision of 40 CFR 144.13 banning "Class IV" injection wells. As defined in 40 CFR 144.6(d), such wells include those which dispose of radioactive waste into or above a formation which contains a USDW within one-quarter (1/4) mile of the well. In the preamble to the amendments to 40 CFR part 191 (58 FR 66398, 66410, December 20, 1993), we said we would further consider the Class-IV well-ban issue in the context of the Yucca Mountain rulemaking. We have done so and are proposing in this rulemaking not to apply the Class-IV injection-well ban to the Yucca Mountain repository. Our position is that this is appropriate in light of the statutory and regulatory provisions, discussed above, relating to "underground injection" and the differences in the purposes of the UIC program and the authority delegated to us under the EnPA to establish public health and safety standards for Yucca Mountain.

The UIC regulations mandate minimum requirements for State programs to prevent underground injection which endangers USDWs, while the 40 CFR part 197 standards proposed for Yucca Mountain are directed toward protecting ground water in the accessible environment in the vicinity of the Yucca Mountain site and establish requirements for performance of the Yucca Mountain disposal system. As discussed below, we believe that the proposed standards for the Yucca Mountain disposal system achieve public health and environmental protections comparable to those of the UIC program. Moreover, as discussed above, we do not believe that the emplacement of radioactive waste in the Yucca Mountain disposal system is a form of underground injection. Therefore, we are proposing to find that the Class-IV well ban does not apply to, and is not needed, in the case of the Yucca Mountain disposal system.

It is important to emphasize that our proposed decision not to apply the Class-IV well ban to Yucca Mountain does not affect other disposal systems that dispose of hazardous or radioactive waste into or above a formation which, within one-quarter (1/4) mile of the disposal system, contains a USDW. We are basing today's proposal upon site- and facility-specific characteristics of the Yucca Mountain repository, and today's proposal is limited to the Yucca Mountain repository.

The Class-IV well ban is part of the UIC program and is recognized in section 3020 of RCRA. As explained previously, the UIC program addresses "well injection" in the common-sense meaning of that term. In contrast, the proposed 40 CFR part 197 regulations address emplacement of radioactive wastes into a uniquely designed and utilized facility. The Yucca Mountain disposal system is planned to be subjected to extremely sophisticated site characterization, design, engineering, containerization, and operational requirements. Given such intense scrutiny, applying a blunt instrument akin to the Class-IV well ban as a siting prohibition appears to be both unnecessarily restrictive and a poor substitute for more sophisticated site characterization studies that may preclude siting of a disposal facility for reasons other than those embodied in the Class-IV restriction. Further, if Congress intended that the Yucca Mountain disposal system be subject to and summarily precluded by the Class-IV well ban, we seriously question whether Congress would have specifically directed us, under the EnPA, to establish public health and safety standards for Yucca Mountain.

Previously, we explained our proposed conclusion that emplacement of radioactive material into the Yucca Mountain disposal system is not underground injection. The materials to be disposed are solid, containerized radioactive wastes emplaced in a mined containment system in which humans operate heavy mechanical equipment. Such emplacement and such materials do not fall under the intent or meaning of the UIC concepts or programs, or more specifically, the Class-IV well ban at 40 CFR 144.13, but are judged more appropriately by the standards mandated by Congress under the EnPA specifically for Yucca Mountain. Further, the ground water protection alternatives presented in today's proposal provide protections very comparable to those under the UIC program.

Taken together, we believe these distinctions are sufficient to justify nonapplicability of the Class-IV well ban under the SDWA. We request comment upon our position that application of the UIC Class-IV well ban is neither legally required nor appropriate for the Yucca Mountain disposal system. Further, we will not address in this rulemaking the relevance of the Class-IV well ban to underground repositories generally.

III.F.3. Which Ground Water Should Be Protected?

Although we propose to find that the Yucca Mountain disposal system is not a form of underground injection in the context of the SDWA, we nevertheless consider the ground water protection principles embodied in the SDWA to be important. Therefore, while not applying all aspects of the SDWA, we are proposing ground water protection standards consistent with the levels of the radionuclide MCLs.

We request public comment upon the proposal and the other approaches, described below, that are designed to protect ground water resources in the vicinity of the repository. We are concerned that ground water resources in the vicinity of Yucca Mountain receive adequate protection from radioactive contamination. The primary purpose of our proposed standards is to prevent contamination of drinking-water resources. (Since the proposed compliance period is 10,000 years after disposal, references to levels of contamination mean those levels projected to exist at specific future times, unless otherwise noted. However, these projections will be made at the time of licensing.) This prevents placing the burden upon future generations to decontaminate that water by implementing expensive clean-up or treatment procedures. We believe it is prudent to protect drinking water from contamination through prevention rather than to rely upon clean-up afterwards. The cost to remediate the effects of radionuclides released from a geologic disposal system, such as Yucca Mountain, could far exceed the costs typically associated with near-surface Superfund sites. Moreover, absent this protection through prevention, the disposal system itself could become subject to clean-up by future generations. Thus, our proposed ground water protection standards stress pollution prevention and provide protection from contamination of sources of drinking water containing up to 10,000 mg/L of TDS. We emphasize that all ground water pathways, including drinking water, are also covered under the proposed individual-protection standard (§ 197.20).

The definition of USDW received extensive discussion in the legislative history of the SDWA as reflected in the report of the House Committee on Interstate and Foreign Commerce. To guide the Agency, the Committee Report suggested inclusion of aquifers with fewer than 10,000 mg/L of TDS (H.R. Rep. No. 1185, 93d Cong., 2d Sess. 32, 1974). We have reviewed the current information on the use of aquifers for drinking water which contain high levels of TDS. This review found that ground water containing up to 3,000 mg/L of TDS that is treated is in widespread use in the U.S. In the Yucca Mountain vicinity, with few exceptions (one being the Franklin Playa area), ground water contains less than 1,000 mg/L of TDS. Our review also found that ground water elsewhere in the Nation, containing as much as 9,000 mg/L of TDS, currently supplies public water systems. Based upon this review and the legislative history of the SDWA, we are proposing that it is reasonable to protect the aquifers potentially affected by releases from the Yucca Mountain disposal system. Therefore, the provisions found in proposed § 197.35 would apply to all aquifers, or their portions, containing less than 10,000 mg/L of TDS. The proposed definitions associated with § 197.35 are taken directly from our UIC regulations found in 40 CFR parts 144–146.

III.F.4. How Far Into the Future Should Compliance Be Projected?

We are proposing a 10,000-year compliance period for ground water protection. This is consistent with the 10,000-year compliance period we are proposing for the individual-protection standard and, therefore, provides internal consistency within the proposed standards. This time period would also make the ground water protection compliance period consistent with 40 CFR part 191. Consistency also is achieved with regulations covering long-lived chemically hazardous wastes which present potential health risks similar to those from radioactive waste.

In addition to trying to achieve consistency with our other hazardous and radioactive-waste programs, we are concerned about the uncertainty associated with projecting radiation doses over periods longer than 10,000 years. The NAS indicated that beyond 10,000 years uncertainty will likely continue to increase (NAS Report p. 72). As a result, it will become increasingly difficult to discern a difference between the radiation dose from drinking water containing radionuclides (limited by the MCLs) and the total dose arriving through all pathways (which is limited by the individual-protection standard).

In fact, we considered incorporating a compliance period of time-to-peak concentration within the geologic stability of the site. However, this approach may be unworkable and duplicative of the requirements already promulgated in the MCLs. The current MCLs for radionuclides are expressed both in terms of radiation dose and concentration. For man-made beta and photon emitters, the MCL is a dose limit of 4 mrem/yr, with specific instructions for determining radionuclide-specific concentrations corresponding to that dose (40 CFR part 141.16(b)). For radium-226 (^{226}Ra) and ^{228}Ra combined, the MCL is a concentration level of 5 pCi/L of water, while for gross-alpha activity (including ^{226}Ra but excluding radon and uranium), the MCL is a concentration level of 15 pCi/L (40 CFR 141.15(a) and 141.15(b), respectively).

The Yucca Mountain disposal system will contain all of these types of radionuclides. To express a regulatory limit for ground water protection in terms of a single limit on peak concentration may be impractical because of the separate, multiple, and distinct MCLs established by regulation. Although the gross-alpha limit is set at 15 pCi/L to limit lifetime cancer risk to about 1 x 10^{-4}, the concentrations of specific alpha-emitting radionuclides corresponding to this risk level may vary widely. For various thorium isotopes, concentrations of 50 to 125 pCi/L are equivalent to this risk, while for either neptunium-237 or plutonium-238, a concentration of 7 pCi/L corresponds to a lifetime cancer risk of 1×10^{-4} (56 FR 33050, 33121, July 18, 1991). To develop a limit on the peak concentration for each radionuclide would be unwieldy, because of the large number of radionuclides involved. To establish a single, overall, limiting peak concentration applicable to all radionuclides would be, at best, an approximation of the public-health protection already embodied in the MCLs. For these reasons, we are concerned that expressing ground water protection requirements in terms of a single, peak concentration or numerous radionuclide-specific limits is not appropriate.

We request comment upon our proposal to impose the ground water protection standards during the first 10,000 years following disposal and whether we should, instead, adopt a compliance period of time-to-peak concentration (see the *How Far Into the Future Should Compliance Be Projected?* section earlier in this notice for a discussion of time-to-peak-dose compliance period which is the basis of this concept). Commenters recommending the time-to-peak-concentration approach should address our concerns, particularly those related to implementability, as expressed above.

III.F.5. How Will the Point of Compliance Be Identified?

To provide a basis for determining projected compliance with § 197.35, it is necessary to establish a geographic location where DOE must project the concentrations of radionuclides in the ground water over the compliance period. We refer to this location as the "point of compliance."

In this section, we will discuss two alternative approaches for determining the location of the point of compliance. In the final rule, we will specify the location to be used by NRC and DOE as the point of compliance. One approach (used in Alternatives 1 and 4) would establish the maximum size for an area around the repository (that is, a "controlled area") which would be exempt from the ground water protection standards. In demonstrating compliance, the Department would choose the point on the area's boundary located above the primary ground water flow pathway and where the highest concentrations of radionuclides are expected to be found. Under the second approach (used in Alternatives 2 and 3), we would specify a specific geographic location where we believe the primary ground water flow pathway and the highest concentrations of radionuclides will be. If the Department's improved knowledge of ground water flow direction changes the expected location of the highest concentrations of radionuclides, DOE must propose that location to NRC as an alternative point of compliance. This new point of compliance, however, must be at the same distance from the repository as the originally promulgated point of compliance. As discussed below, DOE must obtain the approval of the Commission prior to using the alternative point for demonstrating compliance.

Under the "controlled area" approach of Alternatives 1 and 4, the standards would designate an area within which DOE would not have to demonstrate compliance with the ground water protection standards. These standards would apply outside of that area. Under this approach, we are proposing that the Department would have to determine the point on the boundary of the controlled area where the highest projected concentrations of radionuclides will occur. That location would become the point of compliance. In effect, a certain volume of the geologic medium would be dedicated to delaying or keeping releases from the waste within the controlled area and away from the accessible environment. We adopted a generic definition of controlled area in 40 CFR part 191. The definition of controlled area for this rulemaking could take into account unique features in the vicinity of the Yucca Mountain site or we could adopt the definition from part 191. An alternative for each definition is presented and discussed below.

Not applying the ground water protection standards inside a controlled area is consistent with the approach in 40 CFR Part 191 in which the natural geologic barriers surrounding radioactive-waste repositories are a part of the disposal system and may be dedicated for this purpose (50 FR 38066, 38077, September 19, 1985). We implemented this concept in 40 CFR part 191 by requiring compliance with ground water standards outside of the controlled area. This concept was upheld by the First Circuit in *NRDC* v. *EPA*, 824 F.2d at 1272–73 & 1277–79. The court reasoned that allowing for contamination of some area surrounding a geologic repository was consistent with the site-selection provisions of the NWPA and that Congress expected DOE to rely upon geologic barriers and, therefore, "knew of the inevitability of some contamination of ground water in the immediate area of the stored waste." *NRDC* v. *EPA*, 824 F.2d at 1278.

For Yucca Mountain, the EnPA also generally follows the approach of dedicating some portion of the surrounding geology for containment and requiring compliance in the accessible environment outside of such an area. For example, section 801(a)(1) of the EnPA specifically uses the term "accessible environment" (that is, outside of the controlled area) when calling for us to prescribe standards for "releases to the accessible environment from radioactive materials stored or disposed of in the repository." The EnPA also specifically incorporates the definition from 40 CFR part 191 in its direction to NAS to address whether a health-based standard based upon doses to individual members of the public "from releases to the accessible environment (as that term is defined in the regulations in subpart B of part 191 of title 40, Code of Federal Regulations, as in effect on November 18, 1985)" will provide a reasonable standard for protection of the general public.

The second approach (Alternatives 2 and 3) for establishing a point of compliance is the identification of a specific location where DOE must project the concentration of radionuclides. Rather than designating a "controlled area," under this approach we would specify a specific point as the point of compliance. This approach relies upon current knowledge of the ground water flow system in the region around Yucca Mountain with a realization that more information may be available to DOE and NRC at the time of licensing. Therefore, if this approach is the one we adopt in the final standard, it is important to explain our current understanding of ground water flow in the area and to establish a mechanism which allows flexibility for selecting an alternative point of compliance during licensing if the current conceptual model proves no longer valid at the time of licensing. Despite the fact that a particular point would be designated, please note that this approach would allow radioactive contamination in the path of the plume of contamination between the repository footprint and the point of compliance. In fact, the intervening area could contain ground water which is contaminated above the ground water protection standards. However, with this approach, those standards could not be exceeded at or beyond the point of compliance during the proposed 10,000-year compliance period.

Our understanding, based upon current knowledge, of the flow of ground water passing under Yucca Mountain is as follows. The general direction of ground water movement in the aquifers under Yucca Mountain is south and southwest. The major aquifers along the flow path are in tuff, alluvium, and, underlying both of these, much deeper carbonate rocks. At the edge of the repository, even the tuff aquifer is relatively (several hundred meters) deep. It gets closer to the surface as it moves toward its natural discharge points. Potential releases of radionuclides from the engineered barrier system into the surrounding rocks would be highly directional and would reflect the orientation of fractures, rock unit contacts, and ground water flow in the area downgradient from Yucca Mountain. Directly under the repository, we anticipate that any waterborne releases of radionuclides will move through the unsaturated zone and downward into the tuff aquifer, in an easterly direction, between layers of rocks which slant to the east, and then horizontally. The layer of tuff gradually thins proceeding south (downgradient) from Yucca Mountain. As the tuff thins, the overlying alluvium becomes thicker until the tuff disappears and the water in the aquifer moves into the alluvium to become the "alluvial aquifer." Along the flow path, there might be movement of water between the carbonate aquifer and either the tuff or alluvial aquifers. If there is significant upward flow from the carbonate aquifer, contamination in overlying aquifers could be diluted. It is generally believed, however, that any such flow would not significantly affect the concentration of radionuclides in the overlying aquifers. Conversely, downward movement of ground water from the tuff aquifer could contaminate the carbonate aquifer. Today, most of the water for human use is withdrawn between 20 and 30 km away from the repository footprint (that is, at Lathrop Wells and farther south through the Town of Amargosa Valley) where it is more easily and economically accessed for agricultural use and human consumption. It is likely that water within the alluvial aquifer is the source of this water.

Another basis of our understanding is the historical record of water use in the region. That record indicates that significant, long-term human habitation has not occurred in the southwestern area of the NTS, or for that matter anywhere in the vicinity of Yucca Mountain, except where ground water is very easily accessible, for example, in Ash Meadows. This observation coincides with current practice whereby the number of wells generally decreases relative to the greater depth to ground water. The difficulty in accessing ground water in the tuff aquifer in the near vicinity of Yucca Mountain is made more difficult by the rough terrain, the relative hardness of the tuff formations containing the aquifer, and the great depth to ground water there. As described earlier, the ground water flow from under Yucca Mountain is thought to be generally south and southwest. In those directions, the ground water gets progressively closer to the Earth's surface the farther away it gets from Yucca Mountain until it is thought to discharge to surface areas 30–40 km away (the southern boundary of NTS is about 18 km from Yucca Mountain). This means that access into the upper aquifer is easier at increasing distance from Yucca Mountain. It should also be pointed out, the Yucca Mountain site is on several Federally controlled areas of land, i.e., the Nellis Test Range, NTS, and Bureau of Land Management land. In these areas, the U.S. government is the senior appropriator and holds water rights, i.e., water is appropriated for beneficial use by and for the U.S. government.

Because of DOE's ongoing site characterization studies, it is possible that, at the time of licensing, data not now available will reveal important inaccuracies in the preceding conception of ground water flow. In proposing Alternatives 2 and 3 (see discussion below), we intend that the location of the point of compliance will be where the highest concentrations of radionuclides within the plume are projected by DOE and NRC to be. We believe, based upon current information, that the locations specified for the proposed alternative points of compliance in Alternatives 2 and 3 are likely to include such concentrations.

However, if DOE and NRC determine that the direction of ground water flow or location of the highest concentration is different than now believed because new knowledge is available at the time of licensing, we propose to require the Department to propose to the Commission the location where the highest concentration is projected to be. Any such new point of compliance would replace the one we specify in the final rule only if it is at the same distance from the repository as the original point of compliance and is approved by the Commission. It may be moved only to account for new information regarding flow-direction or the location of the highest concentration. We believe such flexibility will enhance the quality of NRC's licensing decision and will provide greater protection of public health and the environment by taking into account the latest available information. We request comment upon this approach.

III.F.6. Where Will the Point of Compliance Be Located?

Introduction to the alternatives. We are presenting four alternatives for comment prior to determining the location of the point of compliance. They are presented in the proposed regulatory text (see proposed § 197.37) and are discussed here in no particular order of preference. For convenience, we refer to them as Alternatives 1, 2, 3, and 4, respectively.

We note that Alternatives 2 and 3 rely upon our current knowledge of ground water flow and use in the region. As discussed above, we are also proposing a method for proceeding under Alternatives 2 and 3, if further knowledge changes the understanding of the flow of the region's ground water or the location of the highest concentrations of radionuclides.

Alternatives in proposed § 197.37. Alternative 1 would establish a "controlled area." In this case, we would define the extent of the controlled area (in proposed § 197.12) as it is in 40 CFR part 191 (with the substitution of the term "repository footprint" for the original wording, "outer boundary of the original location of the radioactive wastes in a disposal system"):

(1) A surface area, identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the repository footprint; and (2) the subsurface underlying the surface area.

The Department would determine where on the controlled area's boundary to place the point of compliance based upon the projected direction of ground water flow and the expected locations of the highest concentrations of radionuclides.

As mentioned earlier, this approach would be consistent with 40 CFR part 191 and would, therefore, maintain consistency with the generic standards which apply to WIPP, GCD, and any future disposal system for SNF, HLW, and transuranic radioactive waste which is subject to 40 CFR part 191. (As described earlier, the GCD facility is a complex of 120-foot deep boreholes, located within NTS, which contains disposed transuranic radioactive waste and WIPP is a geologic disposal system, in New Mexico, for defense-related transuranic radioactive waste.) While this alternative would not provide explicitly for consideration of site-specific factors in determining the size of the controlled area, it would ensure that the boundary of the controlled area would not extend substantially beyond Yucca Mountain itself. This alternative would have the effect of providing natural topographic constraints on access to ground water within the controlled area. Therefore, it would provide a safeguard against use of ground water within the controlled area during the compliance period.

In Alternative 2, we would specify the location of the point of compliance. In this case, the point of compliance would be located near the intersection of U.S. Route 95 and Nevada State Route 373, commonly referred to as Lathrop Wells (Lathrop Wells is actually an area within the Town of Amargosa Valley and is the location closest to Yucca Mountain where the general population currently consumes water). We have found that the depth to the water currently withdrawn for domestic use within the Town of Amargosa Valley ranges from a few meters in the southern parts of the town to 110 meters near Lathrop Wells (see the BID). This alternative would put the point of compliance near the currently assumed location of the RMEI.

In Alternative 3, we would establish an area located about 30 km south of Yucca Mountain within which DOE and NRC would identify a specific point as the point of compliance. The area would be bounded by Frontier Street on the north, Nevada State Route 373 on the east, the Nevada-California border on the south/southwest, and Casada Way on the west. About 75% of the current population and about 60% of the current water-supply wells in what we understand to be the downgradient direction from Yucca Mountain are within this area. This is an area where it is relatively easy to access ground water (see the BID). This option would, therefore, provide direct protection for most of the population currently using drinking water from the alluvial aquifer.

In Alternative 4, the Department, with the consent of NRC, would establish a controlled area outside of which the ground water standards would apply. Its size would be determined by DOE (without exceeding the limits set by us). This controlled area would be a combination of Alternative 1 and site-specific considerations for Yucca Mountain. The site-specific consideration is the proximity of the repository footprint and NTS. The boundary of the controlled area could be no more than five kilometers from the footprint (the same limit applied in Alternative 1), except in those cases where the five kilometers is located within the NTS. In that case, DOE may extend the controlled area to include all or part of the NTS.

We base this alternative, in part, upon the fact that NTS has existed under the control of DOE for about 50 years. Another basis is that we believe that future generations will be aware of the extensive, well-publicized nuclear activities that occurred there. This will likely increase the effectiveness of the passive institutional controls, as discussed below. The NTS is well-known around the world for many reasons but most notably for the approximately 900 tests of nuclear weapons conducted there. This makes NTS unique in the Western Hemisphere because of the resultant presence of hundreds of millions of curies of radionuclides (see the BID). This will presumably lead the Federal government to document the extent of radionuclide contamination and the activities which occurred there, including the Yucca Mountain disposal system, more thoroughly and retain records for longer periods than might occur elsewhere.

To repeat for clarification, the conceptual difference between Alternatives 1 and 4 and Alternatives 2 and 3 is that in Alternatives 1 and 4, we will define an area surrounding the repository outside of which the ground water standards would apply, whereas for Alternatives 2 and 3, we will specify limited areas downgradient from the repository within which DOE and NRC must place the point of compliance.

We request comment upon all of the alternatives discussed above. Commenters should address the effectiveness of these or other alternatives for protecting ground water, including consideration of site-specific characteristics and reasonable methods of implementing the alternatives.

IV. Specific Questions for Comment

In addition to requesting comment upon all aspects of this rulemaking, many of which we have highlighted in the preceding sections of this notice, we also request comment based upon the following specific questions. To be most useful to us, please provide your reasoning in your answers.

1. The NAS recommended that we base the individual-protection standard upon risk. Consistent with this recommendation and the statutory language of the EnPA, we are proposing a standard in terms of annual CEDE incurred by individuals. Is our rationale for this aspect of our proposal reasonable?

2. We are proposing an annual limit of 150 µSv (15 mrem) CEDE to protect the RMEI and the general public from releases from waste disposed of in the Yucca Mountain disposal system. Is our proposed standard reasonable to protect both individuals and the general public?

3. To define who should be protected by the proposed individual-protection standard, we are proposing to use an RMEI as the representative of the rural-residential CG. Is our approach reasonable? Would it be more useful to have DOE calculate the average dose occurring within the rural-residential CG rather than the RMEI dose?

4. Is it reasonable to use RME parameter values based upon characteristics of the population currently located in proximity to Yucca Mountain? Should we promulgate specific parameter values in addition to specifying the exposure scenarios?

5. Is it reasonable to consider, select, and hold constant today's known and assumed attributes of the biosphere for use in projecting radiation-related effects upon the public of releases from the Yucca Mountain disposal system?

6. In determining the location of the RMEI, we considered three geographic subareas and their associated characteristics. Are there other reasonable methods or factors which we could use to change the conclusion we reached regarding the location of the RMEI? For example, should we require an assumption that for thousands of years into the future people will live only in the same locations that people do today? Please include your rationale for your suggestions.

7. The NAS suggested using an NIR level to dismiss from consideration extremely low, incremental levels of dose to individuals when considering protection of the general public. For somewhat different reasons, we are proposing to rely upon the individual-protection standard to address protection of the general population. Is this approach reasonable in the case of Yucca Mountain? If not, what is an alternative, implementable method to address collective dose and the protection of the general population?

8. Is our rationale for the period of compliance reasonable in light of the NAS recommendations?

9. Does our requirement that DOE and NRC determine compliance with § 197.20 based upon the mean of the distribution of the highest doses resulting from the performance assessment adequately address uncertainties associated with performance assessments?

10. Is the single-borehole scenario a reasonable approach to judge the resilience of the Yucca Mountain disposal system following human intrusion? Are there other reasonable scenarios which we should consider, for example, using the probability of drilling through a waste package based upon the area of the package versus the area of the repository footprint or drilling through an emplacement drift but not through a waste package? Why would your suggested scenario(s) be a better measure of the resilience of the Yucca Mountain disposal system than the proposed scenario?

11. Is it reasonable to expect that the risks to future generations be no greater than the risks judged acceptable today?

12. What approach is appropriate for modeling the ground water flow system downgradient from Yucca Mountain at the scale (many kilometers to tens of kilometers) necessary for dose assessments given the inherent limitations of characterizing the area? Is it reasonable to assume that there will be some degree of mixing with uncontaminated ground water along the radionuclide travel paths from the repository?

13. Which approach for protecting ground water in the vicinity of Yucca Mountain is the most reasonable? Is there another approach which would be preferable and reasonably implementable? If so, please explain the approach, why it is preferable, and how it could be implemented.

14. Is the 10,000-year compliance period for protecting the RMEI and ground water reasonable or should we

extend the period to the time of peak dose? If we extend it, how could NRC reasonably implement the standards while recognizing the nature of the uncertainties involved in projecting the performance of the disposal system over potentially extremely long periods?

15. As noted by NAS, some countries have individual-protection limits higher than we have proposed. In addition, other Federal authorities have suggested higher individual-dose limits with no separate protection of ground water. Therefore, we request comment upon the use of an annual CEDE of 250 μSv (25 mrem) with no separate ground water protection, including the consistency of such a limit with our ground water protection policy.

16. We are proposing to require, in the individual-protection standard, that DOE must project the disposal system's performance after 10,000 years. Are the specified uses of the projections appropriate and adequate?

V. Regulatory Analyses

V.A. Executive Order 12866

Section 3(f) of Executive Order 12866 (E.O. 12866) defines "significant regulatory action" for purposes of centralized regulatory review by the Office of Management and Budget (OMB) to mean any regulatory action that is likely to result in a rule that may:

(1) Have an annual effect upon the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities;

(2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;

(3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or

(4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order.

We are classifying this proposed action as significant under the fourth clause. These standards have been mandated by the EnPA which gave us, for the first time, the authority to set site-specific environmental radiation protection standards. Also, the subject of this rulemaking, Yucca Mountain, Nevada, is a unique facility since it is the first and only one of its kind in the United States being studied for the potential disposal of SNF and HLW.

The OMB has reviewed the text of the draft of this rulemaking and associated materials. In accordance with § 6(a)(3)(E) of E.O. 12866, we have placed interagency review materials into the docket and other locations listed at the beginning of this notice. The interagency materials include: (1) the draft document(s) provided to OMB; and (2) document(s) identifying the substantive changes made between the draft submitted to OMB and the proposed rulemaking, and identifying those changes that we made at the suggestion or recommendation of OMB.

V.B. Executive Orders on Federalism

Under Executive Order 12875 (E.O. 12875), "Enhancing Intergovernmental Partnerships," we may not issue a regulation that is not required by statute and that creates a mandate upon a State, local, or tribal government, unless the Federal government provides the funds necessary to pay the direct compliance costs incurred by those governments, or unless we consult with those governments. If we comply by consulting, E.O. 12875 requires us to provide to OMB a description of the extent of our prior consultation with representatives of affected State, local, and tribal governments; the nature of their concerns; any written communications from the governments; and a statement supporting the need to issue the regulation. In addition, E.O. 12875 requires us to develop an effective process permitting elected officials and other representatives of State, local, and tribal governments "to provide meaningful and timely input in the development of regulatory proposals containing significant unfunded mandates."

Today's rule does not create a mandate upon State, local, or tribal governments. The rule does not impose any enforceable duties upon those entities. Accordingly, the requirements of section 1(a) of E.O. 12875 do not apply to this rule. Despite this fact, we nonetheless held public meetings in Nevada and Washington, D.C. in September 1995 (see the *How Has the Public Participated in Our Review of the NAS Report?* section earlier in this notice) during which we received comments from and had discussions with representatives of the State of Nevada and county officials. There were also informal meetings with State and local officials in which those personnel were apprised of the status of the rulemaking.

Finally, while there is a new executive order on federalism, it will not go into effect for 90 days. In the interim, under the current Executive Order 12612 on Federalism, this rule does not have a substantial direct effect upon States, upon the relationship between the national government and the States, or upon the distribution of power and responsibilities among the various levels of government, because the rule only prescribes standards appropriate for one facility in one State.

V. C. Executive Order 12898

Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations And Low-income Populations (Environmental Justice)," directs us to incorporate environmental justice as part of our overall mission by identifying and addressing disproportionately high and adverse human health and environmental effects of programs, policies, and activities upon minority populations and low-income populations.

We find no disproportionate impact in the outcome of this rulemaking. No plan has thus been devised to address a disproportionate impact.

V. D. Executive Order 13045

Executive Order 13045 (E.O. 13045), "Protection of Children from Environmental Health Risks and Safety Risks," (62 FR 19885, April 23, 1997) applies to any rule that (1) is determined to be "economically significant" as defined under E.O. 12866, and (2) concerns an environmental health or safety risk that we have reason to believe may have a disproportionate effect upon children. If the regulatory action meets both criteria, we must evaluate the environmental health or safety effects of the planned rule upon children, and explain why the planned regulation is preferable to other potentially effective and reasonably feasible alternatives that we considered.

This proposed rule is not subject to E.O. 13045 because we do not have reason to believe the environmental health risks or safety risks addressed by this action present a disproportionate risk to children. The public is invited to submit or identify peer-reviewed studies and data, of which we may not be aware, that assessed results of early life exposure to radiation.

V. E. Executive Order 13084

Under Executive Order 13084 (E.O. 13084), "Consultation and Coordination with Indian Tribal Governments," we may not issue a regulation that is not required by statute, that significantly or uniquely affects the communities of Indian tribal governments, and that imposes substantial direct compliance costs upon those communities, unless the Federal government provides the funds necessary to pay the direct compliance costs incurred by the tribal governments, or we consult with those governments. If we comply by consulting, Executive Order 13084 requires us to provide to OMB, in a separately identified section of the preamble to the rule, a description of the extent of our prior consultation with representatives of affected tribal governments, a summary of the nature of their concerns, and a statement supporting the need to issue the regulation. In addition, E.O. 13084 requires us to develop an effective process permitting elected officials and other representatives of Indian tribal governments "to provide meaningful and timely input in the development of regulatory policies on matters that significantly or uniquely affect their communities."

Today's rule implements requirements specifically set forth by the Congress in the EnPA without the exercise of any discretion by us. Accordingly, the requirements of section 3(b) of E.O. 13084 do not apply to this rule.

V. F. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (NTTAA), Pub. L. No. 104–113, section 12(d) (15 U.S.C. 272 note) directs us to use voluntary consensus standards in our regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (e.g., materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs us to provide Congress, through OMB, explanations when we decide not to use available and applicable voluntary consensus standards. This proposed rulemaking does not involve technical standards. Therefore, we are not considering the use of any voluntary consensus standards.

We request public comment upon this aspect of the proposed rulemaking and, specifically, ask you to identify potentially applicable voluntary consensus standards and to explain why such standards could be used in this regulation.

V. G. Paperwork Reduction Act

We have determined that this proposed rule contains no information requirements within the scope of the Paperwork Reduction Act, 42 U.S.C. 3501–20.

V. H. Regulatory Flexibility Act/Small Business Regulatory Enforcement Fairness Act of 1996

Under the Regulatory Flexibility Act, 5 U.S.C. 601 *et seq*., agencies must prepare and make available for public comment an initial regulatory flexibility analysis assessing the impact of a proposed rule upon "small entities" (5 U.S.C. 603). "Small entities" include small businesses, small not-for-profit enterprises, and government entities with jurisdiction over populations of less than 50,000 (5 U.S.C. 601). However, the requirement to prepare a regulatory flexibility analysis does not apply if the Administrator certifies that the rule will not, if promulgated, have a significant economic impact upon a substantial number of small entities (5 U.S.C. 605(b)). The rule proposed today would establish requirements that apply only to DOE. Therefore, it does not apply to small entities. Accordingly, I hereby certify that the rule, when promulgated, will not have a significant economic impact upon a substantial number of small entities.

V.I. Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA, Pub. L. 104–4) establishes requirements for Federal agencies to assess the effects of their regulatory actions upon State, local, and tribal governments and the private sector. Under section 202 of UMRA, we generally must prepare a written statement, including a cost-benefit analysis, for proposed and final rules with "Federal mandates" that may result in expenditures by State, local, and tribal governments, in the aggregate, or to the private sector, of $100 million or more in any one year. Before we promulgate a rule for which a written statement is needed, section 205 of UMRA generally requires us to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows us to adopt an alternative other than the least costly, most cost-effective, or least burdensome if the Administrator publishes with the final rule an explanation as to why that alternative was not adopted. Before we establish any regulatory requirements that significantly or uniquely affect small governments, including tribal governments, we must develop, under section 203 of UMRA, a small-government-agency plan. The plan must provide for notifying potentially affected small governments, enabling officials of affected small governments to have meaningful and timely input into the development of regulatory proposals with significant Federal intergovernmental mandates, and informing, educating, and advising small governments on compliance with the regulatory requirements.

Today's proposed rule is not subject to the requirements of sections 202 and 205 of UMRA because it implements requirements specifically set forth by the Congress in section 801 of the EnPA. We are proposing rules which, when final, would establish requirements that DOE and NRC must follow in connection with licensing the Yucca Mountain disposal system. The EnPA directs the Administrator of EPA to promulgate standards for the protection of the public from releases from radioactive materials stored or disposed of in the repository at Yucca Mountain, Nevada.

Also, today's proposed rule does not impose new, enforceable duties upon State, local, or tribal governments, or the private sector. Thus, we have determined that this rule contains no regulatory requirements that might significantly or uniquely affect small governments as contemplated in section 203 of UMRA.

List of Subjects in 40 CFR Part 197

Environmental protection, Nuclear energy, Radiation protection, Radionuclides, Uranium, Waste treatment and disposal, Spent nuclear fuel, High-level radioactive waste.

Dated: August 18, 1999.

Carol M. Browner,

Administrator.

The Environmental Protection Agency is proposing to add a new part 197 to Subchapter F of Chapter I, title 40 of the Code of Federal Regulations, as follows:

SUBCHAPTER F—RADIATION PROTECTION PROGRAMS

PART 197—ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR YUCCA MOUNTAIN, NEVADA

Subpart A—Environmental Standards for Storage

Subpart B—Environmental Standards for Disposal

Introduction

Individual-Protection Standard

Human-Intrusion Standard

Other Considerations

Ground Water Protection Standards

Additional Provisions

Authority: Sec. 801, Pub. L. 102–486, 106 Stat. 2921, 42 U.S.C. 10141 n.

Subpart A—Environmental Standards for Storage

§ 197.1 What does subpart A cover?

This subpart covers the storage of radioactive materials by DOE in the Yucca Mountain repository and on the Yucca Mountain site.

§ 197.2 What definitions apply in subpart A?

Annual committed effective dose equivalent means the committed effective dose equivalent plus the effective dose equivalent received by an individual in one year from radiation sources external to the individual.

Committed effective dose equivalent means the total effective dose equivalent received by an individual from radionuclides internal to the individual following a one-year intake of those radionuclides.

DOE means the Department of Energy.

Effective dose equivalent means the sum over specified tissues of the products of the dose equivalent received following an exposure of, or an intake of radionuclides into, specified tissues of the body, multiplied by appropriate weighting factors.

EPA means the Environmental Protection Agency.

General environment means everywhere outside the Yucca Mountain site, the Nellis Air Force Range, and the Nevada Test Site.

High-level radioactive waste means high-level radioactive waste as defined in the Nuclear Waste Policy Act of 1982 (Public Law 97–425).

Member of the public means anyone who is not a radiation worker for purposes of worker protection.

NRC means the Nuclear Regulatory Commission.

Radioactive material means matter composed of or containing radionuclides subject to the Atomic Energy Act of 1954, as amended. Radioactive material includes, but is not limited to, high-level radioactive waste and spent nuclear fuel.

Spent nuclear fuel means spent nuclear fuel as defined in the Nuclear Waste Policy Act of 1982 (Public Law 97–425).

Storage means retention (and any associated activity, operation, or process necessary to carry out successful retention) of radioactive material with the intent or capability to readily access or retrieve such material.

Yucca Mountain repository means the mined portion of the facility constructed underground within the Yucca Mountain site.

Yucca Mountain site means the site recommended by the Secretary of DOE to the President under section 112(b)(1)(B) of the Nuclear Waste Policy Act of 1982 (42 U.S.C. 10132(b)(1)(B)) on May 27, 1986.

§ 197.3 How is subpart A implemented?

The NRC implements this subpart A. The DOE must demonstrate to NRC that operations on the Yucca Mountain site will occur in compliance with this subpart before NRC may grant to DOE a license to receive and possess radioactive material on the Yucca Mountain site.

§ 197.4 What is DOE required to do relative to stored radioactive material?

(a) The DOE must ensure that no member of the public in the general environment receives more than an annual committed effective dose equivalent of 150 microsieverts (15 millirems) from the combination of:

(1) Management and storage (as defined in 40 CFR 191.02) of radioactive material which:

(i) Is subject to 40 CFR 191.03(a); and

(ii) Occurs outside of the Yucca Mountain repository but within the Yucca Mountain site; and

(2) Storage (as defined in § 197.02) of radioactive material inside the Yucca Mountain repository.

§ 197.5 When will this part take effect?

The standards in this part take effect on [sixty days after publication of the final standards in the **Federal Register**].

Subpart B—Environmental Standards for Disposal

Introduction

§ 197.11 What does subpart B cover?

This subpart covers the disposal of waste in Yucca Mountain by DOE.

§ 197.12 What definitions apply in subpart B?

All definitions in subpart A of this part and the following:

Active institutional control means controlling access and/or performing work on the Yucca Mountain site by any means other than passive institutional controls.

Aquifer means an underground geological formation, group of formations, or part of a formation that can yield a significant amount of water to a well or spring.

Barrier means any material, structure, or feature that, for a period to be determined by NRC, prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain repository, or prevents the release or substantially reduces the release rate of radionuclides from the waste. For example, a barrier may be a geologic feature, an engineered structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around the waste, provided that the material substantially delays movement of water or radionuclides.

Alternative 1 for § 197.12, Definition of Controlled Area:

Controlled area means:

(1) A surface area, identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the repository footprint; and

(2) The subsurface underlying the surface area. [This definition would be included only if Alternative 1 for § 197.37 were chosen.]

Alternative 2 for § 197.12, Definition of Controlled Area:

Controlled area means:

(1) A surface area, identified by passive institutional controls, that extends horizontally no more than five kilometers in any direction from the repository footprint except that DOE may include in the controlled area any

contiguous area within the boundary of the Nevada Test Site (as established as of the date of promulgation of this part); and

(2) The subsurface underlying the surface area. [This definition would be included only if Alternative 4 for § 197.37 were chosen.]

Disposal means emplacement of radioactive material into the Yucca Mountain disposal system with the intent of isolating it for as long as reasonably possible and with no intent of recovery, whether or not the design of the disposal system permits the ready recovery of the material. Disposal of radioactive material in the Yucca Mountain disposal system begins when all of the ramps and other openings into the Yucca Mountain repository are backfilled and sealed.

Ground water means water below the land surface and in a saturated zone.

Human intrusion means breaching of any portion of the Yucca Mountain disposal system by human activity.

Passive institutional controls means:

(1) Markers, as permanent as practicable, placed on the Earth's surface;

(2) Public records and archives;

(3) Government ownership and regulations regarding land or resource use; and

(4) Other reasonable methods of preserving knowledge about the location, design, and contents of the Yucca Mountain disposal system.

Peak dose means the highest annual committed effective dose equivalent projected to be received by the reasonably maximally exposed individual.

Performance assessment means an analysis that:

(1) Identifies the processes, events, and sequences of processes and events (except human intrusion), and their probabilities of occurring over 10,000 years after disposal, that might affect the Yucca Mountain disposal system;

(2) Examines the effects of those processes, events, and sequences of processes and events upon the performance of the disposal system; and

(3) Estimates the annual committed effective dose equivalent received by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant processes, events, and sequences of processes and events.

Period of geologic stability means the time during which the variability of geologic characteristics and their future behavior in and around the Yucca Mountain site can be bounded, that is, they can be projected within a reasonable range of possibilities.

Plume of contamination means that volume of ground water that contains radioactive contamination from releases from the Yucca Mountain disposal system. It does not include releases from any other potential sources on or near the Nevada Test Site.

Point of compliance is the place where DOE must project the amount of radionuclides in the ground water for purposes of § 197.35. The point of compliance is located above the highest concentration in the plume of contamination as specified in § 197.37.

Repository footprint means the outline of the outermost locations of where the waste is emplaced in the Yucca Mountain repository.

Slice of the plume means a cross-section of the plume of contamination with sufficient thickness parallel to the prevalent flow of the plume that it contains the representative volume.

Total dissolved solids means the total dissolved (filterable) solids in water as determined by use of the method specified in 40 CFR part 136.

Undisturbed performance means that human intrusion or the occurrence of unlikely, disruptive, natural processes and events do not disturb the disposal system.

Waste means any radioactive material emplaced for disposal into the Yucca Mountain disposal system.

Well-capture zone means the volume from which a well pumping at a defined rate is withdrawing water from an aquifer. The dimensions of the well-capture zone are determined by the pumping rate in combination with aquifer characteristics assumed for calculations, such as hydraulic conductivity, gradient, and the screened interval.

Yucca Mountain disposal system means the combination of underground engineered and natural barriers at the Yucca Mountain site which prevents or substantially reduces releases from the disposed radioactive material.

§ 197.13 How is subpart B implemented?

The NRC implements subpart B. In the case of the specific numerical requirements in this subpart, NRC will determine compliance based upon the mean or median (whichever is higher) of the highest results of DOE's performance assessments projecting the performance of the Yucca Mountain repository for 10,000 years after disposal. The DOE must demonstrate to NRC that there is a reasonable expectation of compliance with this subpart before NRC can issue a license.

§ 197.14 What is reasonable expectation?

Reasonable expectation means that the Commission is satisfied that compliance will be achieved based upon the full record before it. Reasonable expectation:

(a) Requires less than absolute proof because absolute proof is impossible to attain for disposal due to the uncertainty of projecting long-term performance;

(b) Is less stringent than the reasonable assurance concept that NRC uses to license nuclear power plants;

(c) Takes into account the inherently greater uncertainties in making long-term projections of the performance of the Yucca Mountain disposal system;

(d) Does not exclude important parameters from assessments and analyses simply because they are difficult to precisely quantify to a high degree of confidence; and

(e) Focuses performance assessments and analyses upon the full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values.

§ 197.15 How must DOE take into account the changes that will occur during the next 10,000 years?

The DOE should not attempt to project changes to society, human biology, or increases or decreases to human knowledge. In all analyses done to demonstrate compliance with this part, DOE must assume that all of those factors remain constant as they are at the time of license submission to NRC. However, DOE must vary factors related to the geology, hydrology and climate based on environmentally protective but reasonable scientific predictions of the changes that could affect the Yucca Mountain disposal system over the next 10,000 years.

Individual-Protection Standard

§ 197.20 What standard must DOE meet?

The DOE must demonstrate, using performance assessment, that there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual receives no more than an annual committed effective dose equivalent of 150 microsieverts (15 mrem) from releases from the undisturbed Yucca Mountain disposal system. The DOE's analysis must include all potential pathways of radionuclide transport and exposure.

§ 197.21 Who is the reasonably maximally exposed individual (RMEI)?

The RMEI is a hypothetical person who could meet the following criteria:

(a) Based upon current understanding, lives within one-half kilometer of the junction of U.S. Route 95 and Nevada State Route 373, unless NRC determines that the RMEI would receive a higher dose living in another location at the same distance from the Yucca Mountain repository;

(b) Has a diet and living style representative of the people who are now residing in the Town of Amargosa Valley, Nevada. The DOE must use the most accurate projections which might be based upon surveys of the people residing in the Town of Amargosa Valley, Nevada, to determine their current diets and living styles and use the mean values in the assessments conducted for §§ 197.20 and 197.25; and

(c) Drinks 2 liters of water per day from wells drilled into the ground water at the location where the RMEI lives.

Human-Intrusion Standard

§ 197.25 What standard must DOE meet?

Alternative 1 for § 197.25:

The DOE must demonstrate that there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual receives no more than an annual committed effective dose equivalent of 150 microsieverts (15 mrem) as a result of a human intrusion. The DOE's analysis of human intrusion must include all potential environmental pathways of radionuclide transport and exposure.

Alternative 2 for § 197.25:

The DOE must determine the earliest time after disposal that the waste package would degrade sufficiently that a human intrusion (see § 197.26) could occur without recognition by the drillers. The DOE must:

(a) Demonstrate that there is a reasonable expectation that the reasonably maximally exposed individual receives no more than an annual committed effective dose equivalent of 150 microsieverts (15 mrem) as a result of a human intrusion, if complete waste package penetration can occur at or before 10,000 years after disposal. The analysis must include all potential environmental pathways of radionuclide transport and exposure; and

(b) Include the results of the analysis and its bases in the environmental impact statement for Yucca Mountain as an indicator of long-term disposal system performance, if the intrusion cannot occur before 10,000 years after disposal.

§ 197.26 What are the circumstances of the human intrusion?

For the purposes of the analysis of human intrusion, DOE must make the following assumptions:

(a) There is a single human intrusion as a result of exploratory drilling for ground water;

(b) The intruders drill a borehole directly through a degraded waste container into the uppermost aquifer underlying the Yucca Mountain repository;

(c) The drillers use the common techniques and practices that are currently employed in the region surrounding Yucca Mountain;

(d) Careful sealing of the borehole does not occur, instead natural degradation processes gradually modify the borehole;

(e) Only releases of radionuclides that occur as a result of the intrusion and that are transported through the resulting borehole to the saturated zone are projected;

(f) No releases are included which are caused by unlikely natural processes and events; and

(g) The intrusion occurs at a time or within a range of time determined by NRC. The NRC must make that determination based upon the following factors

[Paragraph (g) would be included only if Alternative 1 for § 197.25 is chosen]:

(1) The earliest time that current drilling techniques could lead to waste package penetration without recognition by the drillers;

(2) The time it would take for a small percentage of waste packages to fail but before significant migration of radionuclides has occurred; and

(3) Intrusion would not occur during the period of active institutional control.

Other Considerations

§ 197.30 What other projections must be made by DOE?

To complement the results of § 197.20, DOE must calculate the peak dose of the reasonably maximally exposed individual that would occur after 10,000 years following disposal but within the period of geologic stability. While no regulatory standard applies to the results of this analysis, DOE must include the results and their bases in the environmental impact statement for Yucca Mountain as an indicator of long-term disposal system performance.

Ground Water Protection Standards

§ 197.35 What standards must DOE meet?

In its license application to NRC, DOE must provide a reasonable expectation that, for 10,000 years of undisturbed performance after disposal, releases of radionuclides from radioactive material in the Yucca Mountain disposal system will not cause the level of radioactivity in the representative volume of ground water at the point of compliance to exceed the limits in Table 1 as follows:

TABLE 1.—LIMITS ON RADIONUCLIDES IN THE REPRESENTATIVE VOLUME.

Radionuclide or type of radiation emitted	Limit	Is natural background included?
Combined radium-226 and radium-228	5 picocuries per liter	Yes
Gross alpha activity (including radium-226 but excluding radon and uranium).	15 picocuries per liter	Yes
Combined beta and photon emitting radionuclides	40 microsieverts (4 millirem) per year to the whole body or any organ.	No

§ 197.36 What is a representative volume?

(a) It is the volume of ground water that would be withdrawn annually from an aquifer containing less than 10,000 milligrams of total dissolved solids per liter of water to supply a given water demand. The DOE must project the concentration of radionuclides from the Yucca Mountain repository that will be in the representative volume. The DOE must then use the projected concentrations to demonstrate to NRC compliance with § 197.35. The DOE must make the following assumptions concerning the representative volume:

(1) It is centered on the highest concentration level in the plume of contamination at the point of compliance;

(2) Its position and dimensions in the aquifer are determined using average hydrologic characteristics for the aquifers along the radionuclide migration path from the Yucca Mountain repository to the compliance point as determined by site characterization; and

(3) It contains 1285 acre-feet of water (about 1,591,023,000 liters or 418,690,000 gallons).

(b) The DOE must use one of two alternative methods for determining the dimensions of the representative volume. The DOE must propose the method, and any underlying assumptions, to NRC for approval.

(1) The dimensions may be calculated as a well-capture zone. If this approach is used, DOE must assume that the:

(i) Water supply well has characteristics consistent with public water supply wells in Amargosa Valley, Nevada, for example, well bore size and length of the screened intervals;

(ii) Screened interval is centered in the highest concentration in the plume of contamination at the point of compliance; and

(iii) Pumping rate is set to produce an annual withdrawal equal to the representative volume.

(2) The dimensions may be calculated as a slice of the plume. If this approach is used, DOE must:

(i) Propose to NRC, for its approval, where the location of the edge of the plume of contamination occurs. For example, the place where the concentration of radionuclides reaches 0.1% of the level of the highest concentration at the point of compliance;

(ii) Assume that the slice of the plume is perpendicular to the prevalent direction of flow of the aquifer; and

(iii) Assume that the volume of ground water contained within the slice of the plume is equal to the representative volume.

§ 197.37 Where is the point of compliance?

Alternative 1 for § 197.37:

The point of compliance is any point on the boundary of the controlled area.

Alternative 2 for § 197.37:

The point of compliance is any point within a one-half kilometer radius of the intersection of U.S. Route 95 and Nevada State Route 373. However, if NRC determines that there is another location, at the same distance (approximately 20 kilometers) from the center of the repository footprint, where the representative volume would have a higher concentration of radionuclides which were released from the Yucca Mountain disposal system, NRC must specify that location the point of compliance.

Alternative 3 for § 197.37:

The point of compliance is any point within the Town of Amargosa Valley, Nevada, and within the area bounded by Frontier Street on the north, Nevada State Route 373 on the east, the Nevada-California border on the south/southwest, and Casada Way on the west (as they are located at the time of promulgation of this part). However, if NRC determines that there is another location, at approximately 30 kilometers, from the center of the repository footprint where the representative volume would have a higher concentration of radionuclides which were released from the Yucca Mountain disposal system, NRC must specify that location as the point of compliance.

Alternative 4 for § 197.37:

The point of compliance is any point on the boundary of the controlled area.

Additional Provisions

§ 197.40 Are there limits on what must be considered in the performance assessments?

Yes. The DOE's performance assessments should not include consideration of processes or events that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal. The NRC may change this limit to exclude slightly higher probability events. In addition, with the NRC's approval, DOE's performance assessments need not evaluate, in detail, the impacts resulting from any processes and events or sequences of processes and events with a higher chance of occurrence if the results of the performance assessments would not be changed significantly.

§ 197.41 Can EPA amend this rule?

Yes. We can amend this rule by another notice-and-comment rulemaking. However, if we amend this rule, there must be a public comment period of at least 90 days and we must, at a minimum, hold hearings in Washington, D.C. and the Nevada Counties of Nye and Clark.

[FR Doc. 99–21913 Filed 8–26–99; 8:45 am]

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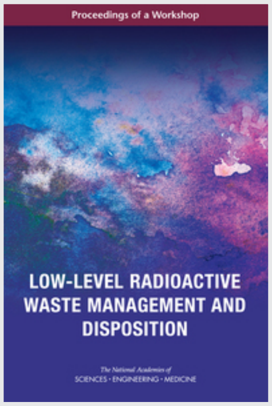

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LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT AND DISPOSITION

Proceedings of a Workshop

Jennifer Heimberg, *Rapporteur*

Planning Committee on Low-Level Radioactive Waste
Management and Disposition:
A Workshop

Nuclear and Radiation Studies Board

Division on Earth and Life Studies

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Reviewers

This Proceedings of a Workshop was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published Proceedings of a Workshop as sound as possible and to ensure that the Proceedings of a Workshop meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this Proceedings of a Workshop:

- John S. Applegate, Indiana University
- Miklos (Mike) Garamszeghy, Canadian Nuclear Waste Management Organization (NWMO)
- Christine Gelles, Longenecker and Associates
- Roger Seitz, Savannah River National Laboratory
- Mark Yeager, South Carolina Department of Health and Environmental Control

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the Proceedings of a Workshop before its release. The review of this Proceedings of a Workshop was overseen by Patricia J. Culligan, Columbia University. She was responsible for making certain that an independent examination of this Proceedings of a Workshop was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this Proceedings of a Workshop rests entirely with the rapporteur and the institution.

Contents

1

Introduction

The Department of Energy's Office of Environmental Management (DOE) is responsible for the safe cleanup of sites used for nuclear weapons development and government-sponsored nuclear energy research. Established in 1989, DOE's cleanup program originally encompassed more than 100 sites. Cleanup is planned to last another 40-50 years with total lifecycle costs approaching or exceeding $350 billion. The annual cleanup budget is around $6 billion.[1]

Low-level radioactive waste (LLW[2]) is the most volumetrically significant waste stream generated by the DOE cleanup program (approximately 17 million cubic meters per year[3]). LLW is also generated through commercial activities such as nuclear power plant operations and medical treatments. DOE disposes of LLW at its own sites as well as at some commercial facilities. Commercial LLW is, with some exceptions, disposed of at commercial facilities.

In the United States, LLW is not necessarily defined by low levels of radioactivity. The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPA amendments[4]) defines LLW as

[1]This value is an average of the past four annual budgets for DOE's Office of Environmental Management (Regalbuto, 2016).

[2]"LLW" and "LLRW" are commonly used acronyms for low-level radioactive waste. "LLW" is used throughout this proceedings unless "LLRW" is included in a quote from other sources.

[3]This average was calculated from a DOE complex-wide disposal rate for LLW and mixed LLW (Marcinowski, 2016). LLW containing hazardous chemicals is referred to as mixed LLW.

[4]"Low-Level Radioactive Waste Policy Amendments Act of 1985," accessed February 24, 2017, https://www.gpo.gov/fdsys/pkg/STATUTE-99/pdf/STATUTE-99-Pg1842.pdf.

low-level radioactive material that:

(A) is not high-level radioactive waste, spent nuclear fuel, or byproduct material (as defined in section 11.e (2) of the Atomic Energy Act of 1954 . . . [[5]]); and

(B) the Nuclear Regulatory Commission, consistent with existing law and in accordance with paragraph (A), classifies as low-level radioactive waste.

Thus, LLW is defined by exclusion (i.e., by what it is not).[6] LLW is physically and chemically diverse, ranging from lightly contaminated soils and building materials to highly irradiated nuclear reactor components.

The laws and regulations related to the disposal of LLW in the United States have evolved over time and across agencies and states (see Box D-2 in Appendix D), resulting in a complex regulatory structure. This structure has provided adequate guidance for the successful disposal of the majority of LLW streams, but there are some types of LLW streams—many of which were not anticipated when LLW regulations were created—that lack an obvious pathway to disposal or whose disposition could be considered incommensurate with the hazard of the waste. "Challenging LLW streams," as used in this proceedings, have potentially non-optimal or unclear disposition pathways due to their origin, content, or incompatibility with existing standards, orders, or regulations.

DOE asked the National Academies of Sciences, Engineering, and Medicine (National Academies) to organize this workshop to discuss approaches for the management and disposition of LLW. The workshop explored the following two issues:[7]

- the key physical, chemical, and radiological characteristics of LLW that govern its safe and secure management and disposal in aggregate and in individual waste streams, and
- how key characteristics of LLW are incorporated into standards, orders, and regulations that govern the management and disposal

[5] "[B]yproduct material . . . as defined in Sec. 11.e (2)" is provided in the Atomic Energy Act of 1954 as amended: "Sec. 11 DEFINITION . . . e. The term 'byproduct material' means . . . 2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. . . ." See "Atomic Energy Act of 1954 as amended by Public Law 114-92, Enacted November 25, 2015," accessed March 1, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

[6] The definition of LLW is complicated, requiring one to understand the definitions of other waste categories such as high-level radioactive waste and byproduct material. The full list of byproduct materials as well as definitions of other waste categories mentioned in this chapter are provided in Appendix D, Box D-1.

[7] Appendix A contains the full statement of task.

of LLW in the United States and in other major waste-producing countries.

This proceedings provides a factual description of the workshop presentations and discussions and is limited to the views and opinions of those participating in the event. Further, the viewpoints and comments from the workshop attendees are their own and are neither necessarily attributable to the organizations for which they work or support nor necessarily representative of the views of all workshop participants, the planning committee, or the National Academies. This proceedings does not contain consensus findings or recommendations.

1.1 WORKSHOP PLAN

A committee of four members was appointed by the National Academies to plan the workshop.[8] The planning committee met once to develop the workshop format and agenda and to identify speakers. In addition, a white paper developed by the rapporteur was distributed to participants prior to the workshop to provide background information on LLW.[9] The workshop was held at the National Academies' Keck Center on October 24-25, 2016.

The workshop began by defining the "universe" of LLW within the United States and elsewhere—first by introducing the types of LLW that exist and then by discussing the standards, orders, regulations, and laws that define and control their disposal. Next, case studies were presented to highlight the successful disposal of a variety of wastes that previously lacked a clear disposition pathway—these case studies are referred to as "success stories." The studies were selected from within and outside of the United States.

The participants explored common themes that led to success within the case studies such as: the use of existing regulations and standards (i.e., waste classification) to provide an anchor for disposal decisions; the identification of lessons learned from similar or analogous problems such as Canada's or France's approach to managing and disposing of very low-level waste (VLLW); and the importance of site characteristics for disposal decisions. These themes were organized into an approach to guide future discussions and disposition decisions for challenging LLW streams—a "common themes approach."[10] The approach is described in Chapter 4.

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[8]The planning committee's role was limited to planning and participating in the workshop. See Appendix B for the planning committee member biographies.

[9]The workshop agenda and white paper can be found in Appendices C and D, respectively.

[10]The "common themes approach" was developed as a discussion tool; it was not intended or presented as a consensus statement by the planning committee or the workshop participants.

The common themes approach was applied to a set of five pre-selected challenging LLW streams that spanned a variety of waste characteristics:

- Greater-Than-Class C (GTCC) and commercial transuranic waste (TRU) waste in excess of 100 nCi/g
- Sealed Sources
- Very Low-level and Very Low-activity Waste[11]
- Incident Waste
- Depleted Uranium

Each of these waste streams presents a unique set of challenges for disposal. For example, "GTCC waste and commercial TRU waste in excess of 100 nCi/g" lack a clear disposition pathway (as will be discussed in Chapter 4), while "Very Low-level and Very Low-activity Waste" have a disposition pathway in which the level of protection may be considered incommensurate with the hazard, or a potentially non-optimal disposition pathway (discussed in Chapters 2 and 4). The application of the common themes approach to these diverse waste streams was intended to explore how adaptable this approach would be as a tool in discussing or presenting a variety of disposal options.

One leader from each breakout group introduced a specific challenging LLW stream to the full workshop and later summarized the breakout group's results of applying the common themes approach to the issues associated with the disposal of this waste stream. Several participants identified short-term actions or "next steps" that could be taken to show progress in addressing each challenging waste stream in the final session of the workshop.

Presenters and attendees provided perspectives from academia, industry, federal agencies (including those outside of DOE), state governments, international organizations, public interest groups, and national laboratories. All participants were encouraged to contribute to the workshop discussions.

Several major topics emerged during the discussions throughout the workshop: complexity of regulations; communication among stakeholders; diversity of the type, source, and hazard of LLW; and integration of knowledge gained from operations. These topics are described below.

1.2 COMPLEXITY OF REGULATIONS

The complexity of the current U.S. LLW regulatory structure was mentioned in several presentations and discussions. Participants noted that the current regulatory structure is the result of "tweaks" and "adjustments"

[11]The planning committee proposed "exempt waste" as a category for the subgroup, but the topic of the subgroup's discussion focused on very low-level waste and very low-activity waste.

to regulations to address unanticipated types of wastes or other challenges. Several participants argued that the current LLW regulatory system should be thrown out and that a new system should be "developed from scratch." This "revolution instead of an evolution" of the LLW regulatory structure was raised several times during the workshop. Participants also discussed the complexity of the definition and regulation of TRU waste, noting that multiple laws and regulations contain definitions of TRU waste that can be inconsistent with each other.[12] It was also noted that the current LLW regulatory system has the flexibility to deal with unanticipated waste streams through case-by-case exceptions—which adds to the system's complexity. The unintended impacts of this complex system include the following: potential loss of public trust and confidence; mounting costs for disposal that are passed on to rate payers; and levels of regulation that are disproportionate to the hazards posed by LLW.

1.3 COMMUNICATION AMONG STAKEHOLDERS

Several participants noted that the complexity of the current LLW regulatory system leads to communication problems with stakeholders. Many stakeholders assume that LLW must be dangerous because the regulations are so strict and complex.

The appropriateness of the language used when discussing stakeholder or public concerns was also questioned by several participants. Some noted a move away from the use of "stakeholder"—which is a term that is difficult to define—to "concerned" or "interested parties" to be inclusive of a wider group including waste producers, academics, and other members of the public. Other phrases often used by experts that raise concern include: "Talking to the public," which implies a one-way flow of information, instead of "talking with the public." Or "educating the public," which was identified as denigrating; its use presupposes that the public is uneducated and also that, if given education, the public would agree with the experts doing the educating. Improving communications among stakeholders involves a change in mindset in addition to a change in language. Decisions on the final disposition of challenging wastes could be informed by a continuing conversation with stakeholders throughout the lifetime of a project.

[12] The Waste Isolation Pilot Plant Land Withdrawal Act provides the definition for defense TRU waste. The USNRC's document, *Statutory Language and Regulatory History of Commercial Transuranic Waste Disposal* (USNRC, 2015a), provides an example of conflicting definitions of TRU waste, which highlights the complexity of the topic (p. 5): "According to section (A)(i) of the [Low-level Radioactive Waste] Amendments Act, TRU waste is LLRW. Based on (A)(ii) of the Amendments Act, the [US]NRC can set the definition of LLRW. Consistent with (A)(ii) of the Amendments Act and because the 10 CFR Part 61 definition of LLRW excludes TRU, TRU is not LLRW."

The topic of accepting responsibility for the waste streams now to ensure safe disposal for future generations was repeatedly discussed at the workshop. Several participants noted that discussions with stakeholders on the final disposition of LLW were aided when the origins and social value of the activities that produced the wastes (i.e., medical treatments, electricity generation) were described.

1.4 DIVERSITY OF LOW-LEVEL WASTE TYPE, SOURCE, AND HAZARD

Participants noted that the "universe" of LLW in the United States is large due to its definition by exclusion. In the United States, high-activity wastes such as irradiated metals and sealed sources of high activity are considered LLW. Also, very low-activity wastes in the United States are subject to disposal requirements that many participants believed exceeded the hazard of the waste. Participants noted that characteristics such as half-life and activity levels (or hazards) of the waste are used in other countries to define waste categories and disposal options. Participants also noted that other countries have a "cleared" or "exempt" category of waste that allows for less protective disposal—an approach that is commensurate to the hazard of the waste—while there is no low-end threshold of activity for LLW in the United States. Also, in the United States, the states have regulatory authority for some radioactive wastes and regulations can be inconsistent across state boundaries even though the characteristics and hazard of the waste remain the same.

1.5 INTEGRATION OF KNOWLEDGE GAINED FROM OPERATIONS

The United States and other countries have been managing and disposing of nuclear waste for at least six decades. Several comparisons of early to modern LLW disposal concepts and facilities were presented at the workshop including: the EnergySolutions LLW Disposal Facility, Barnwell (South Carolina), Waste Control Specialists (Texas), and the Centre de la Manche (CSM) and Centres de stockage de l'Aube (CSA) (France) disposal facilities. These comparisons highlighted the improvements in modern facilities that resulted from applying the knowledge gained from the construction and operation of earlier facilities. Another point that was repeatedly raised by participants at the workshop was the importance of site characteristics of modern facilities in the United States, many of which are located in arid regions of the country. Several participants noted that the United States should find a way to integrate this new knowledge into the regulations and rules that govern the management and disposal of LLW.

1.6 ORGANIZATION OF THE PROCEEDINGS

This proceedings is organized following the general structure of the workshop:

- Chapter 2 includes introductory remarks by the chair and an overview of the scope of the LLW challenge (or the "universe" of LLW),
- Chapter 3 presents the case studies of successful LLW disposition,
- Chapter 4 identifies common themes for finding successful disposition solutions, applies them to a set of five challenging LLW streams, and summarizes concrete next steps towards a disposition pathway that might be taken for each.

2

Describing the Universe of Low-Level Waste

John Applegate, the planning committee chair and executive vice president for University Academic Affairs of Indiana University, welcomed the workshop attendees and provided short introductory remarks prior to initiating the panel presentations and discussions. His remarks are summarized below.

The workshop's objective was to identify approaches that might facilitate the disposition of challenging low-level waste (LLW) streams. These proceedings define "challenging LLW streams" as LLW streams that have potentially non-optimal or unclear disposition pathways due to their origin or content and incompatibility with existing standards, orders, or regulations. These approaches could possibly be used by the Department of Energy (DOE), the U.S. Nuclear Regulatory Commission (USNRC), U.S. states, and others to find safe and acceptable disposition pathways for challenging LLW streams.

Two critiques of the current U.S. LLW regulatory system have significance for this workshop: The first is that the U.S. LLW category is broad and provides limited guidance for dispositioning unusual or unanticipated LLW waste streams. The second is that standards, orders, and regulations tied to the management and disposition of LLW are not sufficiently tied to risk.

With respect to the first critique, the LLW category is defined by exclusion.[1] LLW is *not* high-level radioactive waste, spent nuclear fuel, or

[1] See Chapter 1 for a discussion on the statutory definition of LLW. Also, Appendix D, Box D-1 provides a more detailed definition.

uranium or thorium mill tailings and waste (also referred to as "11.e (2) byproduct material"[2]). Consequently, the LLW category covers a wide and very heterogeneous range of waste streams and, also, disposal requirements.

The fundamental problem with a broad LLW category is the lack of specific guidance for unanticipated LLW streams. Waste generators want to be able to plan for waste disposition; they need to know where their waste will go for disposal, how it needs to be processed and managed to make it acceptable for disposal, how to get it to where it is going to be disposed of, and how much it will cost. The waste recipients (i.e., the operators of disposal facilities and their stakeholders) also need to plan for acceptance of the waste; they want to know what the regulatory requirements are for acceptance; and they want to be able to reassure their stakeholders about the safety of waste disposition. One solution to the problem of unanticipated waste streams is to create new waste classifications that include them. Another option is to use case-by-case exceptions that are based on specific and known criteria and that can be applied in a consistent and predictable way.

With respect to the second critique, that LLW disposition regulations are not consistently tied to the risk, National Academies reports have consistently recommended that disposal of LLW focus on risk as opposed to waste origins.[3] These reports have urged greater attention to risk and a closer relationship between risk and regulatory requirements in the management of radioactive waste.

The report *Improving the Regulation and Management of Low Activity Radioactive Waste* (National Research Council, 2006b) concludes that a risk-informed approach provides the best option for improving the regulation and management of low-activity waste.[4] However, the current LLW regulatory system in the United States is based primarily on waste origins rather than risk. The report found that certain categories of low-activity waste have not received consistent regulatory management, and that current regulations for low-activity waste are not based on a systematic consideration of risk. The report acknowledged that changes to the regulatory structure would likely take many years, require coordination among many federal and state agencies, be highly individualized, and would need many assessments of individual situations. The report recommended adopt-

[2]"[B]yproduct material…as defined in Sec. 11.e (2)" is provided in the Atomic Energy Act of 1954 as amended. See "Atomic Energy Act of 1954 as amended by Public Law 114-92, Enacted November 25, 2015," accessed March 1, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

[3]See National Research Council 1997, 2000, 2001, 2005, 2006a, 2006b, and 2011a.

[4]The term "low-activity waste" in these proceedings refers to waste having very low radioactivity. This is different from DOE's use of "low-activity waste," which refers to a component of tank waste that is not highly radioactive.

ing a tiered approach, identifying a set of changes that could be implemented in order of increasing complexity, resources, and time, to make progress toward converting the current regulatory system into one that is risk-informed.[5]

The objective of LLW regulations is to protect human health and the environment, so consideration of risk is likely to be an important focus of the discussions in the present workshop. Human health effects of radiation are one important aspect of risk. Other factors that contribute to risk include fate and transport of contaminants, site geology, institutional controls, and the longevity of engineered barriers of disposal facilities.

Mr. Applegate asked the participants to balance the two aforementioned critiques against the following. First, the regulatory system reflects the problems it was originally created to solve. As the problems are better understood and/or change over time, the regulations must be adjusted accordingly, resulting in increased regulatory complexity. Challenging LLW streams are examples of such changing problems. New challenging LLW streams can be treated as exceptions to existing regulations and addressed in a case-by-case manner, or regulations can be modified to address them. In any case, the decision-making process is time-consuming, not standardized or predictable, and inconsistent across regulatory agencies, states, or even within individual agencies. Nor do these approaches leverage experience from previous cases.

Second, despite its complexity, the United States has a system for regulating the disposal of LLW that works well in the great majority of cases as demonstrated by the large volumes and variety of LLW streams that have been efficiently and successfully disposed of. However, the challenging LLW streams are not trivial—by volume and/or hazard—and many of these waste streams attract controversy when decisions are made regarding storage, transportation, and disposal. Therefore, one of the goals of the workshop is to examine the methods for addressing such waste in a rational, consistent, and coherent way.

Mr. Applegate ended his introductory remarks with a charge to the workshop attendees. We should ask ourselves questions such as the following: Should there be new classifications for these challenging waste streams? Should we develop criteria for a "below regulatory concern" LLW waste classification? Do we need new regulatory classifications and/or subcategories for LLW? Should those classifications or categories be differentiated from each other by source, risk, and/or inherent characteristics? We should consider how to balance flexibility and individual tailoring of a

[5]Specifically, Recommendation 2 in the report suggests "a four-tiered approach: (1) changes to specific facility licenses or permits and individual licensee decisions; (2) regulatory guidance to advise on specific practices; (3) regulation changes; or if necessary, (4) legislative changes" (National Research Council, 2006b, p. 7).

particular waste stream against predictability and consistency of the regulatory system.

2.1 THE SCOPE OF THE LLW CHALLENGE

The first session of the workshop consisted of two panels.

- The first panel focused on categories and characteristics of LLW; it was moderated by Nina Rosenberg, a member of the workshop planning committee and program director at Los Alamos National Laboratory.
- The second panel focused on the regulations, standards, orders, and guidance that have been developed for LLW; it was moderated by Larry Camper, also a member of the workshop planning committee and recently retired from the USNRC.

The moderators opened each panel with brief presentations of background information, which are summarized below. Invited panelists then presented more detailed information on specific topics. A discussion was held after each panel.

The comments from the moderators, panelists, and other workshop participants are their own. They do not necessarily represent official views of their employers, governments, or other organizations that may be mentioned in their presentations and discussions.

2.2 CLASSIFICATION, CATEGORIES, AND CHARACTERISTICS OF LLW

Dr. Rosenberg moderated the session on the classification, categories, and characteristics of LLW. Her remarks are below. She reminded the participants that, in the United States, LLW is defined "by exclusion." Civilian (usually commercial) LLW is regulated by the USNRC based on specific activity concentrations of radionuclides deposited in a waste matrix and intended for final disposition: Classes A, B, C, and Greater-Than-Class C (GTCC), with Class A requiring the lowest and GTCC requiring the greatest levels of protection (see Tables D-1 and D-2). Near-surface disposal is appropriate for Class A, B, and C wastes but is not appropriate for GTCC wastes.[6] There are currently four commercial sites for LLW disposal using near-surface disposal methods in the United States; they are located in Utah, Texas, South Carolina, and Washington. These facilities are constructed to

[6] The disposal of GTCC is a federal responsibility.

meet generic performance objectives defined by USNRC regulations and have defined waste acceptance criteria.

Government-owned LLW[7] is regulated by DOE. It is DOE policy to dispose of these wastes if possible at the sites where they were generated or are stored. There are currently four DOE sites that dispose of their own wastes: Idaho National Laboratory, Oak Ridge National Laboratory in Tennessee, Savannah River Site in South Carolina, and Los Alamos National Laboratory (Area G) in New Mexico. Two additional DOE sites dispose of offsite LLW in addition to their own wastes: US Ecology, Inc., LLW Disposal Facility at the Hanford Site, Washington, and the Nevada National Security Site (NNSS, previously named the Nevada Test Site). DOE relies on waste acceptance criteria derived from site-specific performance assessments to manage and dispose of LLW at all of its facilities. These DOE facilities use a variety of near-surface disposal methods with engineered structures and surface barriers, depending on site characteristics and waste acceptance criteria.

Both the DOE and commercial sites listed above are located in different climate zones, varying from very wet and humid (South Carolina and Tennessee) to very dry and arid (New Mexico, Nevada, Idaho, Texas, Utah, and eastern Washington). Further information about these sites can be found in Appendix D.

International schemes for managing LLW differ from U.S. approaches in some important ways. The International Atomic Energy Agency (IAEA) bases its guidance[8] on radioactive waste classification on disposal considerations in six categories from exempt, very short-lived waste, VLLW, LLW, intermediate-level waste, and high-level waste.

Three panelists having different backgrounds and with different perspectives were invited to discuss LLW types. They were specifically asked to address the following two questions:

- What are the greatest challenges that you have observed in the management of LLW?
- What key technical criteria and/or waste characteristics are most important to consider in the management and disposal of these wastes?

Miklos (Mike) Garamszeghy, design authority and manager of technology assessment and planning for the Canadian Nuclear Waste Management Organization (NWMO), provided a Canadian perspective; Lisa Edwards,

[7]This has previously been referred to as "defense LLW."

[8]The IAEA provides guidance on the regulation—but does not regulate—the nuclear wastes of its member states.

senior program manager for Electric Power Research Institute (EPRI),[9] provided perspectives from the commercial nuclear industry (as waste generators); and Daniel (Dan) Shrum, senior vice president of regulatory affairs at EnergySolutions, provided perspectives from the U.S. commercial disposal industry.[10]

LLW Challenges—The Canadian Context

Mr. Garamszeghy began his presentation by describing the main difference between the U.S. and Canadian approaches to the management of LLW: in Canada, waste owners are responsible for managing their own waste, from generation to disposal. There is no national organization that looks after waste disposal, but there is a national regulator. Similarly, there are no commercial entities whose sole focus is waste disposal.

Prior to 2008, the Canadian radioactive waste classification scheme was similar to that for the United States—defining LLW by exclusion and using the following waste categories: nuclear fuel waste (used fuel), uranium mining and milling waste, and LLW (everything else). The current classification scheme, established in 2008, follows the IAEA's *General Safety Guide GSG-1* (IAEA, 2009a) for establishing waste categories: exempt, VLLW, LLW, intermediate-level waste, and high-level waste. The Canadian scheme does not establish numerical boundaries between the different waste classes; the values of the boundaries are determined and justified by the waste owners. This classification scheme provides consistency in terms of the IAEA terminology, but the actual distinction between different waste classes is less clear.

Unlike the U.S. approach, the system in Canada allows clearance of waste through the exempt category. Waste can be exempted in two ways: A generic regulation allows waste to be cleared if its activity is below a very conservative limit based on IAEA's *Safety Guide RS-G1.7* (IAEA, 2004). Alternatively, for wastes having slightly higher activities, waste owners may perform case-by-case analysis for the higher limit.

Canada's VLLW and LLW are currently generated from a number of sources, similar to waste generation in the United States. Waste characteristics vary widely based on waste source. Intermediate-level waste, for example, is generated by day-to-day operations at nuclear power plants (NPPs); refurbishment and decommissioning of power reactors; and isotope production.

Mr. Garamszeghy provided the following list of questions that are typically considered by waste owners in Canada when making decisions on the disposition of their radioactive waste:

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[9]EPRI is a nonprofit research entity supported by the electricity industry.
[10]The biographies for the speakers and panelists can be found in Appendix E.

- What type of waste needs disposal?
- Who owns the waste?
- How much waste is there?
- Where is the waste located?
- What are the community preferences?
- What are the total system costs for managing the wastes?
- What other hazards are associated with the waste?
- How is the waste currently packaged and stored?
- How well is the waste characterized?

Mr. Garamszeghy noted that Canada does not currently have any licensed and operational disposal facilities for low- and intermediate-level waste or spent fuel. However, a number of facilities are in various stages of licensing or construction. In Canada, the NWMO has the mandate for the long-term management, including disposal, of spent fuel. There is no national entity for disposal of low- and intermediate-level waste, as mentioned at the start of his presentation. All of the waste is stored by the waste owners in facilities of various designs (i.e., above and below ground) and locations. Figure 2-1 is a map that shows the locations of some of these facilities. Note that these facilities are distributed throughout Canada.

Overview of Commercial Power Plant Wastes

Ms. Edwards' presentation focused on LLW produced by U.S. NPPs. Two types of wastes are produced, dry active and wet waste. Dry active waste consists predominantly of papers, plastic, and cloth, for example the protective clothing worn in facilities. It can also include tools, wiring, and metals that are not compactable. Wet waste is principally made up of resin, charcoal, and filters. Wet wastes are generated during NPP operations, primarily during the cleanup of water systems. Boiling water reactors also produce irradiated hardware LLW streams; however, this waste stream is not included in this discussion because it represents a small fraction of waste.

Figure 2-2a shows the volume of waste types (i.e., dry active and wet wastes) generated by U.S. NPPs between 2003 and 2007; and Figure 2-2b shows the volume of resin wastes generated during this same time period grouped by USNRC waste class (i.e., Class A, B, or C). It is clear that the vast majority (almost 90 percent) of the waste generated is dry active waste or Class A waste. Class B waste is 13 percent, and Class C is 1 percent of the total (Figure 2-2b).

At the time these data were collected, filters made up almost the entire volume of Class C waste, and resins made up the majority of Class B waste. However, once NPPs implement the new concentration averaging requirements from the updated USNRC *Branch Technical Position on Concentra-*

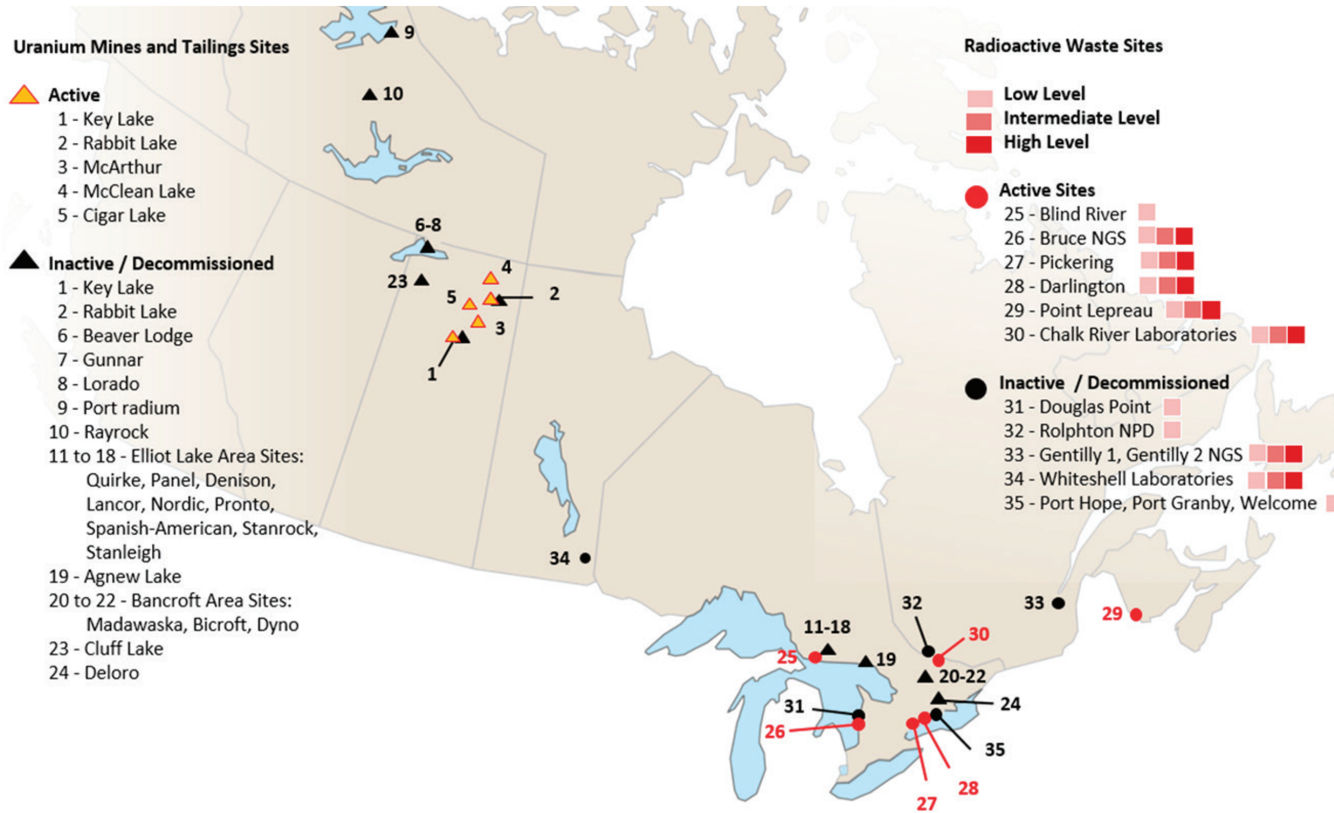

FIGURE 2-1 Major radioactive waste management sites in Canada.
SOURCE: Canadian Nuclear Safety Commission.

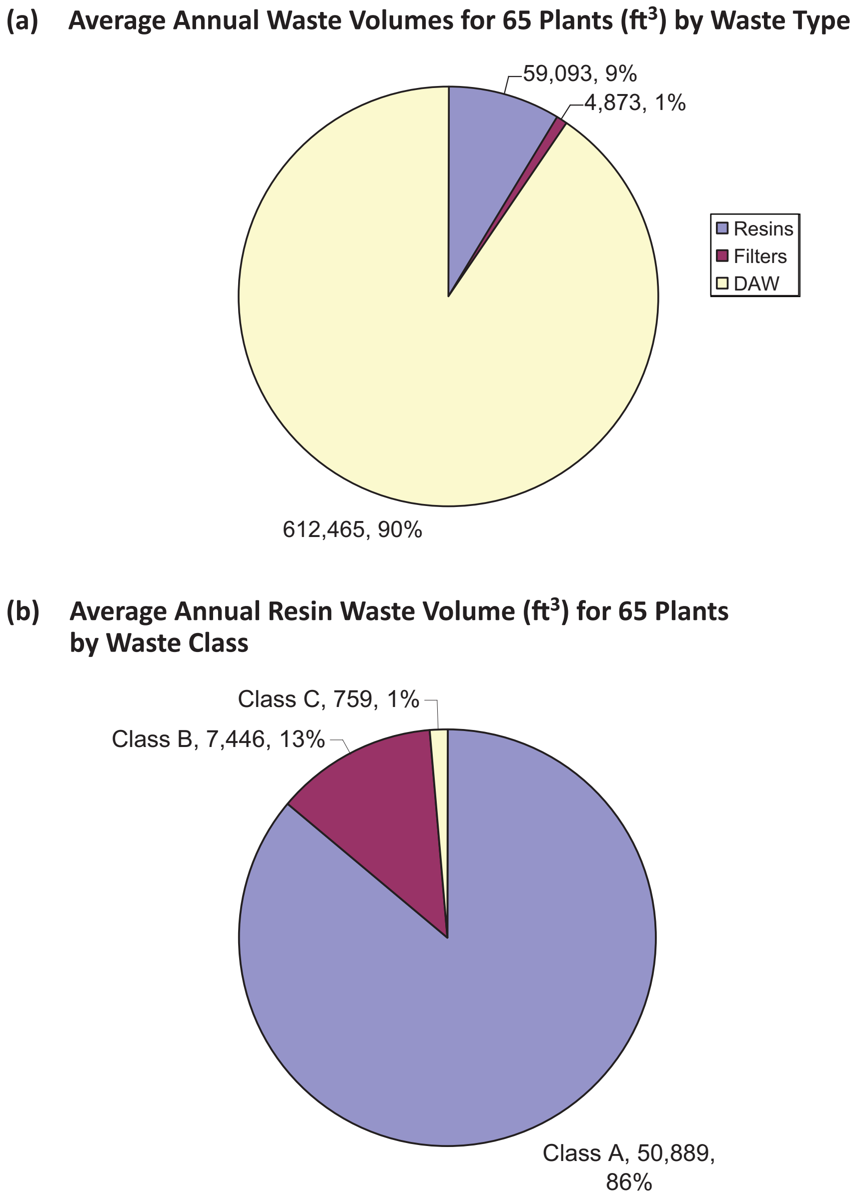

FIGURE 2-2 Historic average annual waste volumes by (a) waste type and (b) waste class (volumes listed in cubic feet).
NOTE: DAW refers to dry active waste.
SOURCE: Courtesy of the Electric Power Research Institute.

tion Averaging and Encapsulation,[11] it is likely that Class C waste will become virtually nonexistent outside of irradiated hardware. Ms. Edwards suggested that the combined Class B and C slice of the pie (Fig. 2-2b) may approach zero once concentration averaging is implemented.

Recent data from an EPRI database, RadBench,[12] show the trends in the generation of dry active and wet wastes from NPPs. There has been a steady reduction in dry active waste (at a rate of approximately 10,000 pounds per year) beginning in 2008. For wet wastes, there was a slight reduction between 2007 and 2011 followed by a near-equivalent increase. The reduction may have occurred for two reasons: (1) the LLW disposal site at Barnwell, South Carolina, stopped accepting LLW from all states except those within its compact,[13] and (2) an EPRI report (Edwards, 2010) released near this time highlighted techniques and practices for reducing the volume of Class B and greater operational waste (which is primarily wet waste). The volume of wet waste began to increase in 2011 when the Waste Control Specialists (WCS) facility in Texas was licensed and began accepting LLW.

LLW management and disposition do not affect the generation of electricity and are not a NPP's primary business. The managers of NPPs make disposal decisions based on the most economical and safe alternatives. The cheapest option that meets safety (and other) disposal requirements is nearly always selected. A rough analogy is the choice that a member of the public makes on who picks up his/her household garbage. The individuals responsible for the packaging and management of radioactive waste are internally motivated; other plant workers may not understand the potential impact of waste management mistakes. Those individuals who are involved in waste management consider themselves to be the environmental guardians of the plant, making sure the NPPs do not encounter problems over the waste management and disposition decisions.

Ms. Edwards noted the lack of a "very low-level waste" category in the U.S. regulatory system but its inclusion in the classification systems of other countries such as Canada. VLLW is defined differently throughout the world, but it is generally characterized as having a very small percentage of the activity defined by other waste class limits and a very low radiation hazard.

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[11]For more details on concentration averaging, see "Branch Technical Position on Concentration Averaging and Encapsulation," last updated October 26, 2016, https://www.nrc.gov/waste/llw-disposal/llw-pa/llw-btp.html.

[12]RadBench is used by NPPs around the world to self-report the volumes of waste that they generate, prior to conditioning and disposal. The disposal volumes may be smaller. See "EPRI Product Abstract: WasteLogic RadBench Web Application (RadBench) v3.0.2," accessed March 1, 2017, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003994.

[13] See Appendix D for a brief explanation of the U.S. state compact system.

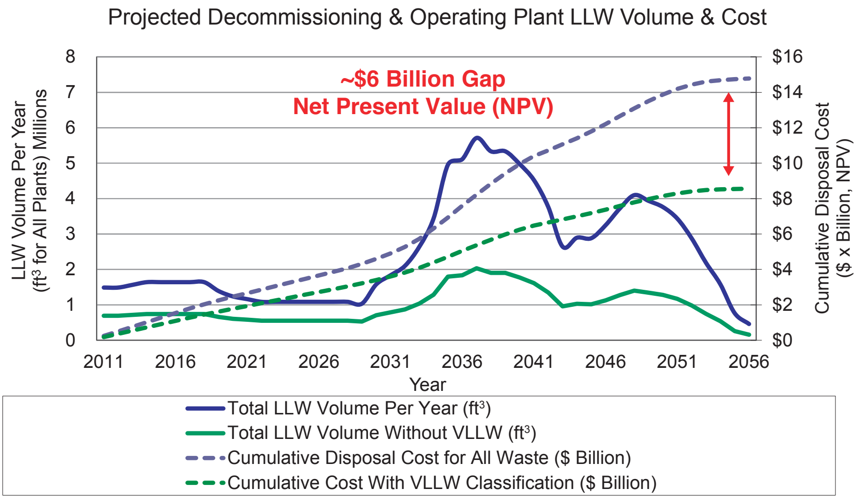

FIGURE 2-3 Potential very low-activity waste cost savings projections. The solid blue line respresents the projected volume of LLW through 2056 that will be produced as NPPs are decommissioned. The solid green line represents the projected volume of LLW minus the lowest activity fraction. The dotted blue and green lines are cumulaitve disposal costs. The difference between the blue and green dotted line by 2056 is roughly $6 billion. The projections for decommissioning wastes change nearly yearly, so the estimates in this figure should be considered rough.
NOTE: ft^3 = cubic feet; LLW = low-level waste; NPV = net present value; VLLW = very low-level waste.
SOURCE: Courtesy of the Electric Power Research Institute.

A strong argument can be made that U.S. regulatory requirements for wastes classified as very low-level (or very low-activity) in other countries are overly burdensome and costly (see Figure 2-3) (EPRI, 2012). Very low-activity waste makes up approximately 80 percent of the volume of waste that is generated during NPP decommissioning; the cost of decommissioning is passed along to the public.

There are regulatory pathways for reducing the costs of disposing of this very low-activity waste, even though a VLLW category does not exist in the United States. For example, an exemption under the USNRC's *Code of Federal Regulations 10 CFR* 20.2002 (referred to as the "20.2002 exemption")[14] allows for specific waste streams to be approved for disposal

[14]A brief explanation of the exemption is provided on the USNRC's website: "10 CFR 20.2002 is available for use by licensees for wastes that typically are a small fraction of the

at Resource Conservation and Recovery Act (RCRA) disposal sites instead of LLW-licensed facilities. The 20.2002 exemption process is not transparent and it is cumbersome (see Chapter 3 and 4 for more discussions on this). Exemptions are granted on a case-by-case basis and implemented differently from state to state.[15]

In Ms. Edward's opinion, the 20.2002 exemption process and case-by-case approvals are subject to political whims, so that they might be affected by the release of a newspaper article or by an election. Adding a classification and set of requirements for the lowest activity of Class A would be more transparent and beneficial.

Figure 2-3 illustrates the potential economic impact of defining a new VLLW classification. The blue solid line represents the total expected LLW to be generated at U.S. NPPs through the year 2056, including generation of very low-activity waste. As current NPPs begin decommissioning, the volume of LLW waste generated will increase. The green solid line excludes the very low-activity portion of the waste that could potentially be diverted to RCRA facilities instead of LLW disposal facilities. The cost of disposing of this waste in RCRA facilities is significantly lower—EPRI estimates the total savings would be in the $6 billion range—than disposing of the waste in a LLW facility. The cost savings is the difference between dotted blue and green lines in the figure.

Low-Level Radioactive Waste

Mr. Shrum began his prepared remarks by commenting on the previous presentation. He agreed that the question raised by Ms. Edwards of how to best address the disposal of the expected large quantity of very low-activity waste from NPP decommissioning (see Figure 2-3) should be answered sooner than later, and also that the United States should have a more uniform standard for addressing very low-activity radioactive waste (see Chapter 3 for more discussion on VLLW and exempt or clearance waste).

Mr. Shrum noted that EnergySolutions (his employer) operates two

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Class A limits contained in Part 61, and for which the extensive controls in Part 61 are not needed to ensure protection of public health and safety and the environment. Thus, 10 CFR 20.2002 provides an alternative, safe, risk-informed disposal method for these materials, which are frequently called 'low-activity waste.' Although these materials could be disposed of in a licensed low-level radioactive waste facility, if a licensee chose to do so, disposal at another type of facility under 10 CFR 20.2002 may significantly reduce transportation distances (often on the order of one to two thousand miles), provide for more disposal options, and lower disposal costs, while still providing for protection of public health and safety and the environment. . . ." (See "Low-Level Waste Disposal Under 10 CFR 20.2002," accessed April 9, 2017, https://www.nrc.gov/waste/llw-disposal/10cfr20-2002-info.html.)

[15]The commercial LLW facilities are regulated by individual Agreement States (see Appendix D), which results in differences between the licensing requirements that they impose.

of the four commercial LLW disposal facilities in the United States: one in Clive, Utah, and another in Barnwell, South Carolina.

The LLW waste classification system in the United States (i.e., Class A, B, C, and GTCC) is based on activity and hazard.[16] The USNRC provides criteria for near-surface disposal of LLW:

- The external exposure to a member of the public resulting from release of the waste shall not exceed 25 millirem/year (mrem), effective dose equivalent (10 CFR Part 61.41); [17] and
- the dose to a person who inadvertently intrudes into the disposal site after loss of institutional control (100 years) shall not exceed a one-time commitment of 500 mrem or an annual dose of 100 mrem for the first 1,000 years after emplacement (10 CFR Part 61.42).

For Class A waste, the hazard is minimal after 100 years; for Class B waste, the hazard timeframe increases to 300 years; and for Class C waste, it is 500 years. Because of its higher hazard, Class C waste must be buried at least 5 meters below the surface and have an engineered barrier.[18]

EnergySolutions has received a wide variety of LLW streams at its disposal facilities including paper, rags, plastic, glassware, syringes, protective clothing, cardboard, packaging material, spent pharmaceuticals, water-treatment residues, contaminated ion exchange resins, filters, tools, irradiated metals from nuclear power plants, and animal carcasses. The animal carcasses have to be incinerated because the facilities cannot directly dispose of organic materials.

Mr. Shrum stated that the main challenge of LLW disposal in the United States is not technical. The main challenge is political. Prior to the enactment of the Low-Level Radioactive Waste Policy Act of 1980 (LLRWPA),[19]

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[16]See the USNRC classifications at "Part 61.55 Waste classification," accessed April 9, 2017, https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html.

[17]Note that 10 CFR Part 61.42 does not list dose limits for an inadvertent intruder. However, the concentrations of radionuclides established in Part 61 Tables 1 and 2 assumed a (maximum) dose of 5 millisievert/year (500 mrem/year). For more information see "Technical Basis for Proposed Rule to Amend 10 CFR Part 61 to Specify Requirements for the Disposal of Unique Waste Streams, including Large Quantities of Depleted Urainum (FSME-10-XXXX)," accessed April 9, 2017, https://www.nrc.gov/docs/ML1110/ML111040419.pdf. Note that the average annual exposure for a member of the public in the United States is 620 mrem/yr, including medical procedures (see "NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States," accessed March 27, 2017, available for purchase at http://ncrponline.org/publications/reports/ncrp-report-160/).

[18]Mr. Shrum noted here that transuranic (TRU) waste is an exception and can be considered LLW in some instances (see LLW definition and notes in Box D-1). During the discussion session, a participant asked for further clarification on Mr. Shrum's statement about TRU waste.

[19]See Box D-2 in Appendix D for a description of the LLRWPA, its amendment in 1985, and other laws related to LLW regulation.

FIGURE 2-4 Locations of the four U.S. commercial LLW disposal facilities; compare the number and distribution to Canadian facilities shown in Figure 2-1.
SOURCE: U.S. Nuclear Regulatory Commission.

there were three operating disposal facilities in the United States: Beatty, Nevada; Barnwell, South Carolina; and Hanford, Washington. The governors of these states testified to Congress that they should not bear the burden of LLW disposal for the whole nation. Congress agreed and established the LLRWPA.

The purpose of the LLRWPA was to distribute LLW disposal obligations across the United States by establishing a state compact system[20]—assuming that regional disposal would be the safest and most efficient and equitable means for managing LLW. The United States now has four operating disposal facilities for commercial LLW (see Figure 2-4 and Table D-1 in Appendix D):

- EnergySolutions LLW Disposal Facility, Barnwell, South Carolina, accepts Class A, B, and C waste;

[20]See Appendix D for further descriptions of Agreement States and the state compact system. Table D-1 lists the state compacts that are associated with each commercial LLW facility.

- EnergySolutions LLW Disposal Facility, Clive, Utah, accepts Class A and 11.e (2) waste;[21]
- WCS, Texas, accepts Class A, B, and C and 11.e (2) waste; and
- US Ecology, Inc., LLW Disposal Facility, Hanford Site, Washington, accepts Class A, B, and C waste.

Since the LLRWPA was enacted, the EnergySolutions LLW Disposal Facility in Clive and WCS in Texas have opened. Clive accepts Class A waste from all 50 states. Both WCS, Texas and the EnergySolutions, Clive facilities can accept DOE waste.

Mr. Shrum noted that when the LLRWPA was enacted, there was no analysis to determine whether there was enough LLW generation to support multiple state compact disposal facilities. Currently, all states have access to some disposal capacity, and waste does not have to be transported very far, which keeps transport risk low—Mr. Shrum stated that the transportation of LLW has a great safety record and is one of the safest aspects of the LLW disposal system.

2.3 DISCUSSION: CLASSIFICATION, CATEGORIES, AND CHARACTERISTICS OF LLW

The content of the discussion sessions is grouped by topic in these proceedings and may not appear in the same order as they occurred during the workshop. The main topics are highlighted in bold headings.

Very Low-Level and Clearance Waste in the United States

Several participants asked questions about the criteria for VLLW and clearance (or exempt) waste, referring to presentations by Mr. Garamszeghy and Ms. Edwards and comments by Mr. Shrum.

Participants asked for more details related to the cost savings of using a VLLW category for decommissioning. Specifically, Francis X. "Chip" Cameron, currently with CameronGray LLC and an ex-USNRC assistant general counsel, asked for an estimated cost difference to send the expected volume of very low-activity waste to a Class A versus RCRA site for the San Onofre NPP decommissioning. Ms. Edwards recalled the cost savings between disposals at a Class A versus a RCRA facility to be approximately a factor of 10. However, she also noted that waste disposal does not make up the majority of decommissioning costs. The main cost for decommissioning is labor (personnel). Gérald Ouzounian, international director at

[21]The Atomic Energy Act, Section 11.e, defines byproduct material "11.e (2)" refers to the tailings or waste produced by the processing of ore to extract uranium or thorium. See Box D-1 in Appendix D for more information.

ANDRA,[22] added that, in France, VLLW has been disposed of in a facility separate from LLW since 2003. The cost savings for disposal is between a factor of 15 and 18. Dr. Ouzounian also noted that the French are moving toward optimization of the full system costs as opposed to the separate costs for dismantling and disposing of the waste.

Scott Kirk, director of regulatory affairs for BWXT, asked Ms. Edwards whether the $6 billion in projected cost savings shown in Figure 2-3 represented the total number of plants that are planned for decommissioning over the timeframe represented in the figure. How was this cost savings calculated?

Ms. Edwards explained that the exact shape and height of the solid blue and green lines in Figure 2-3 could change if there are changes in the assumed scheduling of future NPP shutdowns. However, the area under each of the curves (i.e., the total volume of LLW generated from reactor decommissioning) will be more or less the same regardless of when the reactors are decommissioned. EPRI assumed that the cost of disposing of decommissioning wastes will be the same regardless of the exact timing of decommissioning. In summary, the cost estimate shown in Figure 2-3 represents the total number of reactors that are expected to be decommissioned over the timeframe represented in the figure.

Mr. Camper asked what criteria should be specified in a regulation that would replace the case-by-case exemption process described by Ms. Edwards for VLLW. Ms. Edwards responded by referencing two publicly available EPRI reports, as noted in her presentation. The report, *A Generic Technical Basis for Implementing a Very Low Level Waste Category for Disposal of Low Activity Radioactive Wastes* (EPRI, 2013), analyzed how the VLLW category is applied outside of and within the United States. A comparison between U.S. RCRA disposal facilities and VLLW disposal facilities that exist in France and Spain concluded that the sites compare favorably in terms of protectiveness.

Another EPRI report, *Basis for National and International Low Activity and Very Low Level Waste Disposal Classifications* (EPRI, 2012), proposed a definition for VLLW based on dose and isotopic limits from existing definitions of VLLW in countries in which that waste stream is recognized. The report also considered the characteristics of the waste in which the 20.2002 exemption process was used. Additionally, doses for intruder and other scenarios were developed to postulate criteria and limits. The resulting criteria are more conservative than what is used in other countries. Ms. Edwards noted that the reports were written to provide information to "start a conversation" about this new waste category.

Mr. Shrum noted that very low-activity waste disposal is one of

[22]ANDRA is the French acronym for National Radioactive Waste Management Agency.

EnergySolutions' top priorities. USNRC 10 CFR Part 61 addresses the disposal of LLW. In addition, there is a new ~500-page guidance document for 10 CFR Part 61. Mr. Shrum asked that a guidance document be created to add clarity to the reference of a "few millirem" in the 20.2002 exemption. This detail is important to the waste disposal industry because more very low-activity waste is disposed of under exemption than is disposed of at LLW facilities. Whether intentional or not, the current reality is that regulation of very low-activity waste is occurring through exemption. Additional guidance would help to clarify criteria, for example the "few millirem" reference above, for the industry and practitioners.

Mr. Camper recalled that several years ago, the USNRC's Office of General Counsel asked the USNRC staff to identify a basis for using a "few millirem" for a lower threshold. It was determined then that the USNRC staff was at liberty to use a higher number, but first it needed to alert the Commission. Mr. Camper agreed that it would be good to embody this criterion within regulation.

Both the USNRC and the Environmental Protection Agency (EPA) have spent considerable time and effort considering VLLW, as noted by several participants.[23] Mr. Camper asked John Greeves, USNRC retired, to provide further background on the USNRC's work on the clearance of very low-activity waste. Mr. Greeves noted that there is no lower threshold for LLW classification in the United States. The IAEA document, *Application of the Concepts of Exclusion, Exemption and Clearance Safety Guide* (referenced previously by Mr. Garamszeghy) has a clearance definition that the USNRC staff (including Mr. Greeves and others at the time) had supported but the USNRC never adopted. France has done an outstanding job of resolving this problem and provides an excellent case study on how to manage and dispose of VLLW. The USNRC staff completed an environmental impact statement (EIS) in 2005 to evaluate approaches for managing certain types of VLLW, but no action was taken. Mr. Greeves noted that the federal government and Congress have not focused on addressing this issue.

Mr. Camper recalled that the USNRC and EPA conferred in 2003 as EPA prepared an Advance Notice of Public Rulemaking (ANPR) on very low-activity waste. Mr. Camper asked Mr. Daniel Schultheisz, EPA, Office of Radiation, whether EPA considered developing criteria for VLLW at the time of the ANPR and, if so, how it aligned with what EPRI proposed in the generic technical basis report (EPRI, 2013). Mr. Schultheisz explained that EPA has been looking at the issue of VLLW for quite some time. The ANPR referenced above was released in 2003 and was, in fact, an iteration

[23]While not discussed during the workshop, it is worth noting that DOE utilizes a similar option (called the "authorized limits process") for waste with low concentrations of radioactivity through disposal at on-site Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cells.

of previous work. EPA had originally considered a VLLW disposal option when it considered ways to make it easier for generators to dispose of mixed waste at RCRA facilities. This was broadened in the early 2000s to include working with the USNRC staff—Mr. Greeves in particular offered his staff to provide assistance.

EPA's approach is conceptually similar to what is proposed in the EPRI report (EPRI, 2013). The approach in the rulemakings before the ANPR was to establish specific concentration limits on radionuclides based on certain exposure scenarios. The limits were calibrated to particular dose levels and could be adjusted, allowing states the flexibility to implement as they saw appropriate. The states would not be required to adopt the dose levels.

The EPA received many public comments after the ANPR was released. However, at the same time, EPA staff were significantly distracted by the Yucca Mountain rulemakings. Mr. Schultheisz recalled that there was not significant support within the EPA at the time for a rulemaking on VLLW. Mr. Schultheisz noted that the EPA has continued to perform some modeling of different exposure scenarios—perhaps similar to what EPRI has done. The results are in a draft report, which has not yet been released.

The EPA is considering the application of the VLLW concept to wastes created by a radiological incident, such as a dirty bomb, or a nuclear accident such as occurred at Fukushima and Chernobyl. The EPA is establishing a planning process whereby clearance or VLLW designations could be implemented (see later discussion of this waste type in Chapter 3).

Kevin Crowley, director of the Nuclear and Radiation Studies Board at the National Academies, asked Mr. Garamszeghy whether the Canadian public had accepted the idea of clearance waste and whether there has been a difference in the ease or cost of disposing of this waste. Mr. Garamszeghy responded that in terms of public acceptance, certain members of the public are ideologically opposed. Regardless, clearance of the waste is allowed under regulation. He also noted that allowing for cleared waste has reduced the volumes of radioactive waste that have to be managed. All major nuclear waste producers, such as NPPs and research facilities, have implemented a "likely clean" program. The program is based on the separate collection and monitoring of waste, which, for operational reasons such as the location in the plant of its generation, is considered "likely clean." Those wastes are bulk collected and monitored. They can then be released for conventional recycle or disposal, depending on the waste type. In a number of cases, this resulted in a reduction of more than 50 percent in the amount of waste that has to be treated as radioactive waste.

The "likely clean" program has been in practice for more than 15 years and is very cost-effective. Most of the waste that gets diverted in this fashion is nonradioactive. The release criterion is basically background activity.

Background activity is a very conservative limit, so the waste is essentially clean.

New Rules in Averaging and Reduction in Class B and C Wastes

Ms. Edwards was asked by Diane D'Arrigo, the radioactive waste project director of the Nuclear Information and Research Service, whether her estimate or projection of future volumes of Class B and C wastes being reduced to zero was because of new calculations, physical mixing, or both. Ms. Edwards responded that she suspects that volumes of Class B and C wastes will approach zero due to the updated method for concentration averaging. Not all LLW containers or packages contain homogenous mixtures of waste. Some waste packages have "hot spots"[24] created by waste components that cannot be evenly distributed throughout the package such as filters or irradiated metals. In this case, a calculation determines the allowable activity level for these components of the waste. The term "concentration averaging" refers to this calculation.

The 1995 USNRC guidance on concentration averaging was intended to limit the concentrations of specific radionuclides within a given waste package as compared to the average activity of that package.[25] Updated guidance released in 2015 allows the concentration of the hot spot to be compared to the waste classification limit instead of the average concentration of the package.[26]

Ms. Edwards further explained that the important quantity for waste disposal is the total activity that goes into a single package. If a package meets the averaging constraints described above, then the higher activity from the hot spot is averaged with the other constituents over the total volume. This is the reason for Ms. Edwards' prediction that nearly all Class B and C waste from the utilities will be packaged as Class A waste in the future.

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[24]The USNRC defines a hot spot as (USNRC, 2015b, p. 11) "a portion of the overall waste volume whose radionuclide concentrations are above the class limit for the entire container [or package]."

[25]See 10 CFR Part 61.55, Table 2 for the list of radionuclides and their concentration limits. For the text of the 1995 guidance, see "Issuance of Final Branch Technical Position on Concentration Averaging and Encapsulation, Revisions in Part to Waste Classification Technical Position," accessed April 9, 2017, https://www.nrc.gov/docs/ML0336/ML033630732.pdf.

[26]For the new "factor of 10" rule: the concentration of each radionuclide of concern in each item [or waste package] should be less than 10 times the classification limit for that radionuclide.

Waste Classification of LLW Containing TRU Nuclides

Dr. Crowley asked Mr. Shrum to clarify a comment made during his presentation on how TRU waste might be considered LLW. Mr. Shrum responded that, by definition, TRU waste is not LLW; nevertheless, 10 CFR 61.55 allows for near-surface disposal for waste containing TRU nuclides based on its characteristics. Dr. Crowley suggested that disposal of TRU as LLW might not be a problem because it is apparently allowed by regulation.

Mr. Camper noted two concerns with disposal of TRU as LLW: The first is that TRU waste is not included in the definition of LLW in 10 CFR Part 61 so it is disconnected from the LLRWPA Amendment. The second and larger concern is that Table 1 in 10 CFR 61.55 states that the Class C limit allows up to 100 nanocuries per gram (nCi/g) for waste containing TRU nuclides but it does not explicitly define waste containing more than 100 nCi/g of TRU nuclides.[27] The problem is that some of the waste defined in the final EIS for GTCC[28] waste is non-defense TRU waste for which there is no disposal pathway at present. This is the problem that the Commission directed USNRC staff to address via rulemaking.

Legacy (Historic) Wastes

Jennifer Heimberg, rapporteur and National Academies staff, asked the panel how legacy wastes are handled in Canadian and U.S. regulations and whether they are disposed of at commercial LLW facilities. Mr. Garamszeghy noted that the legacy wastes can be a challenge to address. In Canada, these wastes are the result of a number of activities (research, mining, industrial) dating back to the early 1940s. Many legacy waste streams are not well characterized in terms of radionuclide content, physical forms, or volumes. They have been stored or disposed of in facili-

[27]The following documents provide history and further background on the TRU waste problem (USNRC, 2015a and 2015c): "SECY-15-0094: Historical and Current Issues Related to the Disposal of Greater-than-Class C Low-Level Radioactive Waste," accessed March 28, 2017, https://www.nrc.gov/docs/ML1516/ML15162A807.pdf and "SECY-15-0094, Enclosure 3: Statutory Language and Regulatory History of Commercial Transuranic Waste Disposal," March 28, 2017, https://www.nrc.gov/docs/ML1516/ML15162A828.pdf.

The USNRC makes the following statement (Footnote 4, p. 2, USNRC, 2015a): "TRU waste is explicitly excluded from the definition of LLRW [low-level radioactive waste]. However, the [US]NRC has determined that LLRW containing TRU nuclides meeting certain criteria may be suitable for disposal within a 10 CFR Part 61 disposal facility. See 10 CFR § 61.55(a)(3), Table 1."

[28]See "DOE: Greater-Than-Class C Low-Level Radioactive Waste Environmental Impact Statement (GTCC EIS) Documents," accessed March 1, 2017, http://www.gtcceis.anl.gov/documents/index.cfm#final.

ties that do not meet modern standards. Consequently, there are uncertainties in the characteristics, quantities, and locations of these wastes. The Canadian federal government is ultimately responsible for managing these wastes; the government has a number of programs in place to characterize and manage them. For example, Mr. Garamszeghy recalled from his presentation that there were ~2.1 million cubic meters of VLLW in Canada.[29] This is largely historic waste from contaminated soil, decommissioning of legacy facilities, and similar activities. There is a proposal by Canadian Nuclear Laboratories, a contractor that operates the government's nuclear facility near Chalk River, Ontario, to develop near-surface disposal facility at that site for disposal of Canada's legacy wastes. Most of Canada's legacy waste resides at that site.

Mr. Shrum responded that EnergySolutions receives legacy waste, mostly from DOE. This waste is often referred to as "look what we found" waste because of its unpredictable characteristics. Mr. Shrum noted that DOE has a different waste classification scheme than the one used by the USNRC. If DOE legacy waste is identified and planned for disposal at a commercial facility, DOE will typically use waste processors or brokers to first characterize the waste, confirm that it meets the facility's waste acceptance criteria, and that the waste meets the requirements in 10 CFR Part 61.55.

2.4 REGULATIONS, STANDARDS, ORDERS, AND GUIDANCE CRITERIA

Mr. Camper began the session by providing an overview of the U.S. LLW regulatory process. His remarks are summarized below. The regulatory process has a proven track record and has been shown to adequately protect health and safety. However, the process is complicated (a "regulatory mosaic"), may be difficult to understand or explain, and lacks exact alignment with other international regulatory frameworks. There is room for improvement.

A number of key pieces of legislation directly impact the management and disposal of LLW. These are identified and briefly described in Box 2-1 and in Appendix D.

Mr. Camper identified the key regulators of radioactive waste within the United States and stressed the key role that Agreement States play in regulating the four commercial LLW disposal facilities. The EPA develops standards applicable to LLW disposal. The USNRC has regulatory oversight of commercial radioactive waste in the United States under the

[29] This estimate uses the IAEA GSG-1 classification of VLLW; however, the waste is currently termed "LLW" by the waste owners.

BOX 2-1
Key Legislation for LLW

Atomic Energy Act (1954):
the original statute from which the USNRC derives its authority.

National Environmental Policy Act (1969):
describes the environmental analyses that are performed for licensing actions, including the licensing of LLW disposal facilities.

Transportation Safety Act (1974):
sets forth criteria for the transport of LLW for disposal.

Resources Conservation and Recovery Act (1976):
created the framework for the management of hazardous and non-hazardous solid wastes.

Low Level Radioactive Waste Policy Act (1980) and amendment (1985):
the compact system (see Mr. Shrum's presentation and Appendix D) and enables the states to dispose of their LLW.

Nuclear Waste Policy Act (1982) and Amendment (1987):
requires the USNRC to ensure that licensees providing for the disposal of LLW provide adequate ncial arrangements to permit disposal site closure and reclamation of sites, structures, and equipment.

Comprehensive Environmental Response Compensation and Liability Act (1986):
contains standards that apply to hazardous waste facilities, also referred to as Superfund (see also the Resource Conservation Recovery Act [RCRA]).

Energy Policy Act of 2005:
extended authority of the USNRC as it pertains to discrete sources of NORM (naturally occurring radioactive material).[a]

Ronald Reagan Defense Authorization Act (2005):
addressed DOE's disposal of waste incidental to reprocessing for the Idaho National Laboratory and the Savannah River Site.

[a]The EPAct of 2005 adds the following to the list of byproduct materials: "any discrete source of naturally occurring radioactive material, other than source material, that—(A) the [Nuclear Regulatory] Commission, in consultation with the Administrator of the Environmental Protection Agency, the Secretary of Energy, the Secretary of Homeland Security, and the head of any other appropriate Federal agency, determines would pose a threat similar to the threat posed by a discrete source of radium-226 to the public health and safety or the common defense and security; and (B) before, on, or after the date of enactment of this paragraph is extracted or converted after extraction for use in a commercial, medical, or research activity."

Atomic Energy Act. The DOE is self-regulating for the wastes it generates and stores. Mr. Camper noted that the Department of Transportation also has regulations for transporting LLW, but these regulations are enforced by the USNRC.

DOE regulates its radioactive wastes through two orders:[30]

- Order 458.1—*Radiation Protection of the Public and the Environment,* and
- Order 435.1—*Radioactive Waste Management*.

The key USNRC regulations are the following:

- 10 CFR Part 20—*Standards for Protection against Radiation*
- 10 CFR Part 61—*Licensing Requirements for Land Disposal of Radioactive Waste*
- 10 CFR Part 62—*Criteria and Procedures for Emergency Access to Non-Federal and Regional Low-Level Waste Disposal Facilities*

10 CFR Part 62 was created when there was no access to disposal for Class B and C wastes for 36 states. This provision has not been used to date.

Mr. Camper listed other entities that influence the regulatory process, including the Compact Commissions for the states, Conference of Radiation Control Program Directors, Inc. (CRCPD),[31] International Commission on Radiological Protection (ICRP),[32] Low-Level Radioactive Waste Forum, Inc.,[33] National Council on Radiation Protection and Measurements (NCRP),[34] and

[30]DOE Orders are described as a type of Directive: "Orders establish management objectives and requirements and assign responsibilities for DOE Federal employees consistent with policy and regulations. Requirements must be unique to DOE and must avoid duplicating information from other directives or any existing legal source." These orders and DOE policies provide for site-specific performance assessments and site-specific waste acceptance criteria to establish an envelope of acceptable LLW forms and packages between waste generators and waste disposal sites. See: "DOE: DIRECTIVES HELP," accessed March 1, 2017, https://www.directives.doe.gov/directives-help.

[31]The mission of CRCPD is "to promote consistency in addressing and resolving radiation protection issues, to encourage high standards of quality in radiation protection programs, and to provide leadership in radiation safety and education." For more information, see "An Introduction to CRCPD," accessed March 1, 2017, http://www.crcpd.org/page/About.

[32]According to its website, ". . . the International Commission on Radiological Protection (ICRP) helps to prevent cancer and other diseases and effects associated with exposure to ionising radiation, and to protect the environment." For more information, see "About ICRP," accessed April 9, 2017, http://www.icrp.org/.

[33]The Low-Level Radioactive Waste Forum, Inc. is focused on helping the states and interstate compacts implement the requirements of the Low-Level Radioactive Waste Policy Amendments Act (see Box 2-1). For more information, see "About Us," accessed April 9, 2017, http://llwforum.org/about/.

[34]For more information, see "National Council on Radiation Protection and Measurements: About," (accessed April 9, 2017) http://ncrponline.org/about/.

Organization of Agreement States (OAS).[35] The ICRP and NCRP develop protection criteria that may be used in various statutes and/or guidance. The OAS assists the Agreement States and coordinates actions with the USNRC.

Mr. Camper provided further background on the Agreement States program. The program was established by the Atomic Energy Act (AEA), as amended. Section 274b of the Act allows the USNRC to relinquish portions of its regulatory authority to an Agreement State.[36] The state governor and the chairman of the USNRC must sign an agreement recognizing "the State shall have authority to regulate the materials covered by the agreement for the protection of the public health and safety from radiation hazards" (AEA, Section 274b). The USNRC conducts an integrated management performance evaluation program through inspections and licensing to regularly confirm that the Agreement States' programs are sufficient and compatible with federal regulations.

The states' role in LLW management and disposal have evolved in response to the LLRWPA (see Box 2-1) in three important aspects: first, each state must dispose of LLW generated within its borders, either individually or through compacts. Second, states may assume regulatory authority as discussed above. Third, states have the authority to regulate naturally occurring radioactive material (NORM) and technically enhanced naturally occurring radioactive material (TENORM). Regulatory authority for these materials was not specified in the AEC.

Mr. Camper noted that the United States is fortunate to have four LLW disposal facilities; many countries have not yet determined a long-term solution to storage and disposal of LLW. The fact that the IAEA has safety standards, disposal requirements, and a general safety guide was mentioned by Mr. Camper; these are discussed in further detail later in these proceedings.

Mr. Camper noted that the U.S. regulatory process for LLW relies on an integrated safety system approach, which has proven effective in protecting human health and the environment but is technically complex. The approach involves many considerations such as site selection, site design, facility closure, post-closure stabilization, and institutional controls.

Finally, Mr. Camper noted that these are interesting times for regulation of LLW in the United States. U.S. regulators are addressing complex waste streams that were not included in the original analyses in 1982 for 10 CFR Part 61, including some waste streams identified for discussion in this workshop such as depleted uranium (DU), GTCC, and commercial TRU wastes. USNRC staff have been asked by the Commission to consider

[35]The purpose of the OAS is to "provide a mechanism for these Agreement States to work with each other and with the United States Nuclear Regulatory Commission ([US]NRC) on regulatory issues associated with their respective agreements." For more information, see "About OAS," accessed April 9, 2017, http://www.agreementstates.org/page/about-oas.

[36]Note: Kentucky became the first Agreement State in 1962.

changes to regulations for some of these wastes. There will likely continue to be great stakeholder interest in these regulatory changes.

In introducing the session, Mr. Camper explained that the three invited speakers were asked to address the following questions in their presentations:

- What are the health, environmental safety, and security bases that led to the generally applicable standards and regulations in your line of work?
- What are the strengths and weaknesses of the respective approaches?

Andrew Orrell, section head of waste management and environmental safety, IAEA, provided an international regulatory perspective; Thomas Magette, managing director of PricewaterhouseCoopers, provided an industry perspective; and Mark Yeager, environmental health manager for South Carolina Department of Health and Environmental Control (DHEC), provided perspectives from an Agreement State regulator.

LLW Management and the IAEA, Regulations, Standards, Orders, and Guidance

Mr. Orrell addressed the following topics in his presentation: IAEA statute (authority), IAEA safety standards, supporting guidance, and the Joint Convention. The statute that created the IAEA specifically authorizes it to develop and promote the application of safety standards for the benefit of its member states. These standards are intended to be an expression of international consensus about what constitutes a high-level of safety.[37] However, the IAEA is not a regulator, so its safety standards are not legally binding. They are used in different ways in different countries because the regulation and enforcement of safety is the sole responsibility of each IAEA member state.

The IAEA has produced more than 200 documents related to safety standards that cover nuclear technologies and the full nuclear fuel cycle. The wheel diagram in Figure 2-5 shows all of the current safety standards.[38] The overarching safety fundamentals are the highest in the hierarchy (a single document at the center of the wheel in blue), followed by the safety requirements (seven documents in red) and the more detailed safety guides (more numerous documents shown in green).

[37]The IAEA currently has 168 member states. The statute governing its operation can be found at: "The Statute of the IAEA," accessed April 9, 2017, https://www.iaea.org/about/statute.

[38]For a list of all of the safety standards shown in Figure 1-5, see: "Safety Standards applicable to all facilities and activities," accessed April 9, 2017, http://www-ns.iaea.org/standards/documents/general.asp.

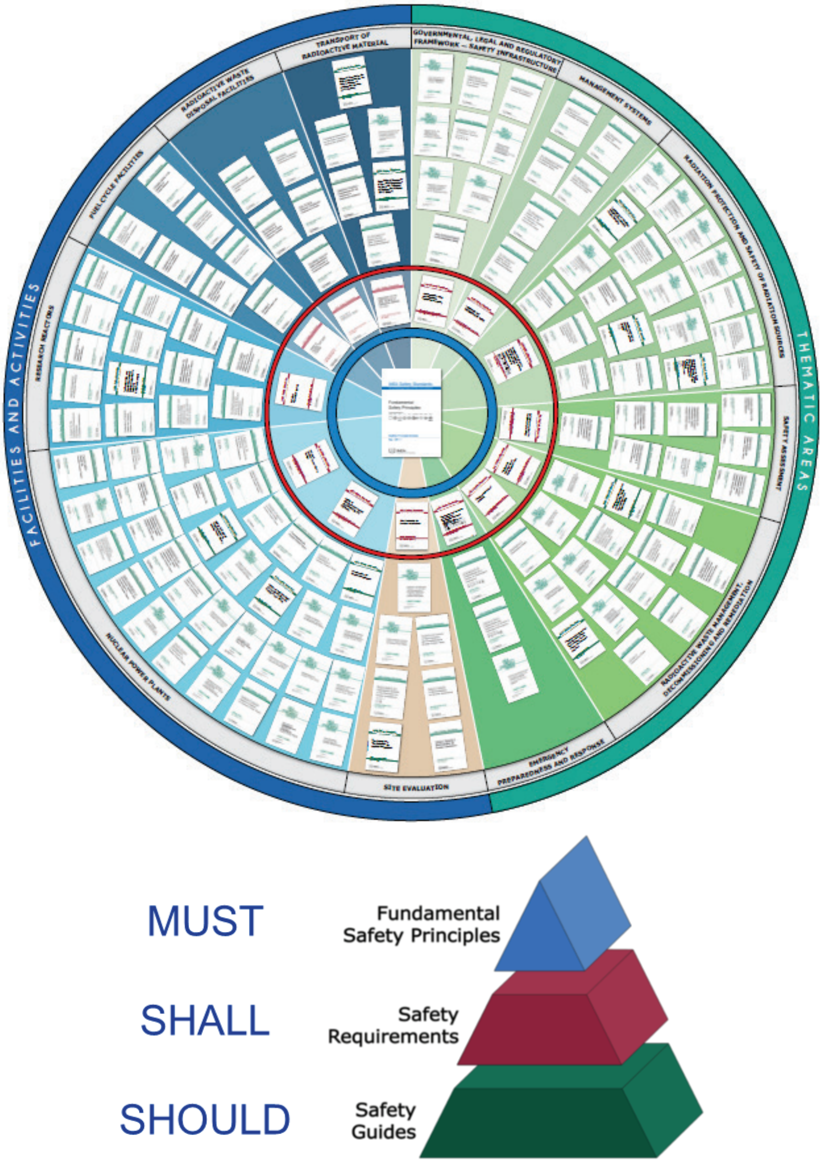

FIGURE 2-5 Safety standards developed by the IAEA. Fundamental Safety Principles are the highest level in the hierarchy (top blue triangle and the blue center of the wheel). Safety requirements are the middle level of the hierarchy (in red). Safety guides are the bottom level of the hierarchy (in green and in the outer rim of the wheel). The small script in the figure does not allow one to read the titles of each document; rather, the figure is meant to illustrate the number and hierarchy of the standards.
SOURCE: Courtesy of the International Atomic Energy Agency.

The safety fundamentals lay out the fundamental safety objective: to protect people and the environment from the potential harm of radioactivity.[39] "People" refers to both the worker and the public.

The safety fundamentals lay out 10 safety principles of protection and safety and provide the basis for the underlying safety requirements:

1. Responsibility for safety
2. Role of government
3. Leadership and management for safety
4. Justification of facilities and activities
5. Optimization of protection
6. Limitation of risks to individuals
7. Protection of present and future generations
8. Prevention of accidents
9. Emergency preparedness and response
10. Protective actions to reduce existing or unregulated radiation risks

These principles are constructed to use "must" statements and are at least notionally binding on member states.

Safety requirements elaborate on the fundamental safety objective and the 10 safety principles. Key safety requirement documents include one each for predisposal and disposal of radioactive waste.[40] The guides are meant to be concise and indicate "what," "by whom," and "when" actions should be taken and "why" the requirement exists. The safety requirements are constructed to use "shall" statements and are also at least notionally binding on member states.

At the bottom of the hierarchy in Figure 2-5 are the safety guides—captured in general and specific guides that provide recommendations on "how" to comply with the upper-tier requirements. The guides cite present international good practices and increasingly reflect best practices. The safety guides are constructed to use "should" statements.

Mr. Orrell's presentation included examples of a number of safety guides relevant to radioactive waste management, predisposal, storage, and disposal. He highlighted a few guides of particular relevance to the workshop: the classification of waste, management systems for predisposal and disposal frameworks, guidance on constructing a safety case and safety

[39] See "The IAEA Safety Standard: Fundamental Safety Principles, No. SF-1," accessed April 9, 2017, http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf.

[40] "Predisposal" is a term used to describe the (IAEA, 2009b, p. 1) "management of radioactive waste from its generation up to disposal, including processing (pretreatment, treatment, and conditioning), storage and transport." For the general safety requirement guide on predisposal of radioactive waste (GSR Part 5), see (IAEA, 2009b). For the specific safety requirement guide for disposal of radioactive waste, see (IAEA, 2011).

assessment (which are crucial to the demonstration of safety of the radioactive waste management), and several specific guides on predisposal and disposal in near-surface and deep-geologic settings.

In addition to the official safety standard series, the IAEA also publishes a large number of supporting documents; these documents elaborate on best practices and/or good international practices for implementing radioactive waste management and also capture the results of technical meetings, conference proceedings, and workshops. All publications are developed by representatives of member states to benefit from their breadth and depth of available expertise.

Mr. Orrell noted that the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management[41] is a legal instrument to the 75 contracting parties that obligates each to implement the principles contained in the IAEA safety standards.[42] The Joint Convention went into force in 2001. Many of the technical obligations in the Joint Convention have strong parallels to the subjects covered in the safety standard series.

Mr. Orrell also noted that the IAEA safety standards represent six decades of experience and expertise, and they provide international consensus on what is needed to achieve a high level of safety. He noted that there is a common commitment to the protection of people and the environment regardless of the scale of a member state's activities. He presented a photograph of a VLLW disposal cell for a small European country with a very small nuclear footprint (Figure 2-6). This one cell has a capacity for 30,000 cubic meters of VLLW. The cleanup from the Fukushima Daiichi accident has generated more than 10 million cubic meters of contaminated soils to date—which would fill roughly 400 of the disposal cells in the small European country.

Complications in the Process of Creating and Revising Regulations

Mr. Magette noted, as have others, that the USNRC is in the midst of updating 10 CFR Part 61. He reviewed the complications of revising and creating regulations to account for challenging LLW streams such as DU and TRU. The update, originally proposed as a "tweak" 8 years ago, was needed to account for the large quantities of DU waste expected to be sent to commercial disposal facilities. Mr. Magette suggested that the level of

[41]For more information, see "IAEA: Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management," accessed March 1, 2017, http://www-ns.iaea.org/conventions/waste-jointconvention.asp.

[42]The number of parties and signatories was last updated on March 3, 2017; see "Joint Convention status," accessed April 27, 2017, http://www.iaea.org/Publications/Documents/Conventions/jointconv_status.pdf.

FIGURE 2-6 An operational disposal site for very low-level waste (VLLW). This facility is one cell (approximately 150 meters in length, 40 meters in width with a capacity of 30,000 cubic meters). Note the small gray cubes at back of facility; each is one cubic meter of VLLW.
SOURCE: Courtesy of Andrew Orrell.

effort required to modify the regulations thus far has been disproportionate to the risk posed by DU waste.

He identified several reasons for his opinion. The first is that Agreement States have been given the authority to regulate LLW. If one were to redesign a system to regulate LLW with our current understanding of the variety and volumes of LLW streams, it is hard to imagine a system that would allow individual states to regulate LLW because there is no distinction in health and safety benefit as one crosses state lines. Mr. Magette explained that the transition of authority from the USNRC to the states was not as clear as suggested previously by Mr. Camper. For example, updating the compatibility category tables,[43] which help to define how states may

[43]Compatibility category tables define how states may interpret USNRC regulations—these should not be confused with the tables used to classify wastes as Class A, B, C or GTCC.

interpret USNRC regulations, has further complicated the recent update process.

Several of the USNRC Commissioners recently and informally asked Mr. Magette if he thought a uniform regulatory regime would be a disincentive for states to develop disposal sites. He responded that it would have little impact because the debates about the development of such facilities are rarely focused on regulations. He also noted that changes to regulations are not a high-priority issue for most of the states because there are only four that host such facilities. Finally, disposal facilities are sited and developed by private entities, not by states and compacts.

Mr. Magette argued that it is necessary to adjust the LLW regulatory system to the situation in which we find ourselves. A small change to the regulations was proposed 8 years ago to address the increasing quantities of DU. The effort expanded to consider the revision of the classification tables in 10 CFR Part 61.55 for DU, GTCC, and TRU—a much more difficult effort than making a small change to the tables to account for DU only. One might reasonably ask whether the process has become overly complicated relative to the risks or hazards posed by the disposal of these materials. The LLW disposal system works today, but it is not clear whether the updates will improve it.

Mr. Magette highlighted several specific waste streams for which the existing regulatory system has become overly complicated. The radioactive emissions from DU increase slowly over time due to a build-up of daughter products—reaching a maximum value in approximately 1 million years. This growth in emissions necessitated a review of the length of the current compliance period for disposal of DU. The USNRC staff proposed to the Commission a two-tiered compliance process: a compliance period of 1,000 years or 10,000 years, depending on whether a facility accepts long-lived waste. However, this proposed change would double the compliance period from 500 years for Class C waste and increase it by a factor of 10 for Class A waste. Mr. Magette pointed out that there is no good technical basis to support this increased regulatory compliance period for non-long-lived waste.

The other complication is the period of institutional control following the closure of the LLW disposal facility. The public debate with USNRC staff focused on institutional controls and whether it was reasonable to maintain such control beyond 100 years. Mr. Magette suggested that the discussion should have focused on acknowledging that the risk diminishes over time; an increased period of institutional control resulted in much lower risk at the end.

Agreement State Programs

Mr. Yeager reviewed the Agreement State programs, addressing the two questions posed at the start of this session. He noted that Texas, Utah, Washington, and South Carolina regulate the four commercial LLW disposal facilities in the United States. These are Agreement States, and each works within similar regulatory structures.

In general, the Agreement States adopt the requirements in these regulations in their state regulations. For example, South Carolina's radiation protection standards for LLW waste disposal are compatible with the USNRC's 10 CFR Part 20, *Standards for Protection against Radiation*. South Carolina's radiation protection requirements are set forth in *Regulation 61-63, Title A, Part III* (State of South Carolina, 2014). The regulations apply to the public, workers, and vendors who provide services at the sites, and they establish occupational dose limits, surveys and monitoring, precautionary procedures, and required records and reports.

The conditions and operational procedures that commercial LLW licensees implement to comply with state and federal regulations are incorporated within their respective radioactive material licenses. In South Carolina, DHEC conducts radiological surveys and the physical inspection of the Barnwell Disposal Facility (BDF) biannually to document that license conditions and corresponding procedures are compliant. The BDF's LLW receipt and disposal operations are inspected weekly, as needed. Weekly inspections are conducted of general site, active disposal trench conditions, and enhanced trench cap conditions resulting from preliminary site closure activities. The review of submittals for new disposal trench construction and on-site inspection of this activity is also conducted by department technical staff.

Mr. Yeager pointed to 10 CFR 61, *Licensing Requirements for Land Disposal of Radioactive Waste*, which are implemented in South Carolina's *Regulation 61-63, Part VII*. As was previously mentioned, Part 61 has recently been revised. As a result, the sited Agreement States will need a guidance document to help implement the changes—hopefully to be released with the updated Part 61. Mr. Yeager agreed with previous comments about the need to account for the costs of the changes. DHEC has not yet determined how the implementation of the changes to Part 61 will affect its program.

The final rule for Part 61 includes the following change (highlighted in the previous presentation by Mr. Magette): the existing technical analysis for protection to the general public will either have a 1,000-year or a 10,000-year compliance period, depending on the quantities of long-lived radionuclides that are planned for disposal or have already been disposed of. The technical analysis should include a new safety case analysis to identify defense in-depth protections and to describe the capabilities of the disposal system. Therefore, the Agreement States will have to provide a new technical analysis for the protection of inadvertent intruders that includes the revised compliance period and corresponding dose limit. In addition, the Agreement States will have to perform a post-10,000-year performance year analysis. This will add a new requirement to update the technical analysis at the time of site closure.

The USNRC *Branch Technical Position on Concentration Averaging and Encapsulation* (BTP) has been an essential tool in assessing proper waste classification, packaging, and disposal trench selection. The recent update of the BTP has affected the volume of LLW received at the BDF by allowing the blending down of Class B and Class C to higher concentrations of Class A. It is also important to mention that each commercial LLW disposal facility has established Waste Acceptance Criteria which both allows and restricts certain waste forms. Examples include radium, DU, and mixed waste.

One of the questions posed to the presenters was related to physical security. Mr. Yeager noted that South Carolina regulations follow the USNRC's 10 CFR Part 37, the *Physical Protection of Category 1 and Category 2 Quantities of Radioactive Material*. The licensee and DHEC determined that some shipments of Class B and C waste, such as irradiated hardware, require security during staging for disposal at the EnergySolutions BDF site. As a result, DHEC worked with a licensee to implement this protection so that it met the Part 37 requirements. Mr. Yeager concluded that EnergySolutions performed well in this respect.

Finally, with regard to regulations related to transportation, South Carolina implements and enforces the provisions of 49 CFR Part 173, *Subpart I for Class 7 (Radioactive) Materials*, and also the applicable provisions of 10 CFR Part 20. All incoming LLW shipments are all inspected to assure that communication requirements and the conveyance meets physical and radiological regulatory standards; the shipment manifest and waste description are reviewed to ensure compliance with waste acceptance criteria; and the packaging is adequate.

With regard to packaging, Mr. Yeager noted that DHEC has been delegated authority to conduct engineering reviews of proposed High-Integrity Containers utilized to assure adequate LLW containment (primarily for the disposal of dewatered ion-exchange resin) for a minimum of a 300-year disposal lifetime. Upon conclusion of construction and mandated testing, DHEC is authorized to issue Certificates of Compliance.

Mr. Yeager noted that one strength of the Agreement States is the opportunity for collaboration during periodic reviews conducted through the USNRC's Integrated Materials Performance Evaluation Program (IMPEP). Each IMPEP team includes an Agreement State member. The oversight by another regulatory program is usually beneficial for both Agreement State programs.

An important challenge faced by Agreement State programs is providing technical assistance to other regulatory programs that find themselves with issues involving the disposition of various solid wastes containing or contaminated with radioactive constituents. Examples of these wastes include, but are not limited to, discrete radium sources (mostly of military origin), radium residuals resulting from water or mineral processing, and tritium resulting from improper disposal of generally licensed devices in solid waste landfills. South Carolina is the home of multiple military installations. As a result, DHEC receives many calls from scrap metal dealers that have come across discrete sources of radium and some byproduct material from improperly disposed of licensed sources. Most dealers are small businesses and do not have the financial resources to properly dispose of these disused or orphan sources. Some sources containing byproduct material can be traced back to the licensee. Fortunately, programs such as DOE's Source Collection and Threat Reduction (SCATR) Program allow for disposal of these sources at minimal or no cost to the generator.

Radium in drinking water and the residuals from ion exchange and filter media present additional disposal challenges. Water providers who are not accustomed or experienced under a regulatory regime have difficulty dealing with the required physical protections for their workers. Also, the water providers are not accustomed to the extreme expense of disposing of radium-contaminated filter media. DHEC has issued Reg. 61-63, Part IX, *Licensing of Naturally Occurring Radioactive Material (NORM)*, to assist in the regulatory oversight of this activity and the resulting radiological wastes.

Finally, it was noted that tritium, due to its elemental form, is an insidious environmental contaminant common in all LLW disposal sites and some solid waste landfills. One area of concern with LLW shallow-land burial at the BDF and other disposal facilities, including some solid waste facilities, is the presence of tritium in off-site environmental monitoring wells. One way the facility operator manages this issue is to restrict access by potential receptors at the release point. At the BDF, construction of enhanced trench cap covers has been very successful in mitigating the percolation of precipitation and the resulting transport of tritium through groundwater off-site.

2.5 DISCUSSION: REGULATIONS, STANDARDS, ORDERS, AND GUIDANCE CRITERIA

Several topics (highlighted in bold) were brought up during the Session 1b discussion. Questions, answers, and general comments pertaining to a specific topic are grouped below. As for the Session 1a discussion overview, this overview does not follow the chronological order of the discussion.

Likelihood of Significant Changes to the U.S. Regulatory System

The panelists were asked about the likelihod of large-scale changes to the U.S. regulatory framework for LLW. All three panelists agreed that large-scale changes were very unlikely. Mr. Magette noted that such changes were "extraordinarily unlikely," and he cited another example of the USNRC's approach to tweaking its regulations to address an evolving problem: the decommissioning rule for NPPs. The USNRC is considering the application of regulations originally written to ensure worker and public health and safety during NPP operations to their decommissioning. He also recalled the failed effort to develop regulations for material below regulatory concern (i.e., exempt or cleared material) originally requested by Congress in the LLRWPA as amended in 1985.

Mr. Orrell provided perspectives both as an IAEA employee and a U.S. citizen. He agrees that the LLW regulatory framework is "not very likely" to change substantially, certainly not in his lifetime. However, he noted that he has seen, both in the U.S. and other nations' regulatory systems, regulatory creep over time. Regulations get more complicated with time as regulators adjust their regulations to address evolving problems, typically by adding to instead of removing standards. Eventually, the regulations become unwieldy, prompting a revolution instead of an evolution to change them. Whether the U.S. nuclear regulatory framework will undergo a revolution is difficult to predict, but other industries such as banking and airlines have gone through punctuated efforts to revise, wholesale, their regulatory frameworks.

Mr. Yeager added another example from his time as chairperson of the Committee on Radioactive Waste Management of the CRCPD. Mr. Yeager described an overly optimistic but failed attempt, at his first meeting as the chair, to obtain consensus on a uniform approach by the states and federal agencies. But he also cited a successful multi-agency effort that created a unified approach to radiological characterization as a reason to be hopeful for a similar effort in LLW management. The EPA's *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM)[44] was a collaborative effort by the EPA, USNRC, DOE, and the Department of Defense.

Another is for LLW disposal organizations responsible for regulatory oversight to consider oversight for each other. For example, the four commercial LLW disposal facilities in the United States are currently regulated by Agreement States. Each respective regulatory program is subject to peri-

[44] *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) "provides detailed guidance on how to demonstrate that a site is in compliance with a radiation dose- or risk-based regulation." More information can be found at: "EPA: Radiation Protection: Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)," https://www.epa.gov/radiation/multi-agency-radiation-survey-and-site-investigation-manual-marssim, accessed March 1, 2017.

odic review by the USNRC to assure compatibility with applicable federal regulations. The IMPEP inspection team is comprised of USNRC inspectors and an Agreement State inspector. DOE, as a self-regulating agency, might benefit from an assessment of its LLW disposal regime by other regulatory entities.

Consensus on a unified approach to LLW disposal across Agreement States and federal jurisdictions is also needed, noted Mr. Yeager. Such a consensus could encourage buy-in from stakeholders and the public and possibly reduce disposal costs. Currently, there are several federal and state regulatory regimes; it can sometimes be frustrating for a LLW (or LLW of very low activity) generator to move from one to another. In South Carolina, for example, the EnergySolutions' BDF is a commercial LLW site regulated by the South Carolina DHEC; RCRA facilities in the state that contain mixed waste are regulated by the EPA; Savannah River is regulated by DOE; but the Mixed Oxide (MOX) Fuel Fabrication Plant at Savannah River is regulated by the both the USNRC and DOE.

Mr. Magette further commented that site-specific regulations are based in part on performance assessments because each site is different. This makes uniform regulations across Agreement States more difficult to develop.

Containment Approach to Addressing the Isolation Period

Ms. Edwards noted that although a substantial revision of current U.S. LLW regulations is unlikely, workshop attendees might consider approaches that extend beyond regulatory changes. In the spirit of the workshop, Ms. Edwards presented such an approach and asked for participants' perspectives.

From a strictly technical viewpoint, LLW poses a hazard with a finite lifetime. It is a fairly straightforward calculation to determine the lifetime of the hazard of the LLW inventory of any disposal site. Ms. Edwards suggested that if society is willing to impose institutional controls for the duration of the LLW hazard, there would be no need to consider exposure to the waste after that period (i.e., intrusion scenarios)—similar to Mr. Magette's comments that an increased institutional control period resulted in lower risk at the end.

The development of intrusion scenarios leads to disagreements that are difficult to resolve, primarily because one must hypothesize about the characteristics of intruder scenario, for example when and how the intrusion occurs and the characteristics of intruder exposures. There are differing viewpoints on what intruder scenarios are "reasonable" to consider; for example, how should one estimate the behavior of an intruder who lives 10,000 years in the future, and how does one determine whether the intrusion would have significant health effects given likely future medical advances? It is difficult to defend a dose analysis for an intruder scenario given these future uncertainties. If LLW is isolated for the duration of its hazard, there would be no reason to consider intruder scenarios. Ms. Edwards acknowledged that there may be cases where longer-term institutional controls are not workable and suggested that a different set of regulations could be developed for those cases.

Mr. Orrell offered a technical perspective based on his experiences in performing and managing many of the safety and performance assessments for the Waste Isolation Pilot Plant (WIPP) and Yucca Mountain. In these analyses, it was assumed that all repositories, near-surface or otherwise, fail when there is an intrusion. Intrusion scenarios are informative in and of themselves to understand the consequences of such failures. Other countries use the results of intrusion scenarios to inform their regulatory processes. In Mr. Orrell's opinion, the intruder scenario serves as a pass/fail element of the U.S. regulatory system rather than as an information-input to the system.

Mr. Orrell agreed that, unless there is a reasonable argument for increasing the characterization of risk or adding to public confidence, extending the isolation period may not make a lot of difference. Mr. Orrell noted it would be straightforward to recalculate an isolation period from 500 to 1,000 years. In practice, however, the uncertainty of the result would need to be reduced by an order of magnitude (or two) to significantly improve the characterization of risk for increasing the isolation period from 500 to 1,000 years.

Mr. Orrell also stressed the importance of the terminology being used in Ms. Edwards' question. For example, WIPP has a containment standard, whereas other repositories have dose standards. There is an assumption that most repositories will have a release over some (long) time period, so a containment standard may drive one to particular disposition solutions that may not always be readily available or achievable.

"Regulatory Morass"

Paul Black, chief executive officer of Neptune and Company, Inc., provided a summary of his thoughts from the session. He recalled Mr. Camper's characterization of the complex framework as a "regulatory mosaic" and suggested another term which he believes is more accurate: a "regulatory morass." Dr. Black highlighted several examples to support this opinion including containment requirements, the compliance period for DU, and overly complicated LLW regulations (Black et al., 2014). His concern is that the complexity and associated costs with disposal of LLW has an upstream effect on the nuclear industry.

He noted that there remains some question on the appropriate regulation for small amounts of DOE TRU waste that may be present in the disposal sites at NNSS and Los Alamos National Laboratory (LANL). There is a question of whether the EPA's containment requirements of 40 CFR 191 (Subpart B Section 191.13) apply or whether other regulations would be more appropriate. Dr. Black explained that 40 CFR 191 was written for deep geologic repositories which allows a small amount of the inventory to escape while still meeting regulatory requirements. Dr. Black argued that containment regulations are ill-suited for the level of risk posed by DOE's TRU waste in this example. The EPA and DOE have not yet determined which regulations apply, so no decision can be made.

Another example is the compliance period for DU, discussed earlier. The performance assessments must meet a peak dose—or peak activity—requirement. Peak activity for DU is 2.1 million years. Compare this to the disposal of uranium mill tailings for which the compliance period is shorter due to the use of different approaches for inadvertent intrusion. Mill tailings waste emits significant radiation from radon, but it will take 100,000 years or more for radon to build up in DU. Additionally, oil and gas producers may dispose of NORM and TENORM waste outside of the radioactive waste regulatory regime.[45]

Long compliance periods and other requirements add to the cost of radioactive waste disposal, which in turn can impact nuclear energy generation and nuclear medicine use. Dr. Black judges that overly conservative radioactive waste regulations are having a severe impact on the nuclear industry.

[45]National Research Council (2006b) also cites this example.

3

Successful Disposition Case Studies

Rebecca Robbins, planning committee member and predisposal unit head at the International Atomic Energy Agency (IAEA), moderated this session, which used case studies to highlight examples of successful low-level waste (LLW) management and disposal within current regulatory frameworks. The case studies presented situations in which previously challenging LLW streams[1] were successfully managed and disposed of. The first two presentations in this session provided case studies from the United States; the next two presentations focused on case studies from outside the United States. A discussion was held after all of these case studies had been presented.

The comments from the moderators, the panelists, and other workshop participants are their own. They do not necessarily represent official views of their employers, governments, or other organizations that may be mentioned in the presentations or discussions.

Dr. Robbins began the session by requesting the workshop participants, as they listened to each case study, to identify the "key characteristics" that contributed to its success. Key characteristics include the practices, activities, attitudes, and actions with respect to the case studies and associated regulatory frameworks.

Melanie Pearson Hurley, headquarters liaison in the Office of Field Operations within the Department of Energy (DOE), presented a DOE case study. Greg Lovato, deputy administrator at the Nevada Division of

[1] "Challenging LLW streams" are defined as LLW streams that have potentially non-optimal or unclear disposition pathways due to their origin or content and incompatibility with existing standards, orders, or regulations.

Environmental Protection (NDEP), provided examples of key characteristics for successful disposition from the perspective of a state regulator. For international case studies, Miklos (Mike) Garamszeghy, design authority and manager of technology assessment and planning for the Canadian Nuclear Waste Management Organization, provided two examples from Canada and Gérald Ouzounian, international director for the National Radioactive Waste Management Agency (ANDRA), provided a case study from France.

3.1 UNITED STATES CASE STUDIES

Case Study 1: Separations Process Research Unit Tank Waste Sludge

Mrs. Hurley presented the Separations Process Research Unit (SPRU) project as DOE's case study. In the early 1950s, research on plutonium and uranium separation techniques such as PUREX and REDOX[2] was performed at SPRU within the Knolls Atomic Power Laboratory (KAPL).[3] KAPL, now an active naval nuclear laboratory, is located near Schenectady, New York, adjacent to the Mohawk River. The inactive SPRU facilities occupy about 5 acres of land immediately adjacent to KAPL.

The research at SPRU was performed on a laboratory scale and supported larger operations at both the Hanford Site in Washington and the Savannah River Site in South Carolina. Radioactive liquid and sludge wastes resulting from the SPRU research were stored in seven tanks located on site. The SPRU project timeline was established by the demolition dates for the buildings in which the research was performed and the wastes were stored. There was a strict requirement that the sludge waste be removed and disposed of by spring 2014.

Figure 3-1 provides a cross-section and plan view of two facilities at SPRU. The top drawing is a cross-section of the G2 building, which housed the laboratories, hot cells, and separations processing and testing equipment, and the H2 building, which was used for liquid and solid waste processing. The G2 and H2 buildings are connected by an underground tunnel. The lower drawing in Figure 3-1 shows the plan view of buildings G2 and H2. The tank farm in the lower-right corner of the figure is the focus of this presentation.

The radioactive waste from chemical processing was stored in the H2 tank farm (seven underground concrete-enclosed stainless steel tanks). This waste included about 200 cubic feet (5.7 cubic meters) of sludge consisting

[2] REDOX (reduction oxidation) and PUREX (Plutonium and Uranium Recovery by Extraction) are processes for separating uranium and/or plutonium from irradiated fuel and targets.

[3] In the 1950s, KAPL was a government research laboratory created by the U.S. Atomic Energy Commission (a predecessor agency to DOE).

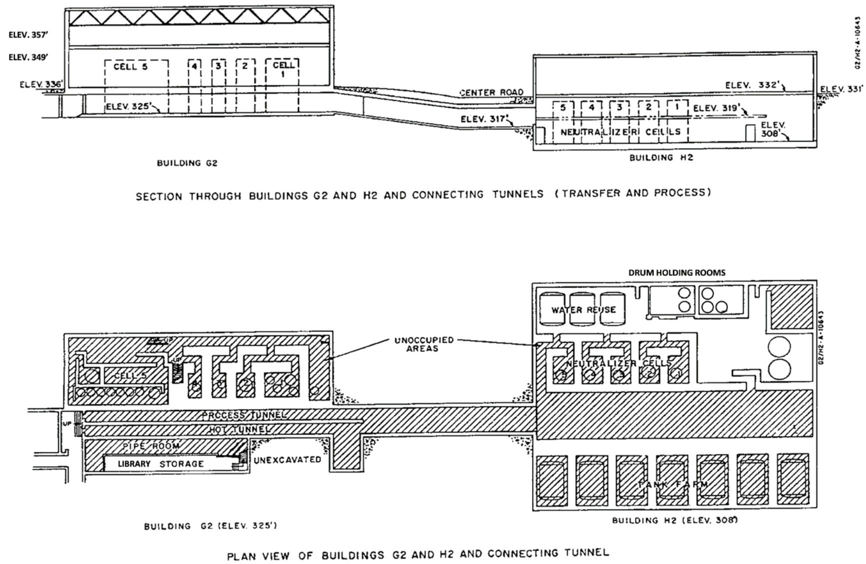

FIGURE 3-1 Schematic of SPRU facility showing cross-sections (top drawing) and plan views (bottom drawing) of Buildings G2 and H2.
SOURCE: Courtesy Jeff Selvey, AECOM.

of fine particulates and liquids containing fission products, mostly cesium and strontium, and long-lived transuranic (TRU) radionuclides, primarily plutonium-239. The sludge contained 36 curies of total radionuclides, including 2.5 to 6.5 curies of TRU radionuclides. The concentration of the long-lived TRU radionuclides in the final waste packages ranged from 11.5 to 65.5 nanocuries per gram (nCi/g).

The total mercury content of the sludge was more than 1 percent, and it contained high levels of lead, chromium, and cadmium. This led to an initial determination that the sludge may be a Resource Conservation and Recovery Act (RCRA) characteristic hazardous waste[4] for metals. This waste classification would have complicated the management of the sludge because the hazardous component would be regulated by the Environmental Protection Agency (EPA) in addition to DOE's regulation of the radioactive component. However, two toxicity characteristic leaching pro-

[4] "EPA: Defining Hazardous Waste: Listed, Characteristic and Mixed Radiological Wastes," accessed February 25, 2017, https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes#character.

cedures (TCLP)[5] confirmed that the hazardous component of the waste was only at 0-3 percent of regulatory levels, due to the low solubility of the metals in the sludge. Consequently, the sludge was determined to not contain hazardous waste and could more simply be managed under DOE orders.

DOE Order 435.1, *Radioactive Waste Management*, was used to guide decisions on disposing of the sludge from SPRU. The Order allows for the disposition of LLW in federal or commercial facilities. An exemption request must be approved by DOE headquarters for waste to be disposed of in a commercial disposal facility. Approval will be given if commercial disposal demonstrates compliance with regulations and waste acceptance criteria (WAC), is cost-effective, and is determined to be "in the best interests of the United States government."

There were two disposal options for the SPRU sludge: the Nevada Nuclear Security Site (NNSS), a DOE disposal site in Nevada, and Waste Control Specialists (WCS), a commercial disposal site in Texas. Both disposal options were explored, and WCS was selected, in part due to the compressed schedule[6] for completing cleanup of the SPRU tanks (spring 2014).

DOE worked closely with Texas regulators and WCS on establishing the waste profile[7] through the standard process described in the WCS Waste Acceptance Plan.[8] Texas regulators accepted DOE's policy that waste is not formally classified until all processing is completed and a stabilized waste form is produced. Mrs. Hurley identified this close collaboration as a "key characteristic" for successful disposition of the sludge.

The plan was to have the waste stabilized using a mixture of cement, fly ash, and slag that was then solidified in the final waste package for transportation and final disposal. The sludge solidification system at SPRU was designed and cold tested off site by the vendor and then installed in the H2 tank vault area. Cold-test operations were conducted on site prior to hot operations to ensure the system would perform as designed.

Figure 3-2 is a schematic of the H2 tank vault area and processing systems. Mrs. Hurley noted that there was an airborne release of radioac-

[5]TCLP testing determines the mobility of organic and inorganic chemical species within in liquid, solid, and multiphasic wastes. TCLP testing follows specific guidelines established by EPA.

[6]DOE had an existing contract with WCS, and WCS allowed for a shorter waste profile review time.

[7]"Waste profiles" are required documents for shipping and acceptance of waste. The waste generator must submit a waste profile of each waste package for approval by the disposal facility prior to shipment. The disposal facility reviews the waste profiles to confirm the waste is compliant with the WAC of the disposal site.

[8]"Application for License to Authorize Near Surface Disposal of Low-level Radioactive Waste, Appendix 5.2-1: Waste Acceptance Plan Revision 9," see Section 5.2: Waste Profile Approval, accessed February 25, 2017, http://www.wcstexas.com/wp-content/uploads/2016/01/Waste-Acceptance-Plan.pdf.

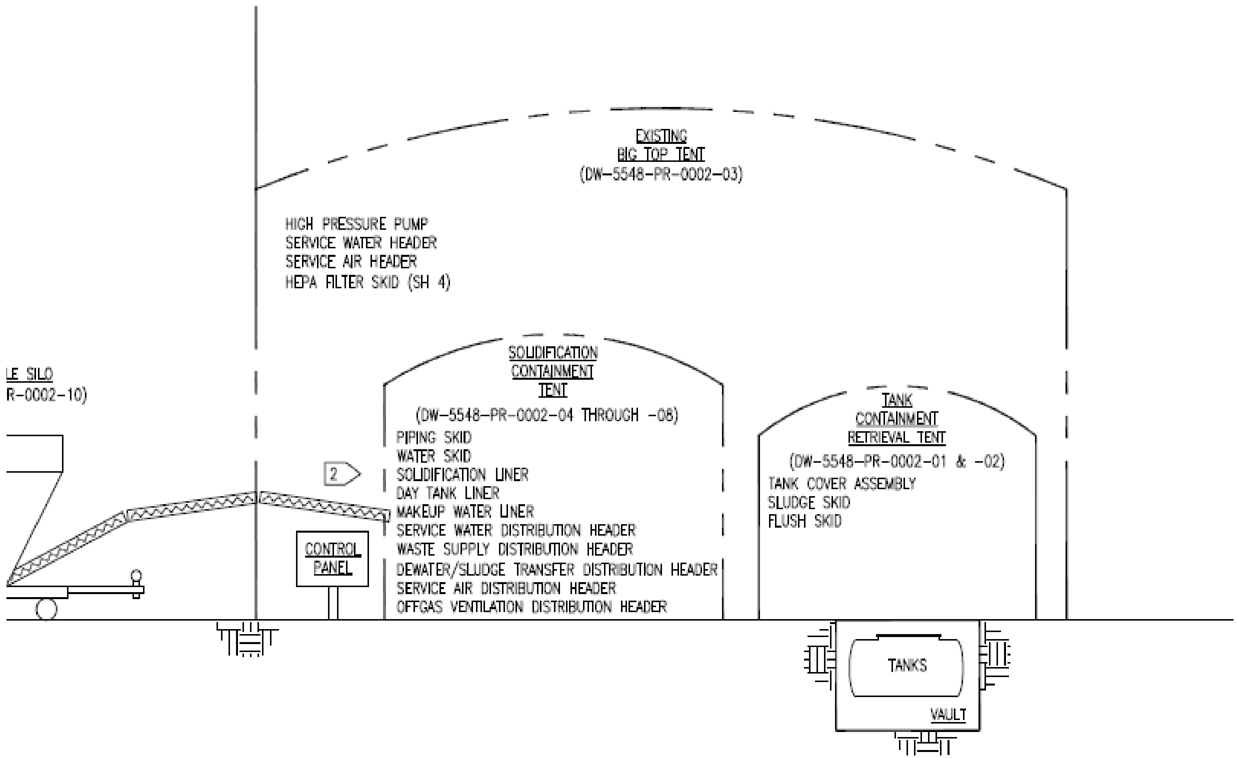

FIGURE 3-2 Schematic of the H2 tank vault area including SPRU processing contamination enclosures consisting of the outer enclosure (Area H2 Tent), the existing Big Top Tent, and two smaller tents for the sludge waste retrieval and processing (the Tank Containment Retrieval and Solidification Containment Tents).
SOURCE: Courtesy Jeff Selvey, AECOM.

tive material at SPRU in 2010. As a consequence of this event, the EPA required DOE to construct a tent enclosure over the H2 facility with portable ventilation units (contained in the outer tent, Area H2 Tent, shown in Figure 3-2). Underneath this larger tent is another tent (Existing Big Top Tent in Figure 3-2) that originally served as a weather enclosure over the tank farm. This weather-enclosure tent was retained when the larger enclosure was constructed to add another level of protection.

Within the Big Top Tent are two additional tents, the Tank Containment Retrieval and Solidification Containment Tents (see Figure 3-2). The sludge retrieval, mixing, processing, and characterization operations were carried out in these tents. Batches of sludge were retrieved from the 509E Tank,[9] mixed to suspend the solids in the waste, transferred to the final waste package, and then combined with cement, fly ash, and slag. The mixture was periodically checked by a penetration test to determine when it was solidified. If there was any remaining free water, additional cement mix was added.

The waste package was moved into a shielded temporary storage area set up in the G2 building (Figure 3-1).[10] The cement mixture curing times were long because the storage area was unheated. Once fully cured, the waste packages were shipped to WCS for disposal.

Sludge processing began on September 9, 2013, and the final shipments to WCS were completed on February 27, 2014.[11] Nearly 10,000 gallons of sludge were processed and solidified in 28 liners. The liners were shipped to WCS via trucks. (There were two liners per truckload and a total of 14 truck shipments.) This campaign removed the majority of the radionuclides from the SPRU site and allowed DOE's deactivation activities to continue in the H2 basement as scheduled.

While this case study highlights many successes, there were obstacles to overcome, including the following:

- Working within a decades-old facility with limited physical and onsite storage. There was no lay-down area where more than one liner could cure at the same time, and the temporary storage area in the G2 building allowed for 3 to 4 liners at a maximum.
- Retrieving sludge from the 509E Tank, including cleaning out solids near the bottom of the tank.
- Working with a waste stream (sludge) that is difficult to characterize and process. A continuous mixing system was used to keep

[9]In 2010, the sludge was consolidated into a single tank, the 509E tank, in preparation for waste processing and disposition.

[10]Mrs. Hurley noted that, at the same time the liners were temporarily stored there, deactivation activities were also taking place to prepare for demolition of the G2 building.

[11]The schedule accounted for the fact that concrete would not fully cure during the winter months (the SPRU tanks were covered by an unheated processing tent).

solids suspended in the waste so that the final waste form was homogenous.

- Performing the sludge processing work immediately adjacent (less than 25 feet or 7.6 meters) to a currently operating research and development laboratory and during deconstruction of the G2 building.
- Performing this work in a tent-type containment structure (Figure 3-2). Portable ventilation units and the HEPA[12] filters were used to ensure that safe working conditions were maintained.
- Addressing waste classification uncertainties. DOE performed historical research and additional evaluations to show that the sludge waste was not high-level waste and could be managed as LLW.

Several key management practices contributed to the success of this project:

- A dedicated and technically competent workforce that understood the mission objective and the importance of safety, including an excellent DOE federal project director.
- Frequent communications among the DOE participants, DOE staff from headquarters, NNSS, DOE's consolidated business center in Cincinnati, and KAPL, the adjacent research and development laboratory. Support from a "Senior Integrated Project Team" was also key to the success of the project.
- Cold testing of the treatment system at the vendor site and on site prior to operation enabled the right combination of nozzles, sluicing, and camera angles to confirm that the solids were removed from the 509E Tank.
- Early and frequent communication and engagement with the waste disposal experts from WCS.
- Coordination with the expertise throughout the DOE complex on packaging and transportation.

A participant asked Mrs. Hurley how DOE verified that solidification was adequate during cold testing. She responded that the cold testing was primarily to confirm the pump's ability to mix the solids and liquids and to confirm homogeneous mixing. Solidification was not tested or verified during cold testing; rather, a cement and fly ash "recipe" that was used successfully at other sites was used to solidify the SPRU sludge.

[12]HEPA is the acronym for high-efficiency particulate air.

Case Study 2: Low-Level Radioactive Waste Streams Reviewed for Disposal at the NNSS: Key Characteristics, Variation, and Management

Mr. Lovato's presentation included an overview of the waste disposal sites at the NNSS, the waste profile review process, key waste stream characteristics and their variation, and key management steps taken to address some of those different characteristics.

Mr. Lovato explained that NDEP was participating in the workshop because of a memorandum of understanding between the governor of Nevada and the secretary of DOE. One of the goals of the agreement is to hold a workshop to bring more transparency and predictability to DOE's waste disposal decisions. Mr. Lovato expressed thanks that the workshop was taking place. He noted the desire by Nevada citizens for context and predictability in DOE disposal decisions and asked the workshop participants for help in developing a LLW classification system that would foster greater confidence in future disposal decisions; he also admitted that these requests were tall orders.

Mr. Lovato suggested one way to think about Nevada's participation in this workshop is illustrated by a famous line from the movie *Jerry Maguire*, in which the sports agent, played by Tom Cruise, is trying to negotiate a contract for a professional athlete, played by Cuba Gooding, Jr. The sports agent repeatedly asks the athlete to "Help me, help you." The goal of the memorandum of understanding between Nevada and DOE is to "Help us, help you."

The NNSS is located about 65 miles northwest of Las Vegas. The Area 5 disposal facility is a secure, 740-acre site located in the southeast corner of the NNSS (see Figure 3-3). The disposal facility is used to dispose of mixed LLW[13] under a RCRA permit with the state of Nevada. The waste is disposed at depths of up to 24 feet (7.3 meters).

Area 5 receives less than 5 inches (13 centimeters) of annual rainfall, and depth to groundwater is 770 feet (235 meters). Infiltration of precipitation below the plant root zone ceased between 10,000 and 15,000 years ago. Consequently, migration of the waste to groundwater is less of a risk than surface erosion from thunderstorms.

NNSS accepts approximately 1.0-1.5 million cubic feet (28,000-43,000 cubic meters) of LLW, mixed LLW, and classified waste[14] per year from more than 25 different DOE facilities. This amounts to between 5 and 10

[13]LLW containing hazardous chemicals is referred to as "mixed LLW."

[14]DOE defines "classified waste" in Order 435.1 as (DOE, 1999, p. I-2): "Radioactive waste to which access has been limited for national security reasons and cannot be declassified shall be managed in accordance with the requirements of DOE 5632.1C, *Protection and Control of Safeguards and Security Interests*, and DOE 5633.3B, *Control and Accountability of Nuclear Materials*."

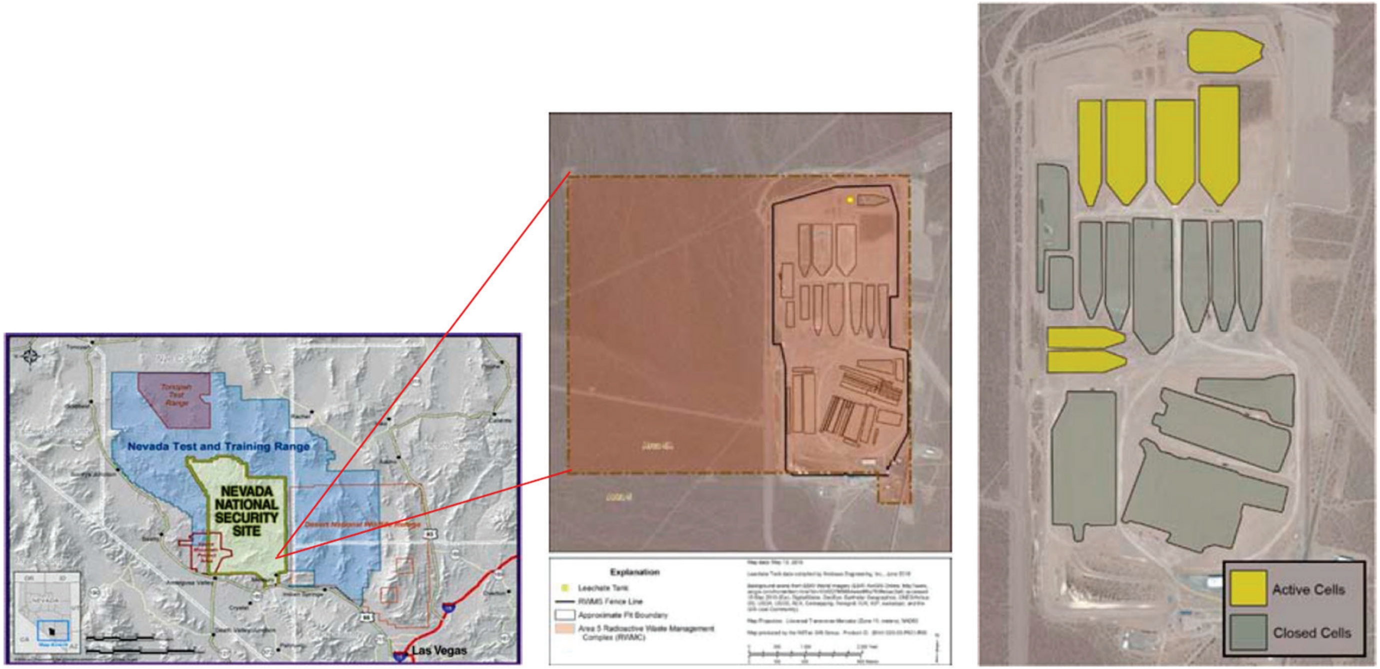

FIGURE 3-3 Maps of the NNSS (left image) and the location of Area 5 (middle image), and Area 5's active (yellow) and closed (gray) cells (right image).
SOURCE: Modified from DOE Office of Environmental Management.

percent of the volume of wastes disposed of across the DOE complex, including DOE wastes disposed of at commercial disposal sites (Marcinowski, 2016).

NDEP is a member of the Waste Profile Review Team. The team includes DOE, contractors, and three members of NDEP and meets weekly to review waste profiles against the NNSS WAC. If a waste stream does not meet the WAC, it will not necessarily be rejected for disposal at the NNSS. The performance assessment for the facility can be reanalyzed to determine whether the waste stream under consideration would meet the facility's performance objectives.

LLW can have a broad spectrum of characteristics. Table 3-1 provides a list of key characteristics of the LLW and mixed-waste streams considered for disposal at the NNSS. (This list was developed by Mr. Lovato based on his experiences at the NNSS.) The table shows that these waste streams have a wide range of half-lives, activities (expressed as a ratio to WAC thresholds), and plutonium equivalent grams.

Using a "plutonium equivalent grams" (PE-g) is a way to normalize the activity of different isotopes in a single package to a single standard (the activity of plutonium-239). This normalization allows for the easy determination of whether a package meets the WAC for the NNSS. (The WAC specifies a PE-g limit for each package.) The WAC for the Waste Isolation Pilot Plant (WIPP) also contains a plutonium equivalency criterion. The list of radionuclides in the WAC for the NNSS is far longer than that for WIPP, suggesting that the NNSS deals with a more diverse range of waste streams. In fact, waste characteristics at the NNSS can have a 6-17 order-of-magnitude range in values (see Table 3-1).

Waste management decisions are usually handled on a case-by-case basis to ensure that waste streams are appropriate for disposal at the NNSS and that stakeholder concerns are addressed. Some of the management steps used at the NNSS include decisions to adjust burial depth or transportation routing, conducting exercises in outreach and notification, and ensuring conditions on any waste profile approvals are met.

Case-by-case decisions can seem ad hoc, subjective, and reactive with-

TABLE 3-1 Variation of Key Characteristics in NNSS LLW Profiles.

CHARACTERISTIC	Radionuclide Half-Life (years)	Ratio of Waste Isotope Activity Level to WAC Thresholds (unitless)	Plutonium Equivalent Grams (g/m^3)
NNSS LLW RANGE	5 to 700,000,000	10^{-9} to 2×10^{6}	2.1 to 3,000,000

SOURCE: Modified from G. Lovato, Nevada Division of Environmental Protection.

out a reference system to compare the decisions to—especially when viewed from the outside. Nevada is interested in facilitating alternatives to disposal at the NNSS, for example by the preventing waste streams from being created and finding alternative disposal locations.

Mr. Lovato suggested a potential categorization scheme for LLW that could aid in final disposition decisions (Table 3-2). This scheme proposes a few key physical, chemical, and radiological characteristics and hazards of LLW that should be considered for its safe and secure management and disposal. Also included are key characteristics of a disposal site (i.e., location, security, and control options such as inherent and engineered barriers of a site). A new regulatory framework would break down these characteristics based on the variety of potential LLW streams and transparently list the proposed disposal criteria.

Mr. Lovato suggested that the regulatory framework should be scalable when considering new LLW streams: concerns about the new LLW stream from the waste generators, recipients, public, and DOE should be captured; options for addressing those concerns should be identified using characteristics similar to those in Table 3-2; and options for the management and disposal of a new LLW stream should be compared against each other in a transparent way. The idea is that this new framework could be created a priori without having knowledge of the LLW streams. This type of regulatory framework would be helpful in providing context on LLW disposal decisions.

Mr. Lovato encouraged the participants not to lose heart in terms of trying to develop a better LLW categorization scheme. He acknowledged that past LLW disposal decisions were likely made for expediency and were weighed against what disposal options and regulatory frameworks were available at the time. But it is incumbent upon us in the present day to improve the system, so that future stakeholders have much-needed context for the decision-making process, which may ultimately improve stakeholder confidence in LLW management and disposal decisions.

TABLE 3-2 Potential Categorization Scheme of LLW to Guide Disposition Decisions

Characteristic	Location	Potential Hazards	Control Options Criteria
Half-Life Activity Fissile Content PE-g Surface Dose Leachability	Where? (Transport?) (Disposal?)	Long Term Protection Radiation Exposure Nuclear Criticality Security	What control options should be evaluated? What criteria should be examined?

SOURCE: Nevada Division of Environmental Protection.

Dr. Robbins asked a clarifying question related to Nevada's desire to facilitate alternatives to the creation of waste streams. Was there a particular waste stream that does not fall within the NNSS' remit to accept? If so, can the NNSS discuss the possible acceptance of this waste stream with the waste generator?

Mr. Lovato explained that it is important to the NNSS and Nevada to not only look for alternative disposal options, but also alternative technologies for generating wastes. For example, the NNSS is seen as the disposal facility for sealed sources. But in Nevada's view, disposal of sealed sources should not default to a single location. So, Nevada is considering alternatives, such as reducing the use of sealed sources to begin with or by considering alternative disposal pathways, so that the NNSS is not relied on for disposal of all sealed sources.

3.2 INTERNATIONAL CASE STUDIES

Case Studies 3-4: Two Low-Level Waste Case Studies from Canada

Mr. Garamszeghy's presentation was split into three parts: background on Canadian nuclear regulation and management, a case study on the Port Hope Area Initiative (PHAI), and a case study on the Deep Geological Repository for low- and intermediate-level wastes. The PHAI disposal facility is currently under construction. The Deep Geological Repository facility for low- and intermediate-level wastes is still in the regulatory approvals phase.

There are 19 operational power reactors at four sites in Canada (three sites in Ontario and one in New Brunswick). All are CANDU[15] pressurized heavy water reactors, and all are owned by the provincially owned electric utilities (Ontario Power Generation [OPG] and New Brunswick Power). Eight of the reactors in Ontario are leased to a private firm for operation, but OPG retains the responsibility for the waste produced by these reactors and for their decommissioning. There are seven other power reactors in Canada in different stages of decommissioning. There are also seven research reactors in Canada, two reactors (one operating, the other shut down) at the Canadian Nuclear Laboratories (located near Chalk River, Ontario) and the others at universities.[16] There are numerous other historic and legacy sites undergoing decommissioning or remediation.

The Canadian Nuclear Safety Commission (CNSC) is the federal nuclear regulator, equivalent to the U.S. Nuclear Regulatory Commission

[15] CANDU refers to CANada Deuterium Uranium reactors. For more information, see: "Canadian Nuclear Association: CANDU Technology," accessed February 25, 2017, https://cna.ca/technology/energy/candu-technology/.

[16] "Canadian Nuclear Association: Research Reactors," accessed February 25, 2017, https://cna.ca/technology/research-development/research-reactors/.

(USNRC) in the United States. Unlike Agreement States in the United States, the CNSC has not devolved any regulatory responsibilities to Canadian provinces.[17] The Canadian Environmental Assessment Agency (CEAA) is the federal agency responsible for the environmental assessment process. In the past there was a Joint Review Panel, which was a project-specific panel set up jointly by the CNSC and the CEAA, to review environmental assessment applications and specific license applications. This process is no longer used for nuclear projects. The proponent or the project owner/operator also has responsibilities as the eventual license holder. The proponents prepare the environmental assessment, the safety report, and the thousands of pages of support documentation.

The CNSC takes its authority from the Nuclear Safety and Control Act of 2000. It is a "quasi-judicial administration tribunal" that reports directly to Parliament. The commission members are independent and mostly part-time. All of the commission hearings are open to the public and are webcasted.

The CNSC has federal jurisdiction over both nuclear facilities and activities, much the same as the USNRC. It also provides regulatory oversight of all the licensees and disseminates objective scientific, technical, and regulatory information to the public—a fairly important role when it comes to public engagement for nuclear- and waste-related projects. The decisions of the CNSC can only be challenged through judicial review in federal court. The CNSC's decision making is transparent and science-based, at least in theory.

Risk assessments that apply to waste disposal include both a normal evolution scenario (climate change and gradual loss of engineered barriers) and disruptive scenarios (such as human intrusion). The assessment timeframe encompasses the time of maximum calculated impact (e.g., peak dose). In the case of a radioactive waste disposal facility, that time may be several million years in the future. The dose constraint for the normal evolution scenario is 0.3 milliseiverts per year (mSv/yr), equivalent to 30 millirem per year (mrem/yr). For disruptive scenarios, it is usually only a guideline of 1 mSv/yr (or 100 mrem/yr).

Canada has several types challenging LLW streams including:

- Higher activity wastes
  - significant amounts of carbon-14 from CANDU reactors,
  - irradiated/activated zirconium and niobium hardware from reactor refurbishments,
  - high-activity cobalt-60 waste, and

[17] Mr. Garamszeghy identified one exception as some uranium mines in Saskatchewan, which has a dual federal-provincial regulatory framework.

 — stored tritium (each storage canister holds about half a million curies of tritium).

- Waste from small waste generators who may have difficulty identifying disposal pathways, especially for intermediate-level waste; and
- Large volumes of historic wastes, of which characteristics and quantities not always well documented.

The PHAI will dispose of approximately 2 million cubic meters of waste, mostly soils, in engineered mound-type facilities with multicomponent caps. This disposal will take place in two locations near Port Hope and Port Granby, located east of Toronto. The Port Hope facility is expected to be in operation in 2017; the Port Granby facility is expected to be in operation in 2018. Most of the wastes to be disposed of in these facilities are located at these facilities or nearby.

The history of the sites that are hosting these facilities can be seen in Box 3-1. The Port Hope site was used first for radium refining and later for uranium refining. These activities contaminated the site and produced large volumes of waste. A task force was established in 1988 to find a site in Canada to dispose of the Port Hope wastes. The task force was unable to reach an agreement with a community in Canada to host a site primarily because of concerns about transporting large volumes of radioactive waste.

In 1997, Hope Township initiated a proposal to construct a long-term waste management facility near the Port Hope site. The PHAI was initiated in 2001, and environmental assessments were completed for Port Hope and Port Granby projects by 2009. Part of the agreement includes the Property Value Protection (PVP) program, which will compensate homeowners should the value of their property be reduced by the presence of the facilities.

The CNSC granted the construction license for the facility in Port Hope in 2009 and a construction license for Port Granby in 2011. The federal government made a major commitment of more than $1 Canadian billion to fund the construction of the two sites in 2012.

The Deep Geological Repository for low- and intermediate-level waste will be used to dispose of OPG-owned waste (i.e., waste from the operation and maintenance of OPG-owned facilities). The repository site is located near the Bruce Nuclear Generating Station on the eastern shore of Lake Huron in Ontario.

The community near the Bruce station volunteered to host the disposal facility. The community preferred that a single facility be used to dispose of all of OPG's waste. Accordingly, a deep geologic repository was designed for co-disposal of low- and intermediate-level wastes. A near-surface facility would not have been able to accept all of the intermediate-level wastes

BOX 3-1
History of Port Hope and Port Granby sites

- **1932:** Eldorado Gold Mine Ltd. opens radium facilities in Port Hope, Ontario
- **1942-1954:** Production emphasis shifts from radium to uranium
- **1930s-1970s:** Properties and sites in the Town of Port Hope become contaminated from spillage during transportation, unrecorded, unmonitored or unauthorized diversion of contaminated and materials, wind and water erosion, and spread from residue storage areas
- **1976-1981:** Atomic Energy Control Board (forerunner of CNSC) directs a large-scale radiation reduction program in the Town of Port Hope (over 100,000 tonnes of contaminated soil are transferred to a site at Chalk River Laboratories)
- **1982:** Low-Level Radioactive Waste Management (LLRWMO) is established by the federal government to manage historic waste in the Town of Port Hope and across Canada
- **1988:** The federal government establishes a Siting Task Force on Low-Level Radioactive Waste Management to site a permanent management facility for Port Hope area wastes
- **1988-1996:** Siting Task Force invites all Ontario municipalities to consider hosting a long-term management facility for low-level radioactive waste. A few communities initially volunteer, but no agreement is reached
- **1997:** Hope Township initiates a community proposal to construct a long-term waste management facility for wastes at the Welcome Waste Management Facility
- **1998:** Port Hope and Clarington also develop proposals to establish long-term management facilities for low-level radioactive wastes within their communities
- **2000:** The Government of Canada and Hope Township, Port Hope (now amalgamated to form the Municipality of Port Hope), and Clarington initial “Principles of Understanding” outlining terms for a project to clean up low-level radioactive waste
- **2001:** The Port Hope Area Initiative begins. A legal agreement is signed that commits the federal government and the municipalities to the safe cleanup, transportation, isolation, and long-term management of historic, low-level radioactive waste
- **2002-2009:** Environmental Assessments completed for Port Hope and Port Granby projects
- **2009:** CNSC grants initial Port Hope Project licence; in 2012, 10-year licence amendment granted to complete project
- **2011:** CNSC grants 10-year licence for Port Granby Project
- **2012:** Phase 2 construction begins when the government of Canada commits $1.28 Canadian billion to complete the Port Hope and Port Granby projects

SOURCE: M. Garamszeghy, LLW presentation, Session 2, slides 14-15.

currently stored on the site. Also, a single deep geologic repository is less costly than building two separate disposal facilities.

The repository has a design capacity of about 200,000 cubic meters as packaged for disposal at a reference depth of 680 meters. Operation was originally expected to begin in the mid-2020s. The repository is currently in the regulatory review process (which is taking longer than the originally scheduled 2 years).

The official hosting agreement was signed in 2004 and was approved by the community in 2005 based on an independent poll of all year-round and seasonal residents.[18] It provides approximately $30 million in compensation to both the official host town (Kincardine) and other surrounding communities. The compensation is tied to project milestones until the repository construction is complete. After disposal operations begin, the compensation is akin to an annual fee.

The environmental assessment and licensing documentation was submitted to the CSNC in April 2011, but Canadian federal elections delayed the appointment of the Joint Review Panel until January 2012. The Joint Review Panel then implemented a public comment period that was originally planned to last for 90 days. However, the period was repeatedly extended and lasted for more than 1 year. There were, in total, 31 days of public hearings, which created 20,000 pages of documentation and more information requests from the Joint Review Panel and public. The Panel's report was submitted to the CSNC in May 2015; it strongly recommended the repository proceed to the licensing phase.

CEAA then held a public comment period. A decision by the Minister of Environment was expected in September 2015 but was subsequently extended to December. Another Canadian federal election in fall 2015 resulted in a change in government. The new minister asked for more work to be done. The responses to the minister's request are expected to be submitted by the end of 2016 with a final decision by the minister on the environmental assessment in early 2017.[19] If the minister approves the project it will move to the licensing phase.

This project has had several successes. Throughout the public review—with extensive local, national, and international scrutiny—the scientific evidence remained sound and passed all credible challenges. Despite a number of changes in government, local leadership, and residents, the politicians

[18]There is a large contingent of weekend cottage owners in the area. When the poll was conducted, both full-time and part-time homeowners were contacted.

[19]Note: the most recent update on this process was posted on April 15, 2017. The public comment period was closed on March 7, 2017. On April 5, 2017, CEAA requested additional information from OPG. "CEAA: Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste," accessed April 27, 2017, http://www.ceaa-acee.gc.ca/050/details-eng.cfm?evaluation=17520.

and the local community remained supportive. The project delays have allowed some opposition groups in Canada and the United States to organize and gain some support. Some members of the public became confused between two nuclear waste disposal projects planned in the same area, one for OPG's low- and intermediate-level waste and the other for spent fuel. Public outreach continues, and OPG continues to respond to public questions and concerns. The formal decision by the Minister will define the project's next step.

Case Study 5: The French Case: Low-Level Radioactive Waste Management

Dr. Ouzounian's case study provided insight into the French approach to disposing of very low-level waste and LLW. He noted that his presentation focused mostly on the LLW because it is more challenging and more interesting in terms of approach and process.

ANDRA is responsible for the long-term management of all radioactive waste produced in France. The agency is independent from waste producers and reports to ministers in charge of the environment, energy, and research. It has approximately 650 employees with an annual budget of €250 million. ANDRA's work is performed within the framework of the *Planning Act of June 28, 2006* on the sustainable management of radioactive materials and wastes.[20]

Safety of the population and protection of the environment are set by a national framework law and are of the highest priority in determining disposal pathways for waste. Forecasts and inventories of waste lead to a National Management Plan, which is used to identify disposition pathways for all types of waste.

There is an effort to identify a safe disposition pathway proportionate to the hazard for each type of waste. French regulations do not allow for clearance of wastes from nuclear-related activities. France uses a policy of "waste zoning" at the generator's plant to segregate waste from zones that generate radioactive waste from those that do not.

The French radioactive waste classification scheme is shown in Figure 3-4 and described below:

- Intermediate-level and low-level wastes are generated by the day-to-day operations at the nuclear power plants (NPP; green box in Figure 3-4). These wastes, previously disposed of at the Centre de la Manche disposal facility (CSM), are currently being sent to the

[20] "ANDRA: Overview of national policy concerning radioactive waste management," accessed February 25, 2017, http://www.andra.fr/international/pages/en/menu21/national-framework/overview-of-national-policy-1593.html.

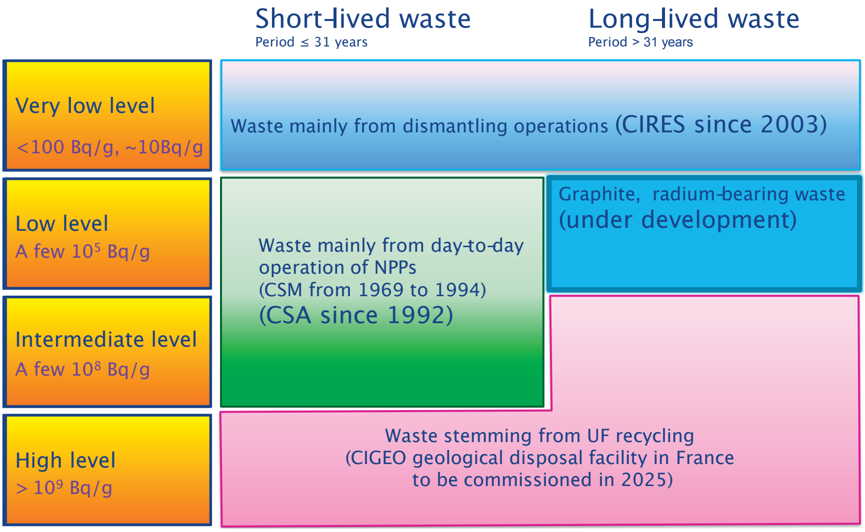

FIGURE 3-4 Classification of radioactive waste streams in France.
NOTES: Bq/g=becquerel per gram, CIGEO=Cigéo Project, CIRES= Centre industriel de regroupement, d'entreposage et de stockage facility, CSA= Centres de stockage de l'Aube, CSM=Centre de la Manche, NPP = nuclear power plant, and UF=used fuel.
SOURCE: Gérald Ouzounian, ANDRA.

Centres de stockage de l'Aube (CSA), which has been operational since 1992.

- Intermediate-level and high-level wastes are generated during uranium fuel recycling (i.e., reprocessing) (pink box in Figure 3-4). This waste will be stored in the geological disposal facility, the Cigéo Project.[21]
- Very low-level waste is generated from shut-down and decommissioning (or dismantling) operations. This waste is disposed of at the Centre Industriel de Regroupement, d'Entreposage et de Stockage (CIRES) facility (upper blue box in Figure 3-4).
- Low-level, but long-lived, waste, is generated from graphite gas-cooled reactors and, for example, from the production of rare earth metals (lower solid blue box in Figure 3-4).

[21]France has made progress toward addressing its intermediate- and high-level wastes through the Cigéo Project, constructed in a clay formation at 500 meters depth and expected to be commissioned by 2025.

Waste from small producers or other nuclear activities can span the range of waste types shown in Figure 3-4 but represents a minor part of the inventory.

There are two characteristics shown in Figure 3-4: activity levels and half-lives. Activity levels (rows in Figure 3-4) span orders of magnitude (less than 100 becquerels per gram [Bq/g] to more than 1 billion Bq/g) because there are specific threshold values for each radionuclide. Activity levels for very low-level waste range from 0 to 100 Bq/g with an average value of approximately 10 Bq/g. Waste is classified as "short-lived" or "long-lived" based on whether its half-life is less than or equal to or greater than 31 years, respectively (columns in Figure 3-4) . The 31-year half-life is approximately the half-life of cesium-137, which is 30.17 years.[22]

It is not possible from an operational standpoint to separate short-lived and long-lived radionuclides in NPP waste. There are always some long-lived radionuclides in this waste. WAC for very low-level and low-level disposal facilities in France allow for the disposal of waste containing certain amounts of long-lived radionuclides.

The principles behind radioactive waste disposal in France are, first, to contain and isolate the waste until it reaches a level of activity that does not represent significant hazard to the public or the environment (the monitoring phase in Figure 3-5). And, second, to limit the transfer of waste to the biosphere and to humans (the post-monitoring phase in Figure 3-5). As seen in Figure 3-5, the containment phase lasts for about 300 years for near-surface disposal of waste with low levels of activity and several hundreds of thousands of years for geological disposal of high-level waste.

Dr. Ouzounian described the CSA disposal facility for low-level and intermediate-level short-lived waste. The facility was licensed and commissioned in 1992 with a total capacity of 1 million cubic meters—enough capacity to contain all of the low- and intermediate-level radioactive waste generated by the present fleet of French NPPs (58 reactors). The CSA facility was designed to contain and isolate the waste for 300 years, as required by the monitoring requirement mentioned previously, and to meet the requirements for the long-term post-monitoring phase.

The French waste disposal system employs the "defense-in-depth" concept with a multi-barrier system. The system consists of the waste package, which includes a containment material enveloping the waste (the first barrier); the disposal vault, which includes a network control gallery to control water that may flow through the disposal facility and final cover (the second barrier); and the geological environment, which has natural barriers such as

[22]The *Planning Act of June 28, 2006* on the sustainable management of radioactive materials and waste specifies that the half-life cut-off between short-lived and long-lived waste is 31 years.

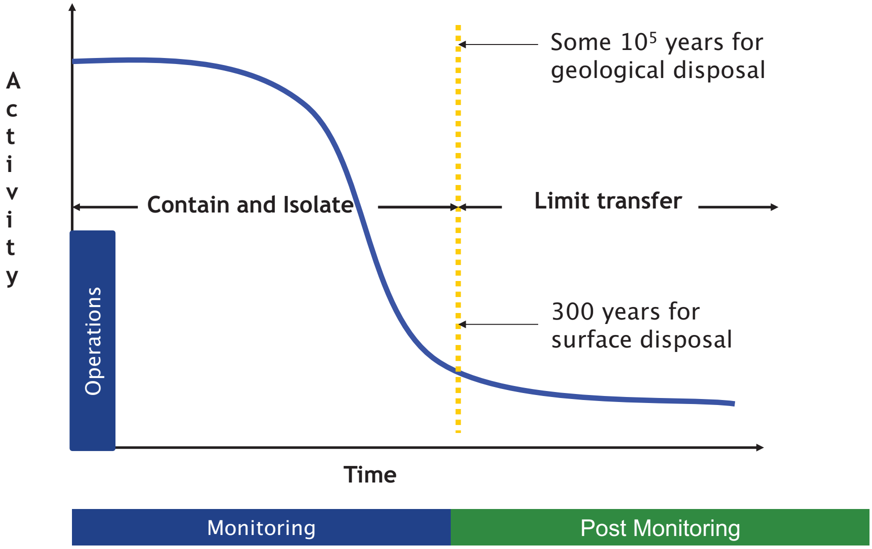

FIGURE 3-5 Disposal principles in the French radioactive waste management system.
SOURCE: Gérald Ouzounian, ANDRA.

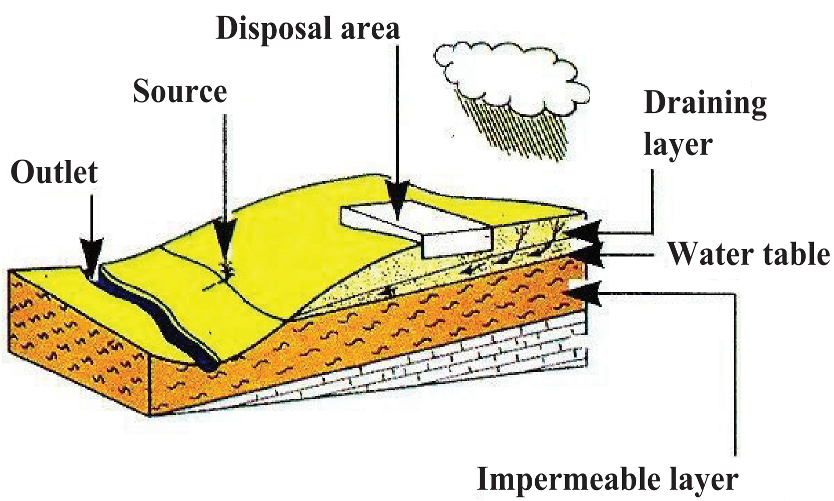

FIGURE 3-6 The French near-surface radioactive waste disposal concept.
SOURCE: Gérald Ouzounian, ANDRA.

clay to retard waste migration (the third barrier). This third barrier is the most important barrier in the post-monitoring phase.

Figure 3-6 is a schematic of the defense-in-depth disposal concept. A draining layer underlays the disposal facility, which in turn is underlain by an impermeable layer. The water table is shown with an outlet, labeled as "source" in the figure.

Inventory monitoring is essential for the effective management of radioactive waste—especially for managing long-lived radionuclides such as carbon-14, chlorine-36, and some beta emitters. NPP operators do not generally monitor for these isotopes because they do not impact daily plant operations. Therefore, the French regulator has established specific characterization requirements for these radionuclides for disposal purposes. For near-surface waste disposal, long-lived radionuclides are the major contributors to public doses in the post-monitoring phase.

Dr. Ouzounian's presentation also introduced France's approach to safety assessments, details on waste control acceptance criteria, and examples highlighting key aspects of safe operations and the defense-in-depth concept. Of particular relevance to this workshop was a discussion on the WAC for waste packages. These include:

- Radiological content
- Physical characteristics
- Chemical stability
- Gas generation
- Expected performance for long time periods
- Leaching rate
- Uniform distribution within the waste package (no hot spots)

Dr. Ouzounian provided historical perspective on the progression of safety rules, disposal concepts, and protection criteria in France. The safety rules were defined progressively, learning through the operational experiences of disposal facilities. Documents were updated and improved according to the experience of the operators—not the regulatory body. However, any changes to improve the safety rules are validated and endorsed by the regulatory body. General operational rules, and safety and radiation protection criteria, are also updated continuously.

John Applegate, the planning committee chair and executive vice president for University Academic Affairs of Indiana University, asked where the WAC (bulleted list above) came from and whether they had a risk basis. Dr. Ouzounian noted that the WAC were generated from safety assessments. Mr. Applegate also commented that experience at the prior disposal facility (CSM) appeared to be very helpful in designing the new facility (CSA), to which Dr. Ouzounian strongly agreed. All the incidents and malfunctions that occurred with the first disposal facility—which was designed without the benefit of detailed computer models—allowed for improvements to the new facility. The first safety regulations (1984 and 1985) are the result of the experiences from the first facility.

Dr. Ouzounian also noted the importance of adapting to knowledge gained from waste disposal experience in general. The process of developing an approach for the management and disposition of nuclear waste began in 1969, and much has been learned progressively. For example, it is now clear that the physical processes likely to occur should be well-understood and well-described, which requires high-quality modeling due to the long timescales involved. It is not possible to run an experiment for 100 to 300 years (or longer) to determine what may happen. The values, characteristics, and sources of hazards that are used in our assessments are the result of the models. This is why waste disposition decisions are site-specific, and also why we cannot transpose from one site to the other.

Dr. Robbins asked for clarification on one aspect of the French waste classification scheme. Is the irradiated graphite shown in Figure 3-4 considered LLW or intermediate-level waste according to the French classification scheme? Dr. Ouzounian explained that it is considered to be low-level but long-lived radioactive waste. One of the disposal options being studied is to segregate different types of graphite for disposal in different types of facilities depending on its irradiation level and activity.

3.3 DISCUSSION: KEY CHARACTERISTICS OF LLW AND CHALLENGING LLW STREAMS

Workshop chair John Applegate moderated the closing discussion on the first day's presentations. He noted that three organizing elements for managing challenging LLW streams were discussed:

- *Characteristics of the waste*. Defining waste characteristics is a technical issue. Mr. Applegate suggested that one could identify which characteristics are most important for making LLW disposal decisions. Alternatively, one could identify which characteristics are not important and are unnecessarily complicating waste disposal decisions.
- *Waste management practices*. Mr. Applegate asked whether participants could identify management practices that were unnecessarily slowing waste management decisions.
- *Regulatory framework*. Mr. Applegate asked participants to identify aspects of the current U.S. regulatory framework that are perceived to be failing. What can we learn from the experiences of other nations and international bodies? Mr. Applegate noted that

> regulatory flexibility is seen to be both useful as well as problematic. How do we manage that flexibility to make it useful, particularly with respect to increasing the predictability of the regulatory framework and/or eliminating requirements that aren't helpful?

Flexibility as a Double-Edged Sword

Kevin Crowley, director of the Nuclear and Radiation Studies Board at the National Academies, suggested that diversity and flexibility within disposal decision making is a double-edged sword. There is not much trouble handling diversity and flexibility from a technical standpoint. Where decision makers tend to fail is when they try to explain the diverse and flexible process to the people they serve. Dr. Crowley noted the importance of clearly communicating with the people who are served about the decision process: say what you are going to do, and do what you say you are going to do. Clear communication may be difficult when a system is too flexible and diverse.

Dr. Ouzounian argued that flexibility is crucially important, but it cannot be "free" flexibility. The flexibility needs to exist within a regulatory framework with clear rules, and one must be able to demonstrate that alternatives are safe and effective.

Mr. Applegate asked what a diverse and flexible framework might look like for LLW management. Mr. Garamszeghy responded that there are probably a couple approaches for establishing such a framework. One might use a performance standard, which requires a demonstration of how waste containment will be achieved. As long as the site is operated within an approved performance standard, there would be flexibility to make disposal decisions that meet that standard. This would be more flexible than a system that is based on compounding and conflicting regulations on allowable disposal options by waste type. Mr. Garamszeghy acknowledged that detailed regulations provide additional guidance to the user, but they also make it difficult to find innovative solutions when exceptions are presented.

Paul Black, chief executive officer of Neptune and Company, Inc., noted that although flexibility is critically important, cost-benefit analysis should also be considered in regulatory decisions and discussions. The current U.S. regulatory framework limits flexibility in strange ways because of competing regulatory structures. In order for the structure to change for the better, Dr. Black argued, one should strive for regulations that are simple and guidance that is process-oriented (rather than prescriptive) and based on cost-benefit considerations. The U.S. Office of Management and Budget (OMB) has the responsibility to evaluate new policies and rulemakings. As part of that evaluation, a cost-benefit analysis must be performed. OMB has developed guidance on using cost-benefit analysis.[23] Dr. Black suggested that both DOE and the USNRC should consider this guidance.

Mr. Applegate offered ALARA[24] as an example of a cost-benefit construct. Dr. Black strongly agreed and suggested that sustainability is another example. Sustainability balances three pillars: costs/economics, sociopolitical factors, and environmental factors. Dr. Black suggested that a framework for regulatory decision-making should combine the sustainability context (National Research Council, 2011b) with OMB's approach and guidance. Dr. Ouzounian noted that before cost-benefit can be assessed, safety must first be robustly demonstrated with a defense-in-depth approach.

Jennifer Heimberg, rapporteur and National Academies staff, asked Mr. Lovato whether he found it beneficial to have flexibility with the way DOE regulates over the USNRC's approach. She asked for any specific examples that showed how DOE's flexibility was utilized. Mr. Lovato noted that the NNSS does not have advance information about the variety of waste streams that will require disposal, so the DOE Orders are a good management structure for evaluating different types of waste streams. As an example, he cited radioisotope thermoelectric generators (strontium-90 sources originally from the Air Force) that required disposal. This waste had to be evaluated slightly differently from other waste streams; the flexibility in the DOE Orders allowed for that. However, he noted that it is always helpful to have a framework (e.g., the USNRC waste classification system) that can be used to explain waste management decisions to members of the public. Mr. Lovato was not advocating that a USNRC framework be used for DOE waste, but he cited it as the type of framework that is helpful for discussions with the public.

Elevating the Importance of Site Characteristics

Mr. Garamszeghy previously suggested that performance assessments be used as a framework for allowing flexibility in decisions while also providing boundaries. Mr. Applegate took this idea a step further by suggesting the following: One of the criticisms of the current U.S. regulatory framework is that it focuses on waste sources. What if the framework

[23] "Circular A-4: Regulatory Impact Analysis: A Primer," accessed March 27, 2017, https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/regpol/circular-a-4regulatory-impact-analysis-a-primer.pdf. Circular A-4 is referenced in the Trump administration's interim guidance: https://www.whitehouse.gov/the-press-office/2017/02/02/interim-guidance implementing-section-2-executive-order-january-30-2017.

[24] ALARA is "as low as reasonably achievable" and refers to the practice of reducing exposure to ionizing radiation through every reasonable effort. "USNRC: ALARA," accessed February 25, 2017, https://www.nrc.gov/reading-rm/basic-ref/glossary/alara.html.

instead focused on disposal facilities? In other words, disposal decisions would be based on whether the waste could be safely disposed of in a facility as demonstrated by a performance assessment, irrespective of the waste source. For example, for waste potentially being sent to WCS, one would ask, "What does it take to make it safe there?"

Mr. Shrum supported this idea and restated it in another form: "Consider the waste. It can go here. It can't go there." He noted that performance assessments have been done at all of the U.S. disposal facilities and is required under 10 CFR Part 61. But Mr. Shrum noted a potential communication problem with this approach: those whom we serve do not necessarily understand the details of a performance assessment, so they will not necessarily trust the output of the analysis. He said that the members of the public often do not understand that performance assessments are used to guide—not make—decisions. He supported Mr. Applegate's approach, but he noted that effective ways would need to be developed to educate the public for this approach to be successful.

He also noted that scientific understanding of radioactive wastes and disposal facilities have grown significantly since the 1950s, when commercial radioactive wastes were first disposed of. Mr. Shrum argued that this new understanding must be used to inform current disposal decisions. The nuclear industry as a whole has not been very good at describing the technical rationale for disposal decisions to the public, and, Mr. Shrum believes, that will have to change as part of a new framework.

Dr. Crowley noted that the workshop was intended to focus on exceptions. There are many exceptions to the existing regulations and rules, and there are questions about the best way to handle exceptions in the future. One option is to change the rules to include the exceptions. But this is unlikely in the short term. Another option is to establish procedures to handle the exceptions, for example by establishing "mini rules" that may not be incorporated into the regulations. Those mini-rules could be implemented at disposal facilities using their WAC, which of course are based on performance assessments.

However, it is difficult to anticipate the full variety of wastes that might come to a facility during its design or construction stages. On the other hand, one could probably think about unanticipated wastes during the design and construction stages and determine how they might be handled. Facility-specific performance assessments are a reasonable way to proceed.

Mr. Applegate commented that Dr. Crowley appeared to have endorsed his idea of focusing on disposal facilities instead of the waste source. A disposal facility could develop WAC to which waste streams are matched. Dr. Crowley agreed that this approach could work as long as the analysis was done within the framework of the current regulations. A near-surface disposal facility is only going to take certain types of waste; the framework suggested by Mr. Applegate should not be used to try to dispose of highly radioactive waste in near-surface facilities.

Dr. Black disagreed with the approach suggested by Mr. Applegate, primarily because he is not content with current regulations for radioactive waste disposal. They are overly conservative, so WACs developed using the existing regulations will also be overly constraining. For example, the inadvertent intrusion scenario in the regulations makes no sense for arid disposal sites according to Dr. Black.

Several years ago, Dr. Black developed a performance assessment for the Nevada Test Site (now NNSS), which allowed a user to enter the characteristics of a waste stream and get an answer within hours on whether it could be disposed of at the site (DOE, 2006 and Crowe et al., 2005). Dr. Black argued that this is a better approach than WACs for evaluating whether a waste stream can be disposed of in a particular facility.

Taking Advantage of Knowledge Gained

Mr. Shrum previously introduced the idea of taking advantage of knowledge gained over decades of disposal operations, and Dr. Ouzounian also mentioned this idea in his case study. Scott Kirk, director of regulatory affairs at BWXT, raised this issue for further discussion, noting that the nuclear waste disposal industry has matured over the past 40 years. Modern state-of-the-art disposal facilities such as the WCS facility in Texas are remarkably different in siting and design than older disposal facilities such as Barnwell, which was state of the art in 1969. The modern sites are in arid environments, far removed from water tables, and designed with insights from 40 years of operating experience. These modern sites might be suitable for disposal of challenging LLW waste streams that could not be disposed of in older facilities. It would be useful to assess the suitability of current regulatory requirements against these modern facilities.

Charles Maguire, director of the Radioactive Materials Division within the Texas Commission on Environmental Quality, highlighted the current state of regulations through an analogy. Most of the huge gothic cathedrals in Europe took approximately four generations to build. The last generation to work on the cathedral had little understanding of the reasons for the size, shape, or composition of the cornerstone. Yet the cathedral was built on it, and the generations of workers that followed improved their skills as cathedral construction progressed. Mr. Maguire noted that we are about to pass our nuclear knowledge on to a fourth generation of workers. But we are telling these workers to use the same tools and techniques as previous generations. We are not "getting better."

Mr. Maguire asserted that we have to get better and to apply what we learn. We now take without question what the generation before said was essential, and we do not apply what has been learned about mitigating risk. He concluded that we need to make sure that as we build up the structure it becomes more beautiful or practical and that we are on a path to do better. Otherwise, we may end up with a regulatory framework that no one can afford to use.

From the Outside Looking In: Public Perception

Ms. Edwards suggested that terminology is important in communicating with the public, and that the LLW classification system makes clear communications difficult. Previously, one could refer to Class A LLW as a hazard that lasted about 100 years, Class C waste as a hazard that lasted 500 years, and high-level waste as a hazard that lasted tens of thousands of years. This hazard differentiation is important because the public can become confused between high-level and low-level waste. But the 1,000-year compliance period for certain types of LLW in the proposed 10 CFR Part 61 regulation blurs the previous hazard distinctions.

Mr. Camper noted that USNRC staff were trying to address the disposal of large amounts of depleted uranium and used this opportunity to add a requirement that was not previously embodied in the regulation (but should have been). The existing 10 CFR Part 61 does not specify a period of compliance but the proposed 10 CFR Part 61 rulemaking specifies a two-tiered approach to a period of compliance, i.e., Tier 1 at 1,000 years and Tier 2 up to 10,000 years.

Mr. Garamszeghy noted that the public perceives "nuclear" and "waste" as highly dangerous in part because of the complicated and prescriptive regulations that govern them. The thought is, "It must be dangerous because there are all these regulations to protect us."

Mr. Applegate asked Mr. Garamszeghy to expand on his presentation about compensating the communities in which the Port Hope and Port Granby LLW facilities were sited. Was there a "general sense of fairness" argument? Or was it seen as compensating for risk? Or simply paying for the privilege? Mr. Garamszeghy explained that the intent of the PVP program was never to, for lack of a better word, "buy" public support. Rather, it was recognized that building and operating the LLW facility would strain the local communities in terms of a number of new people coming in and wear and tear on public facilities, for example. The PVP program ensured that the local towns, communities, and people were no worse off after the facility was in place than they would be if the facility was not there.

Dr. Crowley commented on the recurring topic of public perceptions and communications. The term "educating the public" is often used. He finds this term to be denigrating because it suggests that the public is not educated and that, if it were, the public would agree with the experts' conclusions—which is not always the case. Two-way communications are required to understand the concerns that the people who live around sites have about those sites.

Dr. Ouzounian noted that the term "stakeholders" is no longer used in France. Rather, the terms "concerned" or "interested parties" are used because this involves all parties, including waste producers and academics.

He also noted that the French Parliament passed a law in July 2016 as the result of a public debate on social benefits and responsibilities. The current generation benefits from the electricity generated by nuclear power plants, so it should be responsible for solving the waste management problem for following generations. The law required that a master plan describing all the major milestones of the lifetime of each disposal facility be developed and periodically reviewed. Initially, the planned review period was 10 years. However, Parliament decided that reviews will occur every 5 years with the involvement of all concerned or interested parties.

Dr. Ouzounian also commented on compensation to local communities. Compensation is provided because of expected damage to the infrastructure and the environment, resulting for example from large numbers of trucks on the roads during construction, not from increased risk. Parliament had another important debate in 2006. One side was arguing that nuclear industries were "buying the public" by giving money to communities. The other side was argued by the high commissioner for nuclear power in France. He pointed out that one community will accept the waste that belongs to all French people benefitting from electricity. This one community shows their solidarity with the country. He argued that, therefore, it was the responsibility of the rest of France to also show solidarity by supporting the community in developing its territory and its activities. This latter argument was accepted by the Parliament and ended comments about "buying the people."

Dr. Black also commented on communication and public perception. He recalled that Mr. Shrum said that issues with LLW are more political than technical. The politics really come down to stakeholders, which means everyone associated with the disposal facility or the potential facility and the affected communities. The different outcomes for the Yucca Mountain and WIPP facilities provide a good example. In both cases, decisions on facility siting and construction were influenced by stakeholders and the political environment rather than the technical analyses. Dr. Black believes it is important to understand and "get on top of" the stakeholder issues before addressing regulatory change.

Mr. Camper spoke about the evolution of stakeholder engagement on USNRC decisions. Earlier in his career at the USNRC, staff would create new regulations and guidance documents without public input. But that changed over time for a number of reasons, not the least of which were regulatory failures. Stakeholders and interested parties demanded that decisions not be based entirely on the USNRC's scientific analyses. These demands have changed the way new regulations are developed and released.

"Regulatory Morass" Redux

Dr. Black commented that the "regulatory morass" that he referred to previously includes TRU waste. Defense TRU waste must be disposed of at WIPP, a deep geologic repository, but commercial waste containing less than 100 nCi/g of TRU nuclides can be disposed of in a near-surface disposal facility meeting the requirements of 10 CFR Part 61. Also, there are multiple regulations from DOE, USNRC, EPA, and the states for disposal facilities, some of which overlap or are in conflict.

4

The Common Themes Approach

A conceptual framework to guide future discussions and disposition decisions about challenging low-level radioactive waste (LLW) streams[1] was explored in the final session of the workshop. Case studies presented earlier in the workshop were discussed and "common themes" that led to successful disposition of previously challenging LLW streams were identified. Those themes were organized into a "common themes approach," which was initially presented by John Applegate, planning committee chair. Workshop participants were then divided into five subgroups, each focused on applying the common themes approach to a challenging LLW stream:

- Greater-Than-Class C (GTCC) waste and transuranic (TRU) waste
- Incident waste
- Sealed sources
- Very Low-level and Very Low-Activity Waste
- Depleted uranium (DU)

[1] "Challenging LLW streams," as used in these proceedings, are LLW streams that have potentially non-optimal or unclear disposition pathways due to their origin or content and incompatibility with existing standards, orders, or regulations. This is an imperfect definition as demonstrated by several of the waste streams in the list on this page. For example, many sealed sources do have disposition pathways—this workshop focused on the waste streams that are difficult to dispose of. For example, very low-level waste streams can be disposed of in existing disposal facilities, but the level of protection is not commensurate with the hazard and is therefore not optimal.

These wastes are described later in this chapter and in Appendix D. The subgroups came together at the end of the session to report their results, and the common themes approach was updated during the final discussion.

4.1 THE COMMON THEMES APPROACH

Mr. Applegate opened the session by restating the purpose of the workshop: to identify key characteristics of LLW that govern its management and disposal and to explore how those characteristics are used within existing regulatory frameworks. The workshop planning committee was not charged with inventing a new regulatory framework for LLW. Rather, the workshop used case studies to highlight successful examples of LLW management and disposal within existing regulatory frameworks.

Common themes within the case studies that led to successful disposition of the wastes were identified such as: the use of existing regulations and standards—such as the U.S. Nuclear Regulatory Commission's (USNRC's) Class A, B, and C classification scheme—to provide an anchor for disposal decisions; the identification of lessons learned from similar or analogous approaches such as Canada's or France's approach to managing and disposing of very LLW; and acknowledgement that the disposal site characteristics are as important for safe disposal as the inherent characteristics of the waste. These common themes were organized into a common themes approach that could be used within the current LLW regulations as an aid to guide decisions and direct discussions. The approach has three key elements: anchors, analogies, and adjustments:[2]

- *Anchors*: The current regulatory framework that governs LLW disposal provides a starting point for decisions about the disposition of challenging LLW streams.
- *Analogies*: Learn from successful disposition of similar wastes. Examples of past decisions for successful disposition of challenging LLW streams offer additional guidance for future waste disposal decisions.
- *Adjustments*: Use flexibility within current regulatory frameworks for making decisions about disposing of challenging LLW streams.

Existing U.S. regulations, as well as regulations and standards from international organizations, offer valuable guidance for making decisions

[2]Current USNRC regulations and the Department of Energy (DOE) policies allow for additional analyses and variances to accommodate a variety of waste characteristics. The approach described above and in Figures 4-1 and 4-3 is intended as a clarifying tool, not as a new concept.

about dispositioning challenging LLW streams. One need not write on a blank slate when making such decisions.

The common themes approach also makes use of the roughly proportional relationship between the hazard of a LLW stream and the required protectiveness of the facility that will be used for its disposal. This graphical representation could aid in discussions on identifying the levels of protection for a given level of hazard. This relationship is illustrated conceptually in Figure 4-1. The inherent hazard of the waste stream is represented on the x-axis of Figure 4-1. These hazards arise from the physical, chemical, and radiological properties of the waste stream (e.g., radiation types, activities, half-lives, and chemical toxicity).

The protectiveness of the disposal system is represented on the y-axis of Figure 4-1. The protectiveness characteristics include disposal depth, length of protection, and the number and types of barriers. Barriers can be

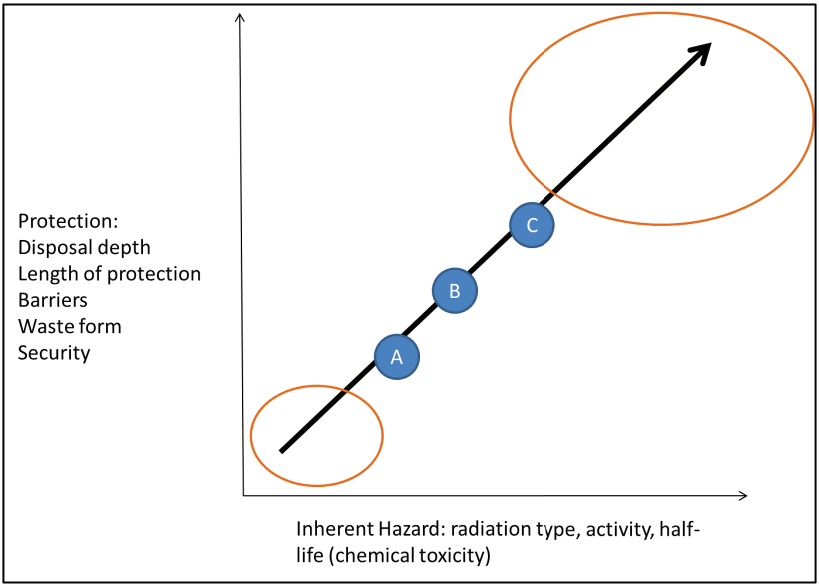

FIGURE 4-1 Conceptual representation of the "sliding scale" relationship between hazard and protection. The common themes approach for disposing of challenging LLW streams acknowledges the roughly proportional relationship between the inherent hazard of a waste stream and the level of protection required from the facility that will be used for its disposal. This proportionality is represented by the solid black line on the figure. Existing classification schemes are notionally identified by Class A, B, and C on the line and can be used as "anchors" (see text); orange circles at the upper and lower ends of the line represent the ranges of challenging LLW streams.

engineered (e.g., the waste form, engineered caps to retard water infiltration into the facility) and natural (e.g., impermeable formations underlying a disposal facility that retard waste migration). Physical security barriers (i.e., guns, gates, and guards) can also be considered if a waste stream poses a security hazard.

The solid line in Figure 4-1 is intended to be a conceptual representation of the proportional relationship between waste hazard and required disposal facility protectiveness. Class A, B, and C wastes (shown in shaded circles in Figure 4-1) have, respectively, increasingly higher levels of hazard and therefore need to be disposed of in facilities having increasingly higher levels of protectiveness. Challenging LLW streams can also be plotted on the conceptual line based on their hazards and needed levels of disposal facility protectiveness.

This type of graphical representation could help guide disposition decisions for wastes without clear or potentially non-optimal disposition pathways and could also help explain disposal decisions to non-experts. This representation is risk informed—a concept advocated by reports from the National Academies and others (National Research Council 1997, 2000, 2001, 2005, 2006b, 2011a, and Omnibus, 2015)—and is relatively easy to comprehend because it uses a small number of readily understood characteristics and shows the relationship between hazard and protection measures. This representation can also help to improve decision-making consistency for challenging LLW streams.

Mr. Applegate noted that there are not an infinite number of unknown LLW streams. Most LLW streams have been identified after many decades of nuclear activities. The waste streams that have been identified are amenable to treatment using the conceptual representation in Figure 4-1.

Planning committee member Nina Rosenberg noted that the barriers in Figure 4-1 are both natural (e.g., site characteristics) and engineered (e.g., waste forms or facility covers). Committee member Larry Camper provided guidance to the subgroups in applying the framework during the breakout session: when determining where each challenging LLW stream falls on the line in Figure 4-1, consider how that location translates to protection criteria.

4.2 DISCUSSION: THE COMMON THEMES APPROACH

Mr. Applegate asked participants for comments, criticisms, changes, or refinements to the proposed common themes approach. Lisa Edwards, senior program manager at the Electric Power Research Institute (EPRI), wondered whether the list of challenging LLW streams developed by the committee was consistent with the wastes that Department of Energy (DOE) is facing. Is very low-activity waste (or "very low-level waste" [VLLW] as previously described by Gérald Ouzounian, international director for ANDRA[3]) a big challenge for DOE, more so than for the commercial sector? Are there other volumetrically large waste streams that have not been identified for discussion in this workshop?

Doug Tonkay, director of waste disposal at DOE, stated that the list appeared to be representative of both DOE's and the USNRC's challenging waste streams. He also stated that VLLW is important to DOE because of its large volume and consumption of available disposal space. The goal for DOE is to find the best deal for the taxpayer for the safe disposal of waste.

Communications

Mr. Tonkay recalled the Session 2 discussions on communications, noting that it is very important for DOE to improve communications with its stakeholders. The tool proposed in Figure 4-1 could help. DOE has expanded communication with the state of Nevada over the past couple of years, meeting quarterly to share information about waste that is anticipated for disposal at the Nevada Nuclear Security Site (NNSS). DOE has also augmented the technical information provided in the waste profiles for potentially challenging LLW streams such as sealed sources; for example, describing how the wastes that need to be disposed of have benefitted society. Mr. Tonkay stressed that he sees communications as a key component of any future approach to guide decision making. LLW has been defined by a patchwork of laws and regulations, resulting in a wide variety of waste streams. Clear decision frameworks are needed to explain how disposal decisions are made to address the wide range of characteristics of the wastes.

Other participants also stressed the importance of communication and suggested that it be a third axis in Figure 4-1. Daniel Goode, research hydrologist at the U.S. Geologic Survey (USGS), commented on the importance for the public to understand the benefits derived from the activities that produced the waste and noted that value judgments and popular opinions within populations evolve over time.

Shape of the Line in Figure 4-1

Several participants questioned whether the shape of the line in Figure 4-1 was linear or nonlinear. Participants noted that if the curve was nonlinear, then extrapolations at its ends—where the challenging LLW streams would fall—would be difficult. Further, Class A, B, and C wastes might better be described by horizontal bars in Figure 4-1 rather than dis-

[3]ANDRA is the French acronym for National Radioactive Waste Management Agency.

crete points. One of the planning committee members noted that the figure is conceptual and intended to convey the message that the need for disposal system protectiveness increases as waste hazard increases. The common themes approach and the figure are helpful for explaining management and disposal decisions on challenging LLW streams.

Commercial Disposal Costs

Participants with commercial disposal experience noted that the costs for disposal will affect disposal decisions, particularly when there is more than one disposal option. For example, Class B waste is usually co-disposed with Class C waste, but Class B waste could potentially be disposed of separately to reduce costs. Disposal costs are a nontechnical constraint (similar to communication) that is not directly captured in Figure 4-1.

Dr. Ouzounian noted that France's approach to managing and disposing of radioactive wastes is consistent with the common themes approach and sliding scale illustrated in Figure 4-1. France has separate facilities for disposal of VLLW and LLW. The site itself is considered protective enough for disposal of VLLW—no additional barriers or protections need to be added. This leads to the factor of 15 to 18 cost savings for disposal as discussed previously in the workshop. In contrast, the protectiveness of both the waste form and the site are considered for the disposal of LLW.

Compatibility with Performance Assessment

A participant noted that the proposed common themes approach might lead to confusion or questions about the legitimacy of using performance assessment to guide decisions. A planning committee member commented that the proposed approach is meant to also guide decision making and could be used in conjunction with (and help with the communications related to) performance assessment.

Use of Chemical Toxicity in Figure 4-1

There were several questions from workshop participants about chemical toxicity and how this characteristic might be represented in Figure 4-1. Dr. Crowley noted that toxicity is a function of oxidation state, for example, and is mutable. The committee agreed that toxicity was not useful as a key characteristic and agreed to remove it from the key characteristics list in Figure 4-1. However, another participant suggested that waste mobility be added instead.

4.3 CHALLENGING LOW-LEVEL WASTE STREAMS

Mr. Applegate moderated the session on challenging LLW streams that would be discussed by the subgroups: GTCC and TRU, sealed sources, very low-activity waste, incident waste, and DU. These waste streams were described by experts from each of the subgroups in plenary session.

Lawrence "Rick" Jacobi, Jr., president of Jacobi Consulting, introduced GTCC and TRU wastes. Tameka Taplin, federal program manager in the National Nuclear Security Administration (NNSA[4]), introduced sealed sources. Lisa Edwards, senior program manager for EPRI, discussed very low-activity waste. William "Will" Nichols, principal environmental engineer at INTERA, provided an introduction to incident waste. Scott Kirk, director of regulatory affairs at BWXT, introduced depleted uranium and its disposal challenges. The biographies for these experts can be found in Appendix E.

GTCC and Commercial TRU Waste Greater than 100 nCi/g

Mr. Jacobi's overview focused mainly on technical challenges for disposing of GTCC and TRU waste. The USNRC defines GTCC waste as waste that is generally not acceptable for near-surface disposal (within 30 meters of the surface). Its waste forms and disposal methods must be more stringent than those for Class C waste. DOE has "GTCC-like" waste,[5] which is waste that is generated and owned by DOE and includes non-defense TRU waste. This GTCC-like waste has characteristics similar to commercial GTCC waste that is regulated by the USNRC. In 2015, USNRC staff recommended to the Commissioners to allow the state of Texas to license the disposal of GTCC waste (USNRC, 2015c).

TRU waste is defined in the WIPP Land Withdrawal Act as waste containing alpha-emitting transuranic nuclides (transuranic nuclides are elements with an atomic number greater than 92 in the periodic table) at concentrations greater than 100 nanocuries per gram (nCi/g) and with half-lives greater than 20 years.

In January 2016, DOE estimated the volume and activity of GTCC and GTCC-like waste in the United States to be about 12,000 cubic meters and 160 million curies, respectively. This is not a volumetrically large waste stream, but it contains a lot of radioactivity. Most of the waste is activated

[4]The NNSA is a semi-autonomous agency within DOE.

[5]GTCC-like waste is a descriptive term DOE adopted for purposes of the Environmental Impact Statement (EIS) for GTCC and GTCC-like waste. It is not a formal waste class within DOE order or U.S. regulation. This descriptive category includes both higher activity DOE LLWs and non-defense TRU wastes that do not currently have disposal pathways and that have characteristics similar to or meet the regulatory definition of GTCC LLW as defined in the 10 CFR 61 tables.

metals from the planned decommissioning of nuclear power reactors. This waste also includes sealed sources, sludge, resin, and contaminated soil. Mr. Jacobi noted that this waste inventory does not include a large number of sealed sources used by the oil and gas industries.

The DOE's final environmental impact statement (EIS) for GTCC and GTCC-like waste (DOE, 2016) proposed several disposal options for GTCC, GTCC-like, and commercial TRU waste, which include:

- A deep geologic repository, such as WIPP.
- A near-surface trench with engineered barriers.
- Above-grade vaults.
- Intermediate-depth boreholes.

Intermediate-depth (more than 30 meters below the surface) disposal is also discussed in the International Atomic Energy Agency *General Safety Guide* (IAEA, 2009a). Mr. Jacobi suggested that intermediate-depth disposal is an appropriate option and that a better name for GTCC waste might be "intermediate-depth waste."

Several participants mentioned the progressive improvement of disposal facilities over the past several decades. Early disposal practices were relatively primitive, waste forms were deficient, and performance assessment modeling was rudimentary. Waste was stored in boxes, drums, and sacks, which were dumped into trenches and covered with dirt. Modern-day disposal facilities are engineered to minimize waste. Operational practices are improved, and waste forms are more robust. Modeling capabilities and techniques are also much better.

As an example, the WCS facility in Andrews, Texas, is the United States' newest LLW disposal facility. The facility is located in an arid environment with low rainfall and a deep groundwater table; the site has low seismicity; the facility is underlain by a low-permeability clay; and the region surrounding the facility has a low population density. Additional engineered barriers have been added to the disposal facility, including compacted clay, concrete sidewalls, geo-synthetic liners, and intrusion barriers. The waste is disposed of in concrete canisters with limitations on void space in the waste as well as waste stability requirements.

Mr. Jacobi proposed that the type of reanalysis required under the USNRC's *Branch Technical Position on Concentration Averaging and Encapsulation* (BTP)[6] (see Chapter 2) would likely result in the reclassification of some portion of GTCC to Class C waste. The remaining GTCC (and possibly TRU waste) could be disposed of in a facility comparable to the

[6] "USNRC: Branch Technical Position on Concentration Averaging and Encapsulation," accessed February 26, 2017, https://www.nrc.gov/waste/llw-disposal/llw-pa/llw-btp.html.

WCS. He recommended that the United States should consider replacing "GTCC" nomenclature with "intermediate waste" following IAEA safety guidance (he noted that the rest of the world is using this nomenclature). He also recommended that future GTCC waste streams need to be considered and planned for—GTCC from Gen IV reactors is a good example. Finally, he recommended that performance assessments used to develop the USNRC waste classification system should be conducted with modern computer codes, newer standards, and data from modern LLW disposal facilities.

Sealed Sources

A sealed source is "[a] radioactive source in which the radioactive material is (a) permanently sealed in a capsule or (b) closely bounded and in a solid form" (IAEA, 2014, p. 423). There are thousands of sealed sources in use and in storage in the United States and around the world. Ms. Taplin explained that her role within the NNSA Off-Site Source Recovery Program (OSRP)[7] is to collect disused sealed sources from domestic and international locations and store and dispose of them in the United States. As mentioned previously by Mr. Tonkay, DOE provides information about the beneficial uses of sealed sources to stakeholders so that these societal benefits are considered in making disposal decisions.

Sealed sources can be highly radioactive (e.g., tens to hundreds of thousands of curies for radiotherapy or radioisotope thermoelectric generators [RTGs]), so proper packaging and transportation is a very important part of managing their disposal. Sealed sources normally have adequate documentation about their manufacture and use; this documentation is useful for planning for the disposal of these sources.

As an example of a challenge for the program, Ms. Taplin noted that occasionally the transportation certification for the packaging of a sealed source is found to be expired. This adds some complication to the recovery and for communication (i.e., the description of the process to others). DOE engages and communicates with communities along the planned transportation routes for these sources, including information about the beneficial uses of these sources.

Exempt and Very Low-Activity Waste

Ms. Edwards framed her presentation in the context of VLLW and very low-activity waste instead of clearance or exempt waste. She suggested a rough definition of VLLW as waste containing less than or equal to 10 per-

[7]OSRP's broader mission is to remove excess, unwanted, abandoned, and orphan radioactive sealed sources that pose a potential risk to national security, health, and safety.

cent of the Class A waste activity limits. She admitted that this was not a technically refined definition, but that it was a good-enough definition for the purposes of the workshop.

VLLW is a large-volume, low-activity waste stream with a low intrinsic hazard compared to other LLW streams, even most Class A waste streams. It falls on the lower part of the notional line on Figure 4-1 represented by the lower orange circle. VLLW is recognized in the IAEA radioactive waste classification scheme and in other countries as a formal waste classification. Dr. Ouzounian described how this waste classification has been successfully employed in France. Spain and other countries also use this waste classification.

One question to be discussed during the breakout session is whether the United States needs to develop a formal regulatory definition for VLLW. The USNRC exemption process (i.e., the 20.2002 exemption) is currently used to manage some VLLW streams. The exemption process allows lower-hazard waste to be disposed of in less-protective (but still adequately protective) disposal facilities than higher-hazard waste. However, the exemption process lacks transparency and can make it difficult to communicate with the public about waste-disposal decisions. The industry has asked the USNRC to publish the requirements it uses for making 20.2002 exemption decisions in a publicly available guidance document.

Some Agreement States have issued licenses to disposal facilities to accept certain VLLW streams. For example, some VLLW is approved for disposal in Resource Conservation and Recovery Act (RCRA) facilities.

Ms. Edwards argued that it would be preferable for the United States to develop a formal regulatory definition for VLLW (or very low-activity waste) that could be used to guide its disposal, rather than relying on the current exemption process. The regulatory definition would identify the key characteristics of this waste that could be used to determine its hazard for the purposes of selecting an appropriate disposal method. Having a formal regulatory definition would have a large economic impact. Ms. Edwards estimated that impact would be about $6 billion in cost savings for disposing of decommissioning wastes from U.S. nuclear plants (see Figure 2-3 in Chapter 2)—a cost savings that some have argued is a gross underestimation. The diversion of VLLW to other disposal facilities would free up capacity in LLW disposal facilities to dispose of higher-hazard waste. VLLW is expected to consume a large portion of currently available LLW disposal capacity in the United States, perhaps far into the future.

Incident Waste

For the purposes of this workshop, "incident waste" is defined as radioactive waste that would be generated from a nuclear accident or nuclear/radiological terrorist attack, collectively referred to here as a nuclear/radiological emergency. Mr. Nichols recently participated in an IAEA consultancy that developed a technical guidance document on the management of large volumes of radioactive waste that would result from a nuclear/radiological emergency.[8] He provided highlights from the draft IAEA guidance document to scope the workshop's breakout discussions on incident waste.

Much can be learned about incident waste from previous nuclear/radiological. The most important examples are the Chernobyl and Fukushima accidents, but less well-known examples can also provide important insights. For example, the 1987 Goiânia accident in Brazil resulted in extensive environmental contamination after a teletheraphy source was removed from its protective housing in a device that was left behind in an abandoned clinic. The breached source contaminated several people and sites. The Chernobyl and Fukushima nuclear accidents further highlight the need for planning for the management of large quantities of incident wastes that would be very suddenly generated following such emergencies.

The nature, scale, and timing of nuclear/radiological emergencies cannot be predicted. However, one can plan for the impacts of such emergencies, including health and safety, environmental, societal, and financial impacts. A large-scale emergency would place instant demands on national resources and present key challenges for managing incident wastes. These include characterizing and managing the waste during the emergency response and responding to public concerns about those wastes. Mr. Nichols noted that the decision making and regulatory frameworks were severely strained in the nuclear/radiological emergencies studied during the IAEA consultancy, particularly when there was no pre-planning or regulatory framework to cope with incident wastes.

Key challenges for managing incident waste are the need for (1) rapid characterization to assess its hazard and (2) waste segregation by those characterized hazard levels. Incident waste must be segregated by hazard level to be managed effectively. Otherwise, all of the waste must be managed to the highest hazard level of any of its components. Mr. Nichols suggested that proposed regulatory framework illustrated in Figure 4-1 was a good way to quickly and clearly segregate incident wastes.

Incident waste management is unlikely to get much attention in the initial stages of a nuclear/radiological emergency. But early decisions and actions could potentially have long-term, unintended consequences for waste management and disposal if not considered in planning and preparation for such emergencies.

[8]This guidance report has not yet been released.

Depleted Uranium

DU is depleted in the isotope uranium-235 relative to uranium-238. It is produced during the uranium enrichment process. Mr. Kirk provided background and history on the DU waste stream in the United States. In 1982, the USNRC promulgated 10 CFR 61, which defined uranium-containing waste as Class A waste. The analysis supporting the rulemaking considered typical or expected waste streams that were in existence at that time, such as small quantities of DU from commercial generators. In 2003, Louisiana Energy Services (now URENCO USA) proposed construction of a national uranium enrichment facility near Eunice, New Mexico, which would produce much larger quantities of DU than previous generators. DU had been determined to be more hazardous than previously thought when this enrichment facility was proposed. The USNRC commissioners directed agency staff to determine whether DU could be safely disposed of in a near-surface (i.e., within 30 meters of the surface) disposal facility. The commissioners later directed agency staff to begin a rulemaking to develop requirements that would be site specific and could be used to demonstrate that disposal of large quantities of DU could be done safely (USNRC, 2008). The final rulemaking is expected to be sent to the USNRC commissioners in the near future.

The USNRC also developed guidance for Agreement States to process requests for disposal of DU received prior to the completion of the rulemaking. This guidance suggested that disposal of DU may be appropriate in a near-surface disposal facility under certain conditions, such as when robust engineered barriers were used and/or the uranium was disposed of at greater depths.[9]

Mr. Kirk explained why DU is more hazardous than previously thought. Figure 4-2 shows the activity ratio (i.e., the activity at the waste at some future time divided by its initial activity) for typical LLW streams (solid blue line in Figure 4-2). The activity of the typical LLW stream decays to 1/100th of its original value after approximately 1,000 years. The activity ratio for DU increases almost tenfold due to ingrowth of daughter products (dotted blue line in Figure 4-2).[10] Therefore, the risk to public health and safety for disposal of depleted uranium is substantially different from other types of LLW.

The USNRC's analyses show that disposal of DU in facilities located at arid sites is adequate to protect public health and safety if the DU is

[9]This guidance has been used by Waste Control Specialists, LLC (WCS) to amend its license to allow for DU disposal at increased burial depths (i.e., 100 feet). "License Amendment Enhances Disposal Options," August 28, 2014, http://www.wcstexas.com/2014/license-amendment-enhances-disposal-options/.

[10]The decay of uranium-235 and uranium-238 produces a number of radioactive daughter products that slowly build up (or grow into) the DU, increasing its activity ratio.

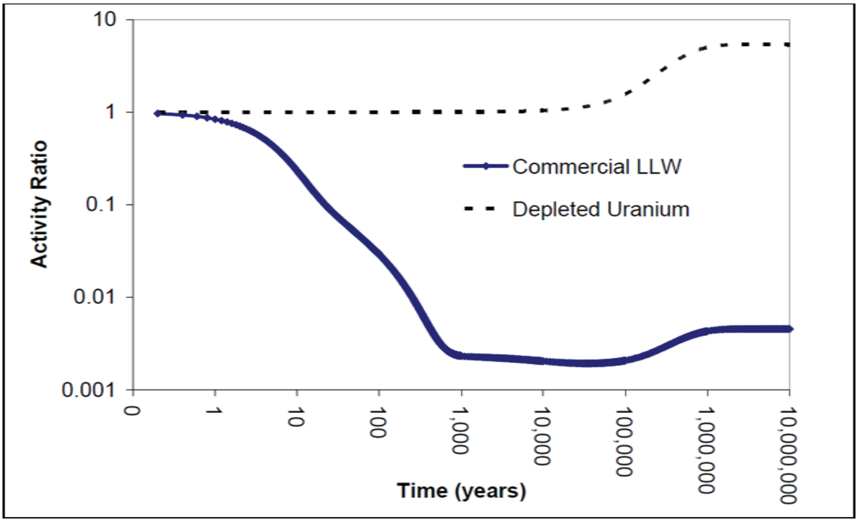

FIGURE 4-2 The activity ratio of DU as a function of time (years).
NOTE: Activity ratio is the activity of the DU at some future time divided by its initial activity. LLW = low-level waste.
SOURCE: Courtesy of James Scott Kirk, BWXT.

disposed of at appropriate depths using appropriate engineered barriers. The USNRC's proposed rule for disposal of DU suggests three tiers of protection: a 1,000-year period of compliance, 1,000-to 10,000-year assessment period, and greater-than-10,000-ear period of performance. The rule requires performance assessments to demonstrate less than 25 millirem per year (mrem/yr) (less than 0.25 milliseivert per year [mSv/yr]) exposure, an intruder analysis to show less than 500 mrem/yr (5 mSv/yr), and an analysis to show site stability.

Mr. Kirk used the WCS license application for disposing of DU to highlight examples of natural and engineered barriers. The site characteristics in the application included red clay beds (nearly as impermeable as concrete and 600 to 800 feet [180-240 meters] in thickness), the water table (about 600 to 1,000 feet [183-305 meters] below grade), and annual rainfall (approximately 15 inches [38 centimeters]) per year, with a potential evapotranspiration of about 60 inches [150 centimeters] per year). The only expected exposure pathway after disposal is through intrusion. Engineered barriers include a cover system (about 33 feet [10 meters] in thickness to retard migration of radon) and a reinforced concrete barrier surrounding the disposal site. The Texas regulator mandated that WCS dispose of DU at the deepest depth possible—which is about 120 feet (37 meters) below grade.

4.4 SUMMARIES FROM BREAKOUT SESSIONS

The discussion of breakout session summaries was moderated by Mr. Applegate. He first presented an update to and further explanation of the common themes approach in response to the earlier discussion. To recapitulate, the common themes approach consists of three steps:

- Consideration of four elements: anchors, analogies, adjustments, and anticipation, the latter element added after the earlier discussion,
- Use of an updated sliding scales graph (Figure 4-3) to connect the hazard of the waste to protectiveness of the disposal system, and
- And a new step: Review of "further dimensions," which are not included in the sliding scales graph of Figure 4-3, such as communication.

"Anticipation" was added to the original three key elements (i.e., anchors, analogies, and adjustments) in recognition that surprises can be avoided through anticipation of future waste streams. The dotted lines in

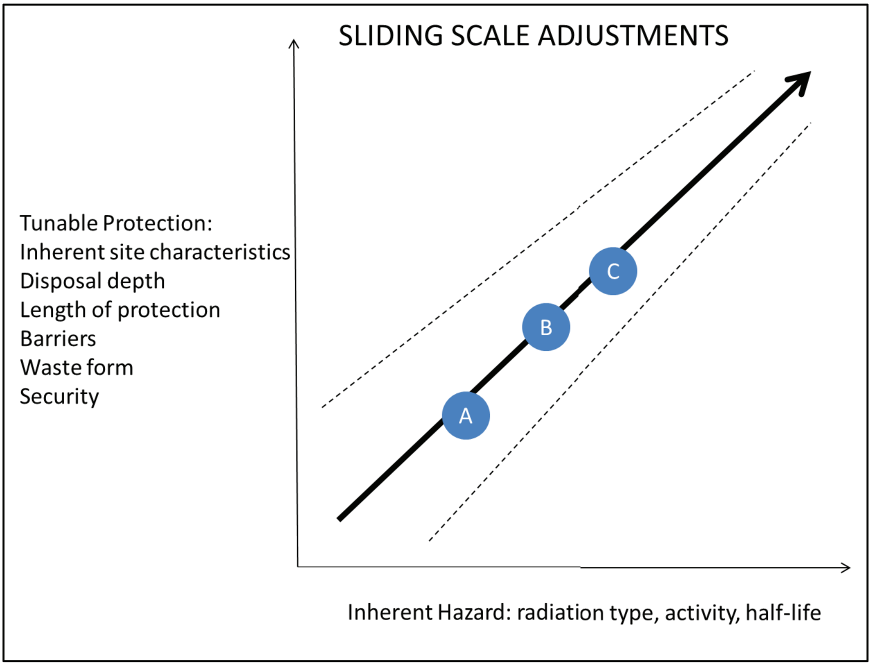

FIGURE 4-3 Updated sliding scale of hazards versus protections of the common themes approach. Changes made to Figure 4-1 based on discussion and input from workshop participants.

the updated graph (Figure 4-3) reflect the flexibility of current LLW regulatory frameworks. Note that chemical toxicity was dropped from the x-axis of the figure, and the y-axis includes both inherent site characteristics and engineered barriers for site protections.

The y-axis label was also updated to reflect the fact that the protectiveness of the disposal facility can be adjusted ("tuned") to match the waste hazard. In other words, the solid line in the graph becomes a sliding scale that can adjust waste hazard to disposal facility protectiveness.

The "further dimensions" are not shown on the updated figure. Nevertheless, they need to be considered when making disposal decisions. Such dimensions can include chemical hazards, sustainability, the beneficial activities that generated the waste (i.e., waste source), and political and public concerns.

Experts from each subgroup summarized the subgroup's discussions on applying the common themes approach to the previously identified challenging LLW streams. Subgroup members offered additional comments and identified actions that could lead to finding management and disposal decisions for challenging LLW streams.

Subgroup 1: GTCC/TRU

Mr. Jacobi summarized the discussion of the GTCC/TRU subgroup. The subgroup recognized that the USNRC, state of Texas, and WCS are currently involved in the ongoing 10 CFR Part 61 rulemaking for GTCC/TRU wastes and that each of these entities has a different perspective and approach to the problem. The USNRC's approach to updating Part 61 is to be generic in identifying characteristics and criteria, because the agency cannot create regulations with specific disposal sites in mind. However, a likely site for the GTCC/TRU wastes is WCS in Texas, which does have specific characteristics—both inherent and engineered—that make it potentially suitable for disposal of these wastes.

The subgroup concluded that Part 61 should strive to have specific technical criteria that form a baseline for analysis (i.e., the "anchor" in the common themes approach), but also that Part 61 needs to be as generic as possible—an admitted paradox. Once a site is selected, the "generic technical criteria" can be converted to site-specific technical criteria in a formal performance assessment. This would be the "adjustments" element of the common themes approach.

Several "further dimensions" were identified during the subgroup discussions. Communications and engagement with the public need to be part of the approach. Institutional challenges must not be overlooked, either. Charles Maguire, director of the Radioactive Materials Division within the Texas Commission on Environmental Quality, explained that the jurisdiction for

GTCC waste decisions in Texas has not yet been clarified by the USNRC. Until that happens, GTCC, GTCC-like, and/or TRU waste cannot be accepted at WCS.

There was a short clarifying discussion about the origin of the classification that specified the TRU waste 100 nCi/g activity level between Class C and GTCC waste. A lower threshold established in the early 1980s (10 nCi/g) was increased to the current value (100 nCi/g) because the lower value was difficult to measure and verify with then-existing survey equipment. Additionally, a "fudge factor" was added so that the application of the new threshold would result in very limited amounts of GTCC or TRU waste above the Class C threshold, or so it was thought at that time.

Mr. Kirk noted that it was recognized early on that a repository would suffice for GTCC and TRU disposal, but exceptions (described below) were provided so that a percentage of lower-hazard GTCC and TRU waste could be disposed of in a Part 61-like (i.e., near-surface) facility. Specifically, the Land Withdrawal Act for the Waste Isolation Pilot Plant defined TRU waste as waste containing transuranic elements that exceeded 100 nCi/g with a half-life longer than 20 years. But the Act provided three exceptions [WIPP, 1996, pp. 1-2]:

> A. High-level radioactive waste;
>
> B. Waste that the Secretary [of Energy] has determined, with the concurrence of the [Environmental Protection Agency] Administrator, does not need the degree of isolation required by the disposal regulations; or
>
> C. Waste that the [US] Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with Part 61 of Title 10, Code of Federal Regulations.

Some participants pointed to the increasing complexity of the regulations as problematic for disposing of these wastes. There should be a calculation of the risk of "doing nothing" when updating or creating regulations, especially when the volumes of the wastes are significant. A few participants noted that there is no immediate pressure from nuclear power plants to dispose of their commercial GTCC wastes, but DOE is pursuing the disposal of these wastes. Regardless, the USNRC rulemaking needs to move forward because the commercially stored wastes will eventually need to be disposed of.

Mr. Camper and Theresa Klickzewski, DOE, identified the following near-term next steps. Mr. Camper's suggestion was to provide comments on the GTCC rulemaking when requested by USNRC staff through Federal Register notices or public meetings. He made a similar suggestion for the expected (in the next year or so) rulemaking for TRU waste.

Ms. Klickzewski provided a few suggestions related to DOE's next actions. A DOE report required by the *Energy Policy Act of 2005* (EPAct of 2005)[11] on GTCC disposal options will soon be delivered to Congress. The Act requires DOE to await Congressional action, but it does not specify what form that action will take. DOE and Congress have agreed to hold a meeting to determine how Congress will provide its recommendations to DOE (e.g., by letter, verbally). After the recommendation is received from Congress, DOE will be able to issue a record of decision (ROD) that defines the acceptable disposal pathway(s).

Another "next step" that DOE will take in parallel is to continue to work with the USNRC as part of the 10 CFR Part 61 update process. DOE will need to receive USNRC's technical criteria for GTCC to be able to dispose of its GTCC waste.

Subgroup 2: Sealed Sources

Ms. Taplin provided a brief summary of the sealed sources subgroup discussions. Sealed sources are distinct from the other types of wastes discussed today. Sealed sources come in a variety of shapes, sizes, and activity levels. Those that contain very high-activity sources, for example sources used in irradiators, are usually doubly encapsulated and stored in heavily shielded containers. These containers can weigh thousands of pounds. The risks of radioactive material leakage from these very large sealed sources during normal handling and use is nearly nonexistent, and scenarios to calculate exposure risks are restricted to individuals with malicious intent.

An example of a challenging sealed sources waste stream is high-activity cesium sources that contain greater than 130 curies of cesium-137. This waste stream is challenging because it requires additional analysis before a disposition can be made. The upcoming USNRC *Branch Technical Position on Concentration Averaging and Encapsulation* (BTP) for Class A, B, and C waste may affect how these types of sealed sources are managed and disposed of. The determination of final disposition for this type of sealed

[11]DOE has a statutory responsibility from the LLWPA amendment to site a GTCC LLW disposal facility and explicit direction to proceed with the EIS from the *Energy Policy Act of 2005* (EPAct). From the EPAct, Sec. 631: "(B) ANALYSIS OF ALTERNATIVES.—Before the Secretary [of Energy] makes a final decision on the disposal alternative or alternatives to be implemented, the Secretary shall—

(i) submit to Congress a report that describes all alternatives under consideration, including all information required in the comprehensive report making recommendations for ensuring the safe disposal of all greater-than-Class C low-level radioactive waste that was submitted by the Secretary to Congress in February 1987; and

(ii) await action by Congress."

For more details, see "Energy Policy Act of 2005," accessed April 9, 2017, https://www.gpo.gov/fdsys/pkg/PLAW-109publ58/pdf/PLAW-109publ58.pdf.

source would be a good test of the common themes approach presented by Mr. Applegate. In fact, Figure 4-3 was used by the subgroup as a way to discuss risk reduction for a potential malicious intruder by increasing the disposal depth (but no specific depths were suggested).

Subgroup participants noted that site-specific characteristics and protections will ultimately determine whether disposal is allowable for a given type of sealed source. The subgroup agreed with the GTCC subgroup that specific technical criteria that form a baseline for analysis should be as generic as possible. For example, sealed source waste generators—hospitals, for example—would welcome an approach that did not require detailed, site-specific technical analysis for every disposal decision. If the regulations become too unwieldy for waste generators, the likelihood of the sealed sources remaining on site in storage increases, which also increases the potential risk that the sources could be stolen or weaponized in place.

Ms. Taplin and David Martin, a contractor for the NNSA, suggested a next step by the USNRC would be clear implementation guidance on the Branch Technical Position mentioned previously. It provides guidance on what can be disposed of at USNRC-regulated facilities. Sources that have activities above certain thresholds (e.g., 130 curies for cesium) require additional special analysis for disposition.

Mr. Martin noted that challenging sealed source waste streams are limited in number and identifiable (the "anticipation" step outlined in the updated common themes approach). He suggested the creation of a forum to review these challenging source waste streams and to identify what additional protections, such as inherent site characteristics, depth of disposal, and/or engineered barriers (i.e., the y-axis of Figure 4-3) would be necessary to allow these sources to be disposed of in near-surface facilities. Waste generators could use the information generated by the forum to guide disposal of these sources. Mr. Applegate suggested that disposal pathways for these sources could be explicitly identified by the forum.

Subgroup 3: Clearance or Very Low-Activity Waste

Ms. Edwards explained that this subgroup's discussion focused on very low-activity waste (i.e., VLLW) and the current approaches to disposing of it, including an exemption process within current USNRC regulations (i.e., the 20.2002 exemption discussed in Chapter 2). The subgroup did not discuss clearance or exempt waste.[12]

The 20.2002 exemption is currently used by many Agreement States and their licensed disposal facilities to dispose of large volumes of VLLW

[12]To clarify terms, "exempt waste" is not waste that has been subjected to the 20.2002 exemption process. Further, the 20.2002 exemption process does not reclassify the waste—it remains LLW.

in RCRA-like facilities. For example, WCS is currently authorized through this exemption process to dispose of LLW by means other than those defined in 10 CFR Part 61 as long as certain requirements are met, such as the waste streams have very low activities. The process grants an exemption to RCRA facilities to receive VLLW, subject to certain requirements by the state regulator.

Other organizations have different ways of managing VLLW. DOE, which is self-regulating, uses the "authorized limits process" to dispose of wastes with low levels of radioactivity at on-site disposal cells. France has a separate classification and disposal process for VLLW as discussed earlier in the workshop.

One could point to the 20.2002 exemption, or the authorized limits process, as "anchors" for VLLW. Alternatively, the French classification system could be used as an "anchor" or "analogy" should the United States decide to add a classification level for VLLW. In fact, Ms. Edwards noted that the subgroup supported the idea of adding a new classification category for this waste type.

The subgroup thought it would be easier to describe VLLW disposal decisions to stakeholders and the public through a new classification than through the current exemption process, which is complicated, granted on a case-by-case basis, and lacks transparency. The terminology is also confusing: VLLW is reviewed through an exemption process for disposal at a RCRA facility, but the waste is not "exempt" waste. There is also the need to reserve space in LLW disposal sites for wastes that pose a higher hazard than VLLW as noted previously.

Dr. Goode suggested that an independent study be commissioned to review the current status and processes for disposing of VLLW. The study should identify the volumes and activities of VLLW in the United States and its possible disposal pathways. The study would provide a broad but thorough picture of the U.S. approach to the disposal of this waste and would inform the scientific community and the public.

Andrew Orrell, section head for waste and environmental safety at the IAEA, identified a slight tension between the interests of DOE and commercial parts of the disposal system, specifically with respect to the introduction of a new waste category versus anxiety by commercial facilities, for example, about changes to the current regulatory structure. He recommended the creation of a task force to help decide whether creating another waste category would actually result in cost savings for industry and enhance public understanding.

Subgroup 4: Incident Waste

Mr. Nichols summarized the subgroup's discussion and attempted to link it directly to the common themes approach, outlined by Mr. Applegate at the start of the session. What are the characteristics of the anticipated waste? Incident waste is highly heterogeneous, including radioactively contaminated biological materials (e.g., plants, agricultural products, and animals), infrastructure (e.g., buildings, vehicles), liquids,[13] and ion exchange resins used to remove contamination from liquids. The quantity of waste is potentially large, rapidly produced, and geographically distributed. Incident waste potentially covers the range of hazards in Figure 4-3.

The challenges for disposing of incident waste are many:

- Characterization and segregation of the waste will be challenging given its volume and distribution. Waste management will not be the highest priority during the initial response to a nuclear/radiological emergency, but early decisions on segregation could have long-term impacts on disposal options.
- Identifying the disposition endpoints (i.e., how clean is clean enough?) will require input from stakeholders and will help determine what areas are cleaned up and to what extent.
- Waste storage sites will need to be found or designated until the waste can be disposed of.
- The capacity of existing LLW disposal sites could easily be overwhelmed by a single large-scale nuclear/radiological emergency.

The subgroup identified preplanning as a critical component in addressing these challenges. The wastes would initially be characterized and segregated by activity level to manage the threat/hazard, but it should not be subject to waste classification at this initial stage. In fact, some in the subgroup thought that "incident waste" ought to be established as a separate waste classification and that performance assessment be used to guide its management.

Mr. Tonkay noted that the right of eminent domain should be added to the challenges for management of incident waste—or perhaps to the "further dimensions" step. Citizens' property could become contaminated as a result of the event. Initially, it might be clear that property owners and citizens should evacuate, but preplanning could help to clarify when they can be allowed to return and how their contaminated property will be dispositioned.

Mr. Nichols suggested that a next step would be to consider creating a special category for incident waste, recognizing of course that such wastes

[13] For example, contaminated liquid wastes from building decontamination and waste removal activities.

would have to be managed using a risk-informed approach. Also, a regulatory analysis needs to be included in the emergency planning to determine how the classification might hinder or help recovery actions.

Dr. Crowley added a few comments. He noted that the Environmental Protection Agency (EPA) has done significant work on Protective Action Guidelines (PAGs), which at least provide a conceptual understanding of what to do from a protective standpoint. However, there is less understanding of how to deal with the waste itself. There have been a couple of unintentional experiments, the Chernobyl and Fukushima accidents. A next step, if not already done, would be to see how incident waste from those accidents was handled and what lessons could be learned. This information could be used to develop guidance for policy makers in the United States about how to respond to future nuclear/radiological emergencies. He also noted that incident waste is not likely to be a problem for DOE unless there was an accident at a DOE site. Rather, an accident/attack was more likely to occur in the civilian sector, for example a nuclear plant accident or a terrorist attack on a major city.

Mr. Orrell noted that the IAEA is almost ready to release two publications on incident waste: a safety guide and a technical document on preparing for and managing incident waste. Dr. Ouzounian noted that in France they have prepared and practiced a concept for managing waste from emergency situations, a concept that has been in place for a few years.

Subgroup 5: Depleted Uranium

Mr. Kirk noted that there is a well-known amount of DU and that work has focused on identifying the right waste form. Most DU is in the form of uranium hexafluoride (UF_6)[14] in cylinders. DOE recognized early on that UF_6 would have to be converted into a more stable solid such as uranium oxide (e.g., U_3O_8) to make it suitable for disposal.

Mr. Kirk noted that the newly added dashed lines in Figure 4-3, representing the flexibility of existing regulatory frameworks, were also appropriate "anchors" for DU, which grows more radiotoxic (from Class A waste to higher classes) as daughter products grow in over time (Figure 4-2). Pathways for disposition of a significant amount of DU have already been determined—for example, DU has been disposed of at the EnergySolutions LLW disposal facilities at Hanford, Washington, and Barnwell, South Carolina. DU may also be appropriate for disposal at more modern LLW disposal facilities, for example the WCS facility in Andrews, Texas—subject to the completion of the final 10 CFR Part 61 rulemaking.

[14] At atmospheric temperature and pressure, UF_6 is a solid. It will sublime into a gas at 134°F (57 °C) and ambient pressure.

Existing regulatory protection standards were discussed as "analogies" within the common themes approach. For example, the WCS license contains a general prohibition against disposal of large quantities of DU, but there was also an activity limit of 10 nCi/g—meaning that DU could be disposed of if its activity is less than 10 nCi/g.

The rulemaking poses some regulatory hazard to facilities that have already disposed of DU. It is possible that the rulemaking will require that additional protections be added at older facilities that have disposed of DU as Class A waste. (The rulemaking could affect other waste streams that have been disposed of as Class A waste.) Mr. Garmaszeghy noted that the wastes currently disposed of at disposal facilities are subject to changes in regulations. Daniel (Dan) Shrum, senior vice president of regulatory affairs at EnergySolutions, noted that facilities have to comply with changes in USNRC regulations, even for waste that has already been disposed of, on a case-by-case basis.[15]

Mr. Kirk suggested two steps that could be taken to advance the decision-making process for disposal of DU. The first is for DOE to complete its National Environmental Policy Act (NEPA) review[16] and, second, for the USNRC to finish the 10 CFR Part 61 rulemaking. The NEPA review is a requirement before federally owned DU can be disposed of at commercial facilities. The facilities will need to review the updated Part 61 rulemaking to determine its meaning and impacts. Mr. Shrum noted that the EnergySolutions LLW Disposal Facility in Clive, Utah, is working on a DU performance assessment to amend its existing license to accept large quantities of DU. The assessment had been dropped to a lower priority, but there is renewed focus by EnergySolutions to finish the assessment so that the state regulator can evaluate it.

Mr. Camper commented that 10 CFR Part 61 is based on an EIS that was prepared at the time the regulation was created, but the EIS has never been updated. Facility design and operation assumptions that were used in the original EIS may be different from modern facility designs and operations. For example, the EIS did not envision disposal facilities like WCS in Texas or EnergySolutions in Clive, or even the changes to facility designs and operations that have occurred at the EnergySolutions LLW disposal facility in Barnwell, South Carolina. Also, the volumes and types of LLW

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[15] See USNRC 10 CFR 61.1: "(a) … Applicability of the requirements in this part to Commission licenses for waste disposal facilities in effect on the effective date of this rule will be determined on a case-by-case basis and implemented through terms and conditions of the license or by orders issued by the Commission." Accessed March 29, 2017, https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0001.html.

[16] "DEPARTMENT OF ENERGY Notice of Intent To Prepare a Supplemental Environmental Impact Statement for Disposition of Depleted Uranium Oxide Conversion Product Generated From DOE's Inventory of Depleted Uranium Hexafluoride," posted August 26, 2016, https://energy.gov/sites/prod/files/2016/08/f33/EIS-0360-S1-NOI.pdf.

being disposed of at these facilities are remarkably different from original assumptions. The USNRC should update the EIS to represent actual waste streams and disposal facility designs and operations. The existing EIS is difficult to amend, and a new EIS is expensive to develop. If a new EIS is not feasible, then an independent study or analysis could be carried out to more accurately capture modern LLW disposition practices. Such a study could be funded from DOE, USNRC, and possibly industry. The general public, as well as other countries, would also benefit from this analysis.

4.5 FINAL THOUGHTS: REVIEW OF THE COMMON THEMES APPROACH

Mr. Applegate asked the participants for final thoughts on using the decision framework (or, as he referred to it, the Common Themes approach). Ms. Klickzewski's comment was that federal agencies should *do something*. They should take an action to show movement and progress. Whether it is the BTP from the USNRC, or a ROD from DOE on GTCC waste, or the NEPA for DU, action is needed. Mr. Applegate agreed with her comment. He was surprised at the activity that has already taken place for many of the waste streams and wondered why they are seen as "challenging" by DOE and the USNRC. He hypothesized that perhaps the final disposition decisions are actually close to being made—or closer than it was assumed when the workshop was requested by DOE.

Mark Yeager, division of waste management at South Carolina's Department of Health and Environmental Control, noted that states deal with multiple regulatory regimes: DOE, the USNRC, and the EPA. He suggested that these three agencies come together to develop an integrated approach for regulation of LLW, perhaps using the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) as a model. He stressed that until there is a consistent and complete regulatory framework across the regulatory agencies, it will continue to be difficult to gain confidence from the public. Ming Zhu, acting budget director for DOE's Office of Environmental Management, agreed with the need for integration across agencies and noted that this was a key finding from a recent omnibus risk review,[17]

[17]The Consolidated Appropriations Act, 2014 (referred to as the "Omnibus") (Omnibus, 2015, p. v) directed DOE to "retain a respected outside group . . . [to] undertake an analysis of how effectively [DOE] identifies, programs, and executes its plans to address risks [to public health and safety from the DOE's remaining environmental cleanup liabilities], as well as how effectively the Defense Nuclear Facilities Safety Board (DNFSB) identifies and elevates the nature and consequences of potential threats to public health and safety at the defense environmental cleanup sites." See "A Review of the Use of Risk-Informed Management in the Cleanup Program for Former Defense Nuclear Sites," accessed March 2, 2017, http://www.tri-cityherald.com/news/local/hanford/article33023001.ece/BINARY/Omnibus%20Risk%20Review%20Report_FINAL.

which also concluded that within EPA there is need to integrate regulatory requirements, policies, and guidance under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, known also as Superfund) and RCRA (Omnibus, 2015, pp. viii-ix). Dr. Zhu further commented that agencies are already actively engaging in the use of performance assessments to guide risk-informed decisions on managing wastes. He noted that agencies have come together in recent years to compare processes and develop lessons learned and best practices in conducting performance and risk assessments for supporting decision making, including on disposal facility operations.

Ms. Edwards agreed that a comprehensive picture of the regulations across agencies would be valuable. To be able to show that there is a single framework guiding decisions on LLW disposal would be useful. Such a framework might also be able to show how different rules and regulations across the agencies work (or do not work) together.

4.6 FINAL THOUGHTS: COMMUNICATION

Mr. Applegate started the discussion about communications by talking about the meaning of the term "stakeholder." He noted that there are many people involved with or affected by LLW disposal who have many different perspectives, levels of understanding of the issues, and objectives. He asked participants to describe what steps could be taken to improve communications with these different groups.

Ms. Edwards responded that communication and transparency with the public are important throughout the entire lifecycle of LLW. We are deficient in communicating about LLW not only because the system is difficult to explain, but also because radioactive waste is portrayed as a "boogeyman." One approach is to avoid public discussion altogether, but this is a very short-sighted perspective. It may be difficult to communicate about the good protective measures that are being taken with radioactive waste, but it is our job to do so.

She recalled Dr. Goode's comments about the public's perception of a waste being affected by the perception of how the waste was generated or stored. For example, there may be more public support for disposal of radioactive waste from medical treatments than from weapons development or for the disposal of sealed sources to reduce terrorist threats. Even if the waste characteristics and hazards are similar, the fact that it was generated from different processes influences public perceptions. Perhaps there is an opportunity to communicate with the public about wastes it perceives as being generated from processes that are acceptable or valuable. It would at least open the possibility of a discussion of actual hazards and technical solutions that could be used to address those hazards. One could then explain how waste from other processes could be managed. It would also be an opportunity to discuss disposal options that are commensurate with the level of hazard posed by the wastes.

Dr. Crowley noted that we have to change the way we talk to our stakeholders, as he explained earlier in the workshop (i.e. "educating the public"). He provided several suggestions. The first is to understand that there is not *a* public, there *are* publics. There are many different people at different levels that we need to communicate with, for example state legislators, city councils, concerned citizens, or even the League of Women's Voters. We have to understand who those audiences are, and then we have to understand what they are interested in. And to do that, we have to go out and ask them. Communication begins with discussions with the publics to find out what their interests are and what their questions are. And then you have to try to answer those questions. A true dialogue is needed.

These concepts are well understood but difficult to implement. Dr. Crowley explained that the National Academies try to implement this approach for communicating with the public in some of the studies that they carry out, and he knows from these experiences that this type of communication is very difficult to do because we operate in a very low-trust environment, particularly with respect to the government. Dr. Crowley suggested that improving communications will be a long-term effort, and that it will take a long time to establish sufficient trust to have a useful dialogue.

Mr. Garamszeghy noted that the use of the term "talking to the public," which has repeatedly been raised throughout the workshop, is indicative of the wrong attitude. Talking "at the public" or "to the public" turns people off. As mentioned by Dr. Crowley, it is necessary to talk *with* members of the public to understand what their concerns and issues are. Ask them what their needs are. Communication is a two-way street. Members of the public want to know and feel that they are being respected, their views are respected, and their input is valued.

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Appendix A

Statement of Task

The National Academies of Sciences, Engineering, and Medicine will convene a workshop of domestic and international technical, regulatory, and policy experts to discuss the safe and secure management and disposition of low-level radioactive waste. The workshop presentations and discussions will address the following topics:

- Identification of key physical, chemical, and radiological characteristics of low-level radioactive waste that govern its safe and secure management (i.e., packaging, transport, storage) and disposition, in aggregate and for individual waste-streams.
- How key characteristics of low-level waste are incorporated into standards, orders, and regulations that govern the management and disposition of low-level radioactive waste in the United States and in other major waste-producing countries.

A summary of the workshop discussions will be prepared by a designated rapporteur. The summary will not contain consensus findings or recommendations.

Appendix B

Biographies of Planning Committee and Staff

JOHN S. APPLEGATE (*Chair*) is executive vice president for University Academic Affairs of Indiana University (IU) and the Walter W. Foskett Professor of Law in the IU Maurer School of Law. He has served as a vice president for IU since 2008. He teaches and has written extensively in the fields of environmental law, administrative law, regulation of chemicals and hazardous wastes, international environmental law, risk assessment, and the management of radioactive waste. He chaired the Fernald Citizens Advisory Board at the Department of Energy's (DOE's) Fernald facility in Ohio from 1993 to 1998, and he served on the DOE Environmental Management Advisory Board from 1994 to 2001. He has also served on several Academies studies. A member of the American Law Institute, Professor Applegate has also taught at the University of Paris (Panthéon-Assas) and University of Erlangen-Nürnberg and has been a research fellow at Cardiff University. Before moving to Indiana, he was the James B. Helmer, Jr., Professor of Law at the University of Cincinnati College of Law and was a visiting professor at Vanderbilt University Law School. He was a judicial law clerk for the U.S. Court of Appeals for the Federal Circuit and an attorney in private practice in Washington, D.C. Professor Applegate received his B.A. in English from Haverford College in 1978 and his J.D. from Harvard Law School in 1981.

LARRY W. CAMPER is an executive consultant with Advoco Professional Services, LLC, and senior nuclear safety consultant with Talisman International. Mr. Camper retired from the U.S. Nuclear Regulatory Commission (USNRC) in September 2015, as the director of the Division of Decommissioning, Uranium Recovery and Waste Programs. For the preceding 10 years, Mr. Camper served as the director of the Division of Waste Management and Environmental Protection in the Office of Federal and State Materials and Environmental Management Programs. Prior to assuming that position, Mr. Camper served in several Senior Executive Service positions within the USNRC including: 2 years as the deputy director, Spent Fuel Project Office; 4 years as the chief, Decommissioning Branch; and 4 years as the chief, Materials Safety Branch. Mr. Camper also served for 10 years as the U.S. Representative to the Waste Safety Standards Advisory Committee of the International Atomic Energy Agency in Vienna, Austria. Mr. Camper is an experienced health physicist, radiation safety expert, environmental remediation expert, and executive. He has more than 40 years of professional experience with various aspects of the nuclear industry within both the private and public sectors including: radiation safety; medical, research and academic uses; commercial uses; industrial uses; environmental assessment and management; LLW oversight; uranium recovery; decommissioning of reactors and complex material sites; and spent fuel management and performance assessment. Mr. Camper received a B.S. degree in radiological science and administration (School of Medicine and Health Care Sciences) and an M.S. degree in administration (School of Business), both from George Washington University. Mr. Camper also completed graduate course work in applied health physics at Oak Ridge Associate Universities, and he completed a graduate-level Certificate in Implementation of the National Environmental Policy Act from Duke University, co-sponsored by the Council on Environmental Quality. Mr. Camper completed a certificate in Strategic Management of Regulatory and Enforcement Agencies at Harvard University, John F. Kennedy School of Government, Executive Education.

JENNIFER A. HEIMBERG is a senior program officer in the Division of Earth and Life Studies (DELS) and the Division of Behavioral and Social Sciences and Education (DBASSE). In her work for the Nuclear and Radiation Studies Board in DELS, she has focused on nuclear security, nuclear detection capabilities, and environmental management issues, and she has directed studies and workshops related to nuclear proliferation, nuclear terrorism, and the management of nuclear wastes. She directed a DBASSE study on assessing approaches for updating the U.S. metric known as the Social Cost of Carbon. Previously, she worked as a program manager at the Johns Hopkins University Applied Physics Laboratory, where she established its nuclear security program with the Department of Homeland Security's Domestic Nuclear Detection Office. She has a B.S. in physics from Georgetown University, a B.S.E.E. from Catholic University, and a Ph.D. in physics from Northwestern University.

REBECCA A. ROBBINS is currently the predisposal unit head at the International Atomic Energy Agency (IAEA) in Vienna, Austria. In this role she is responsible for working with IAEA member states to develop and disseminate IAEA guidance in all aspects of the processing, packaging, and storage of all type of radioactive waste. She has more than 20 years of experience in the nuclear industry in both the United Kingdom (UK) and the United States. Dr. Robbins has supported and led projects related to the cleanup of legacy wastes including transuranic waste at Idaho National Laboratory site and Hanford tank waste. She earned a Ph.D. in inorganic chemistry from the University of Leeds, UK.

NINA D. ROSENBERG has 25 years of experience in both technical and leadership roles at two of DOE's National Nuclear Security Administration national laboratories. She is currently the program director of Nuclear Nonproliferation and Security at Los Alamos National Laboratory (LANL). Dr. Rosenberg previously worked at Lawrence Livermore National Laboratory from 1998 to 2011. Also, she was a staff scientist in the Earth and Environmental Sciences Division at LANL from 1991 to 1998. Dr. Rosenberg is a geoscientist with experience in subsurface contaminant transport and remediation, water resources, and geologic repositories for nuclear waste. She received a B.A., summa cum laude, in geological and geophysical sciences from Princeton University and an M.A. and Ph.D. in geological sciences from the University of California, Santa Barbara.

Appendix C

Workshop Agenda

Low-Level Radioactive Waste Management and Disposition: A Workshop

October 24–25, 2016
Keck Center
500 5th Street, NW
Washington, DC 20001

Monday, October 24

9:00 am Welcome
John Applegate, organizing committee chair
Executive Vice President for University Academic Affairs, Indiana University

Jenny Heimberg, study director
Nuclear and Radiation Studies Board, The National Academies

Opening Remarks
Douglas Tonkay
Director, Office of Waste Disposal, Office of Environmental Management, Department of Energy (DOE)

9:15 am Workshop Background and Objective
John Applegate, organizing committee chair

Session 1: The Scope of the LLW Challenge

9:45 am Categories and Characteristics of Low-Level Waste (LLW)
Moderator:
Nina Rosenberg, organizing committee member
Program Director, Nuclear Nonproliferation and Security, Los Alamos National Laboratory

Each of three panelists will outline the variety of LLW streams, followed by a moderated, full-panelist discussion.

Questions for panelists:
- What are the greatest challenges that you have observed in the management of LLW?
- What key technical criteria and/or waste characteristics are most important to consider?

Miklos (Mike) Garamszeghy
Design Authority and Manager, Technology Assessment & Planning Nuclear Waste Management Organization (NWMO), Canada

Lisa Edwards
Electric Power Research Institute (EPRI)

Daniel B. Shrum
Senior Vice President Regulatory Affairs, EnergySolutions

11:00 am BREAK

11:15 am Regulations, Standards, Orders, and Guidance Criteria
Moderator:
Larry Camper, organizing committee member
Nuclear Safety Consultant, Advoco Professional Services, LLC; U.S. Nuclear Regulatory Commission (USNRC), retired

Each of three panelists will answer a set of questions, followed by a moderated discussion.

Questions for the panelists:

- What are the health, environmental safety, and security bases that led to the generally applicable standards and regulations in your line of work?
- What are the strengths and weaknesses of the respective approaches?

Andrew Orrell
Section Head for Waste and Environmental Safety, International Atomic Energy Agency (IAEA)

Thomas Magette
Managing Director, PricewaterhouseCoopers Advisory Services, LLC

Mark A. Yeager
Environmental Health Manager, South Carolina Department of Health and Environmental Control

12:30 pm LUNCH

Session 2: Lessons Learned in Establishing LLW Disposition Pathways

1:30 pm Case Studies of Successful LLW Disposal Solutions
Moderator:
Rebecca Robbins, organizing committee member
Predisposal Unit Head, IAEA

United States case studies

Case Study 1:
Separations Process Research Unit (SPRU) Tank Waste Sludge Case Study
Melanie Pearson Hurley, DOE-EM Headquarters Site Liaison for the SPRU project

Case Study 2:
Low-Level Radioactive Waste Streams Reviewed for Disposal at Nevada National Security Site—Key Criteria, Variation, and Management
Greg Lovato
Deputy Administrator, Nevada Division of Environmental Protection

Questions for the panelists:

- What were the key characteristics of the waste stream that affected management decisions for waste processing, transportation, storage, and disposal?
- Why did it work? Lessons learned for management from each example.
  - —waste characteristics (technical)
  - —management practices (process)
  - —regulatory structure (manageable, predictable, consistent)
- Were there instances in which it almost did not work?
- What were the obstacles to successful waste management and disposal?
  - —waste characteristics
  - —management practices
  - —regulatory structure

2:30 pm BREAK

2:45 pm Case Studies of Successful LLW Disposal Solutions (continued)
Moderator:
Rebecca Robbins, organizing committee member

International case studies

Case Study 3:
Canada, Licensing a Low-Level Waste Facility
Case Study 4:
Deep Geologic Repository for Low- and Intermediate-Level Waste Repository
Mike Garamszeghy, NWMO

Case Study 5:
France, Very-Low-Level and Intermediate-Low-Level Waste facilities
Gérald Ouzounian, Director, International Division, ANDRA-Agence nationale pour la gestion des déchets radioactifs

Questions for the panelists: (see questions for U.S. case studies

Full Workshop Discussion

3:45 pm Key Characteristics of LLW and Challenging LLW Streams: Initial Discussions
John Applegate, organizing committee chair

4:45 pm Wrap-up
John Applegate, organizing committee chair

5:00 pm ADJOURN

Tuesday, October 25

9:00 am Welcome
John Applegate, organizing committee chair, and
Jenny Heimberg, study director

9:10 am Common Themes from Yesterday's Discussions (Characteristics and Methodologies)
Moderator:
John Applegate, organizing committee chair

10:10 am BREAK

Session 3: Applying Common Themes to Problem Cases

10:25 am Moderator:
John Applegate, organizing committee chair

Description of the problem case studies by experts:

1. Greater than Class C (GTCC) and Commercial Transuranic (TRU) Waste > 100 nCi/g
   Lawrence R. Jacobi, Jr., Jacobi Consulting
2. Sealed Sources
   Temeka Taplin, NNSA
3. Clearance or Exempt Waste and Low-Activity Waste (e.g., lowest 10% Class A Waste)
   Lisa Edwards, Electric Power Research Institute (EPRI)
4. Incident Waste
   Will Nichols, INTERA
5. Depleted Uranium (DU)
   Scott Kirk, BWXT

10:50 am BREAK-OUT Session

Evaluating the Usefulness of Common Themes Applied to Problem Cases

Organizing committee members and study director to each lead a breakout group.

Each group will be encouraged to think about the challenges of one particular waste stream in light of previous remarks.

- What are the characteristics of the wastes?
- What are the challenges to disposal?
- How might the proposed methodology or approaches be applied to this WWP category?

12:00 pm LUNCH

1:00 pm Summary of Morning Session by Each Group Lead

2:15 pm BREAK

Session 4: Concluding Discussion

2:30 pm Full Workshop Discussion
Moderator:
John Applegate, organizing committee chair

- What have we learned? Do we have the pieces here for an integrated solution/system for LLW without a disposition pathway?
- Is there information missing that keeps us from developing an integrated solution?

4:00 pm Concluding Remarks/Reactions from Agencies
Douglas Tonkay, DOE-EM

4:15 pm Wrap-up
John Applegate, organizing committee chair

4:30 pm ADJOURN

Appendix D

Low-Level Radioactive Waste Management and Disposition: Background Information

The Department of Energy's Office of Environmental Management (DOE) is responsible for the cleanup of sites used by the federal government for nuclear weapons development and nuclear energy research. DOE "cleanup" involves the retrieval, treatment, storage, transportation, and disposal of a wide variety of radiological and hazardous wastes and materials. Low-level radioactive waste (LLW) is the most volumetrically significant radiological waste stream in the DOE cleanup program, consisting of millions of cubic meters per year.

LLW is defined by exclusion in the United States—that is, it is a residual category for radioactive waste material that is not otherwise categorized—and has no lower or upper activity limits (see Box D-1). As a result, its physical, chemical, and radiological characteristics are extremely diverse. Examples range from lightly contaminated soils and building materials to highly activated nuclear reactor components and sealed sources.

This workshop is charged to explore:

- the key physical, chemical, and radiological characteristics of LLW that govern its safe and secure management (i.e., packaging, transport, storage) and disposal, in aggregate and for individual wastestreams, and

NOTE: An earlier draft of this paper was provided as background material to the workshop participants. The draft was updated and edited after the workshop to produce the document shown in this appendix.

BOX D-1
U.S. Definitions for Nuclear Materials and Wastes

See Box D-2 for summaries of the laws noted below.

Source material:
by the Atomic Energy Act of 1954, as amended (AEA),[a] "The term 'source material' means (1) uranium, thorium, or any other material which is determined by the [Nuclear Regulatory] Commission pursuant to the provisions of section 61 to be source material; or (2) ores containing one or more of the foregoing materials, in such concentration as the Commission may by regulation determine from time to time."

Special nuclear material:
by Section 11 of the AEA;

"(1) plutonium, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Nuclear Regulatory Commission, pursuant to the provisions of section 51, determines to be special nuclear material, but does not include source material; or

(2) any material enriched by any of the foregoing, but does not include source material."

Spent nuclear fuel:
by Section 2 of the Nuclear Waste Policy Act of 1982[b]; "fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing."

High-level waste (HLW):
by the AEA and the NWPA as amended in 2004;[c]

"(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 products in concentrations; and

(B) other highly radioactive material that the Commission, consistent with existing law, determines by rule requires permanent isolation."

Transuranic waste (TRU):
by the Waste Isolation Pilot Plant Land Withdrawal Act;[d] "waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for:

1) high-level radioactive waste,

2) waste that the Secretary of Energy has determined, with the concurrence of the Administrator of Environmental Protection Agency, does not need the degree of isolation required by the disposal regulations; or

3) waste that the U.S. Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with the Code of Federal Regulations (CFR), 10 CFR Part 61."

Byproduct material:

From the AEA, Section 11;

"The term 'byproduct material' means—

(1) any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material;

(2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content;

(3)(A) any discrete source of radium-226 that is produced, extracted, or converted after extraction, before, on, or after the date of enactment of this paragraph for use for a commercial, medical, or research activity; or

(B) any material that—

(i) has been made radioactive by use of a particle accelerator; and

(ii) is produced, extracted, or converted after extraction, before, on, or after the date of enactment of this paragraph for use for a commercial, medical, or research activity; and

(4) any discrete source of naturally occurring radioactive material, other than source material, that—

(A) the Commission, in consultation with the Administrator of the Environmental Protection Agency, the Secretary of Energy, the Secretary of Homeland Security, and the head of any other appropriate Federal agency, determines would pose a threat similar to the threat posed by a discrete source of radium-226 to the public health and safety or the common defense and security; and

(B) before, on, or after the date of enactment of this paragraph is extracted or converted after extraction for use in a commercial, medical, or research activity."

Low-level waste:

The Low-Level Radioactive Waste Act (LLRWPA) of 1980 and the Low-Level Radioactive Waste Amendments Act (LLRWPA amendments) of 1985[e] LLW as "radioactive material that—

(A) is not high-level radioactive waste, spent nuclear fuel, or byproduct material[f] (as in section 11.e (2) of the Atomic Energy Act of 1954…); and

(B) the Nuclear Regulatory Commission, consistent with existing law and in accordance with paragraph (A), as low-level radioactive waste."

This waste has no lower or upper activity limits. USNRC 10 CFR 61.2 LLW similarly but adds byproduct materials (3) and (4).

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[a]"Atomic Energy Act of 1954, as amended through Public Law 114-92, enacted November 25, 2015," accessed February 24, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

continued

BOX D-1
Continued

[b]"Nuclear Waste Policy Act of 1982," accessed February 24, 2017, http://www.epw.senate.gov/nwpa82.pdf.

[c]"Nuclear Waste Policy Act, as amended, 2004," accessed February 24, 2017, http://www.energy.gov/ .

[d]The DOE and USNRC of TRU waste are not consistent.

DOE's follows the WIPP Land Withdrawal Act (accessed February 24, 2017, http://www.wipp.energy.gov/library/cra/baselinetool/documents/regulatory%20tools/10%20wipplwa1996.pdf). The USNRC is reviewing its current ("Statutory Language and Regulatory History of Commercial Transuranic Waste Disposal," accessed February 24, 2017, https://www.nrc.gov/docs/ML1516/ML15162A828.pdf).

[e]"Low-Level Radioactive Waste Policy Amendments Act of 1985," accessed February 24, 2017, https://www.gpo.gov/fdsys/pkg/STATUTE-99/pdf/STATUTE-99-Pg1842.pdf . Note that the NWPA, as amended 2004, LLW differently by adding "transuranic waste" to the list of what LLW is not ("is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as in section 11.e (2)…").

[f]"[B]yproduct material…as in Sec. 11.e (2)" is provided in the Atomic Energy Act of 1954 as amended: "Sec. 11 DEFINITION…e. The term 'byproduct material' means . . . (2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content…" See "Atomic Energy Act of 1954 as amended by Public Law 114-92, Enacted November 25, 2015," accessed March 1, 2017, https://legcounsel.house.gov/Comps/Atomic%20Energy%20Act%20Of%201954.pdf.

- how key characteristics of LLW are incorporated into standards, orders, and regulations that govern the management and disposal of LLW in the United States and in other major waste-producing countries.

To accomplish this task, case studies will be presented to show how LLW previously without clear or non-optimal disposition pathways have been successfully managed in the United States and internationally. Lessons to be learned from these successes will be highlighted and discussed, particularly with respect to how they can be applied to LLW waste streams that currently lack clear or have potentially non-optimal disposition pathways—referred to as challenging wastes[1] in these proceedings.

The LLW "universe" contains numerous examples of challenging waste streams whose management and disposal pathways do not align directly with the existing U.S. regulatory regime. This workshop will consider waste characteristics, classification, and criteria that have promise for matching

[1]This proceedings refers to LLW without a clear or potentially non-optimal disposition pathway due to their origin, content, or incompatibly with existing regulations and rules as "challenging LLW."

challenging waste streams with appropriate disposition options and could be applied more broadly to other LLW streams in the United States. International classification schemes and case studies will also be presented.

This white paper is intended to inform the workshop discussions and provides background information on the following:

- Entities responsible for the management and disposal of LLW,
- Classification of wastes,
- Current disposal options for LLW,
- Current regulatory landscape for LLW,
- Previous relevant Academies studies, and
- An overview of case studies and challenging LLW.

D.1 ENTITIES RESPONSIBLE FOR THE MANAGEMENT AND DISPOSAL OF LOW-LEVEL WASTE

The main agencies that regulate and oversee LLW disposal in the United States are DOE, the U.S. Nuclear Regulatory Commission (USNRC), and the Environmental Protection Agency (EPA). The states also serve an important role, including regulatory oversight of the four commercially operating LLW disposal facilities in the United States.

The mission of DOE is to safely address the environmental legacy brought about from five decades of nuclear weapons development and government-sponsored nuclear energy research.[2] During the Manhattan Project and the Cold War, LLW was generated through the production and utilization of special nuclear materials, including uranium enrichment, reactor fuel and target fabrication, reactor operations, and plutonium production and recovery. In addition, DOE continues to generate LLW through cleanup activities such as facility decommissioning, tank waste retrieval and immobilization, and soil and groundwater cleanup. This waste is referred to as "government-owned LLW" (previously referred to as "defense LLW").

DOE manages the largest, most diverse, and technically complex environmental cleanup program in the world. While it has completed the cleanup of more than 90 of the original 108 sites in its cleanup program,[3] the remaining sites present some of the most difficult technical and regulatory challenges—including those posed by the diversity and volumes of LLW. For example, in fiscal year 2015 the DOE complex-wide disposal rate

[2]"Mission and Functions Statement for the Office of Environmental Management," accessed February 24, 2017, http://energy.gov/em/downloads/mission-functions-statement-office-environmental-management.

[3]A site may still contain radioactive and chemical contamination after cleanup is completed. These sites will continue to be managed by DOE into perpetuity.

for LLW and mixed LLW (MLLW[4]) was 16.67 million cubic feet per year (Marcinowski, 2016).

The USNRC regulates the civilian use of radioactive materials within the United States under the Atomic Energy Act[5] and also has the responsibility to ensure safe and protective disposal of commercial radioactive waste. Commercial LLW is generated through the maintenance and decommissioning of nuclear power facilities, and through industrial, medical, and research activities. The USNRC may relinquish a portion of its regulatory and licensing authority to Agreement States.[6]

The EPA has the authority to set limits on radiation exposure and issue guidelines for radiation protection to federal agencies, including the USNRC and DOE. The EPA also has authority to regulate hazardous chemicals through the Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act (TSCA). MLLW contains hazardous chemicals and is subject to regulation by the EPA and states that host DOE facilities.

LLW is generated in nearly every U.S. state. The Low-Level Radioactive Waste Policy Act of 1980 and its amendment in 1985 (see Box D-2) assigned to each state the responsibility of disposing of its own LLW. Disposal may also be facilitated through state compacts (congressionally ratified agreements among groups of states).

D.2 CLASSIFICATION OF LOW-LEVEL WASTE

LLW is defined by U.S. law, but there is no standard classification system for LLW across federal agencies. For example, DOE identifies requirements for LLW to be disposed of in near-surface disposal facilities using waste acceptance criteria. The USNRC utilizes a classification system based on the content and concentration of specific radionuclides: Class A, B, and C wastes and Greater-than-Class C (GTCC) wastes. Moreover, international regulatory schemes, discussed in a later section, follow a different system.

Most LLW generated in the United States readily aligns with current LLW classification system and regulatory structure. However, some types of LLW were not anticipated or in existence when the classifications,

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[4]MLLW is LLW that contains hazardous chemicals.

[5]In addition, the Energy Policy Act 2002 gave the USNRC the authority for regulating discrete sources of radium and accelerator-generated material.

[6]Section 274b of the Atomic Energy Act allows the USNRC to relinquish portions of its Act-derived regulatory authority to states for source materials, byproduct materials, and small quantities of special nuclear materials. An Agreement State has agreed to take responsibility of licensing commercial storage facilities under authority of the USNRC through a written agreement between the state's governor and the USNRC.

BOX D-2
Laws that Govern the Regulation and Management of LLW

1954: Atomic Energy Act (AEA) of 1954, as amended

The AEA requires that civilian uses of nuclear materials and facilities be licensed, and it empowers the USNRC to establish, by rule or order, and to enforce standards to govern these uses. Section 274b of the Act allows the USNRC to relinquish portions of its Act-derived regulatory authority to states for source materials, byproduct materials, and small quantities of special nuclear materials. An amendment to the Act[a] established compensation for, and limits on, licensee liability for injury to off-site persons or damage to property caused by nuclear accidents.

1969: National Environmental Policy Act (NEPA) of 1969, as amended

NEPA requires federal agencies to prepare a detailed environmental impact statement for every major federal action that may affect the quality of the human environment. Such a statement includes a discussion of alternatives to the action and of measures to avoid or minimize any adverse effects of the action.

1982: Nuclear Waste Policy Act (NWPA) of 1982, as amended

The NWPA established statutory for high-level radioactive waste, spent nuclear fuel, and LLW.

1985: Low-Level Radioactive Waste Policy Act (LLRWPA) of 1980, as amended in 1985

The LLRWPA established state (including state compacts) and federal responsibilities for the disposal of commercial LLW, assigned responsibility for managing GTCC wastes to the federal government (DOE EM was later assigned the responsibility), and requires disposal of GTCC LLW at a facility licensed by the USNRC. Recent conclusions and recommendations by USNRC staff for GTCC wastes have been summarized in SECY-15-0094, *Historical and Current Issues Related to Disposal of GTCC LLW* (USNRC, 2015). USNRC staff conducted an analysis of an Agreement State's Texas') authority to license and regulate the disposal of GTCC, GTCC-like, and TRU waste.[b]

1986: Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986

CERCLA authorizes the EPA and state regulators to investigate and remediate sites placed on the National Priorities List;[c] several USNRC-licensed and DOE-managed sites contaminated with radioactive material have been placed on the NPL.

2005: Energy Policy Act (EPAct) of 2005

This Act requires DOE to submit a report to Congress on alternatives for disposing of GTCC LLW. DOE must await action by Congress before issuing a Record of Decision on a preferred disposal alternative.

continued

BOX D-2
Continued

[a]Also known as "The Price-Anderson Amendments Act of 1988," accessed February 24, 2017, http://uscode.house.gov/statutes/pl/100/408.pdf.

[b]"SECY-15-0094: Historical and Current Issues Related to Disposal of Greater-Than-Class C (GTCC) Low-Level Radioactive Waste," accessed February 24, 2017, http://www.nrc.gov/docs/ML1516/ML15162A849.html.

[c]The National Priorities List (NPL) is the list of national priorities among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories. The NPL is intended primarily to guide the EPA in determining which sites warrant further investigation ("Superfund: National Priorities List," accessed February 24, 2017, https://www.epa.gov/superfund/superfund-national-priorities-list-npl).

regulations, and laws were developed and do not readily conform to existing classification systems. Some examples include GTCC and transuranic (TRU) wastes, sealed sources, and incident wastes. Thus, the appropriate disposition pathway and destination for permanent disposal are difficult to plan and the final decisions can be contentious. These and other examples are discussed in a later section.

D.3 CURRENT LOW-LEVEL WASTE DISPOSAL OPTIONS

It is DOE policy to reduce, manage, and dispose of government-owned LLW at its site of generation (i.e., onsite generated LLW) to the extent allowable by site conditions. Government-owned LLW that cannot be disposed of onsite will be disposed of at offsite DOE-managed facilities—except that DOE may also dispose of government-owned LLW in commercial facilities when appropriate for cost reduction or as needed to supplement DOE's capabilities. There are currently six DOE facilities available for the disposal of government-owned LLW: four allow for the storage and disposal of onsite generated LLW, and two allow for disposal of LLW and MLLW generated offsite.

The four DOE sites that allow for disposal of onsite generated LLW are the Idaho National Laboratory; Los Alamos National Laboratory, New Mexico; Oak Ridge Reservation, Tennessee; and Savannah River Site, South Carolina. The other two sites—the Hanford Site near Richland, Washington, and the Nevada National Security Site (NNSS)—allow for disposal of both onsite and offsite generated LLW and MLLW, as long as the waste meets each sites' waste acceptance criteria.[7] In addition, there are two commercial sites that can accept government-owned LLW: EnergySolutions LLW Disposal Facility in Clive, Utah; and Waste Control Specialists (WCS) in Andrews, Texas.

There is currently no disposal capability in the United States for GTCC LLW. However, DOE published the final environmental impact statement for the "Disposal of Greater-Than-Class C (GTCC) Low-Level Radioactive Waste and GTCC-Like Waste" in January 2016 (DOE, 2016);[8] it identifies land disposal at generic facilities and/or the Waste Isolation Pilot Plant (WIPP) as preferred options for the disposal of GTCC LLW and GTCC-like waste.[9]

There are four commercial LLW disposal sites in the United States. They are located in Barnwell, South Carolina, and operated by EnergySolutions; in Clive, Utah, also operated by EnergySolutions; the Hanford site in Washington, operated by U.S. Ecology; and Andrews, Texas, operated by WCS LLC (see Table D-1). Each of these sites is located in an Agreement State and are licensed by their host states under authority provided by the USNRC. Three of the sites (Barnwell, Hanford, and WCS) serve state compacts, and the fourth site (Clive) accepts Class A waste from all U.S. states. The Agreement States determine the types of LLW allowed for disposal in the facilities. Refer to Table D-1 for additional information.

D.4 CURRENT REGULATORY LANDSCAPE FOR LOW-LEVEL WASTE

Several U.S. federal laws govern the regulation and management of LLW; see Box D-2.[10] DOE is self-regulating and implements its responsibilities and authorities for waste management and disposal through directives and orders. These are incorporated into government contracts and enforced through contract and federal oversight (e.g., the Low-level Waste Disposal

[7] "Disposal Information," accessed February 24, 2017, http://www.hanford.gov/page.cfm/DisposalInformation and "Nevada National Security Site Waste Acceptance Criteria," accessed February 24, 2017, http://www.osti.gov/scitech/servlets/purl/1080356/.

[8] "Greater-Than-Class C Low-Level Radioactive Waste Environmental Impact Statement (GTCC EIS) Documents," accessed February 24, 2017, http://www.gtcceis.anl.gov/documents/index.cfm#final.

[9] "GTCC-like waste" is waste generated or owned by DOE that contains concentrations of radionuclides that are similar to commercially generated GTCC LLW.

[10] See also *Improving the Regulation and Management of Low-Activity Radioactive Wastes* (National Research Council, 2006), for descriptions of other U.S. laws that are not listed in Box D-1 (see Sidebars 2.1 and 2.2, Appendix A, available as https://www.nap.edu/catalog/11595/improving-the-regulation-and-management-of-low-activity-radioactive-wastes [accessed April 9, 2017]).

TABLE D-1 Facilities Available for Commercial LLW Disposal

	Class	Barnwell, SC (EnergySolutions)	Clive, UT (EnergySolutions)	Hanford, WA (U.S. Ecology)	Andrews, TX (WCS)
Types of commercial LLW accepted	**A**	x	x and 11e.(2)	x	x and 11e.(2)
	B	x		x	x
	C	x		x	x
Available to		Atlantic Compact: South Carolina, Connecticut, and New Jersey	All states	Northwest Compact (Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Washington, and Wyoming) and Rocky Mountain Compact (Colorado, Nevada, and New Mexico)	Texas Compact (Texas and Vermont) and other states on a case-by-case basis
Accepts DOE LLW			yes		yes

SOURCE: Data from "USNRC Information Digest, 2016-17," NUREG-1350, Volume 28, Section 5: Radioactive Waste, accessed February 24, 2017, http://www.nrc.gov/docs/ML1624/ML16245A052.pdf).

Facility Federal Review Group [LFRG]). The directives and orders may be revised over time.

There are two DOE orders that govern radioactive waste management and disposal:

- DOE Order 458.1, *Radiation Protection of the Public and the Environment*, requires DOE to establish requirements to protect the public and the environment against undue risk from radiation associated with radiological activities conducted under the control of DOE.[11]
- DOE Order 435.1, *Radioactive Waste Management*, provides requirements for the management and disposal of HLW, TRU, government-owned LLW, DOE-accelerator produced waste,[12] and the radioactive component of mixed waste.[13]

Under DOE Order 435.1, for instance, a Disposal Authorization Statement (DAS) is required for design and operation of a LLW disposal facility. The DAS consists of a variety of technical documents, including a performance assessment and composite analysis.[14] Waste acceptance criteria are required on a case-by-case basis for each site to meet the order's performance objectives.

The Atomic Energy Act (AEA) (see Box D-2) assigns the USNRC the responsibility for regulating and licensing commercial disposal facilities. The USNRC regulations in 10 CFR Part 61: *Licensing Requirements for Land Disposal of Radioactive Waste* apply to all commercial LLW containing source, special nuclear, or byproduct material (see Box D-1 for definitions) suitable for near-surface land disposal. A subsection within this regulation, Part 61.55,[15] defines three LLW classes from lowest radioactivity levels to highest: Class A, B, and C (see Tables D-2 and D-3). LLW with concen-

[11] "DOE O 458.1, Radiation Protection of the Public and the Environment," accessed February 24, 2017, https://www.directives.doe.gov/directives-documents/400-series/0458.1-BOrder.

[12] "DOE-accelerator produced waste" is radioactive waste produced as a result of operations of DOE accelerators. Accelerator-produced waste is not included in the AEA or NWPA.

[13] "DOE O 435.1 Chg 1, Radioactive Waste Management," accessed February 24, 2017, https://www.directives.doe.gov/directives-documents/400-series/0435.1-BOrder-chg1.

[14] From the "LFRG DOE Order 435.1," accessed February 24, 2017, https://energy.gov/em/lfrg-doe-order-4351, p. IV-12:

> "(3) Composite Analysis: For disposal facilities which received waste after September 26, 1988, a site-specific radiological composite analysis shall be prepared and maintained that accounts for all sources of radioactive material that may be left at the DOE site and may interact with the low-level waste disposal facility, contributing to the dose projected to a hypothetical member of the public from the existing or future disposal facilities."

[15] "USNRC: Part 61.55 Waste Classification," accessed February 24, 2017, https://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol2/pdf/CFR-2011-title10-vol2-sec61-55.pdf.

TABLE D-2 Near-Surface Disposal for Allowable Concentrations of Long-Lived Radionuclides

Radionuclide	Concentration (curies per cubic meter)
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha emitting transuranic nuclides with half-life greater than 5 years	[a]100
Pu-241	[a]3,500
Cm-242	[a]20,000

[a]Units are nanocuries per gram.

TABLE D-3 Allowable Concentrations of Short-Lived Radionuclides for Near-Surface Disposal

Radionuclide	Concentration, (curies per cubic meter)		
	Class A	Class B	Class C
Total of all nuclides with less than 5-year half-life	700	([a])	([a])
H-3	40	([a])	([a])
Co-60	700	([a])	([a])
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1	44	4600

[a]There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table D-2 determine the waste to be Class C independent of these nuclides.
SOURCE: for Tables D-2 and D-3, "USNRC Part 61.55: Waste Classification," Tables 1 and 2, accessed February 24, 2017, https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html.

trations of radionuclides that exceed the Class C limits are referred to as GTCC wastes.

Federal laws have assigned three responsibilities to the states related to LLW management and disposal:

- Each state must dispose of LLW generated within its borders, either within the state or through state compacts.
- States may assume portions of the USNRC's regulatory authority for LLW by becoming an Agreement State.
- States regulate non-AEA wastes under authority provided by the state legislature (non-AEA wastes are not covered by federal laws).

The International Atomic Energy Agency (IAEA) issues safety standards to protect health and minimize danger to life and property. The IAEA uses these standards in its own operations, and its member states incorporate these standards in whole or part into their own regulations. The *IAEA Classification of Radioactive Waste—General Safety Guide, No. GSG-1* (IAEA, 2009) presents a scheme for classification and management of radioactive waste based on specific radionuclides, their half-lives, and activity levels in the waste. The standards define six categories of waste (listed here from lowest to highest level of radioactivity):

- exempt waste (EW),
- very short-lived waste (VSLW),
- very low-level waste (VLLW),
- low-level waste (LLW),
- intermediate-level waste (ILW), and
- high-level waste (HLW).[16]

The objective of the IAEA's classification system is to ensure the long-term safety of the public and the environment through the proper management and disposal of the waste. Therefore, the waste is classified according to the degree of containment and isolation required based on the activity content and half-lives of the contained radionuclides.

DOE has previously requested the advice of the National Academies on its waste management programs. *Improving the Regulation and Management of Low-activity Radioactive Wastes* (National Research Council, 2006), funded in part by DOE, is particularly relevant to the current workshop. The report recommended a tiered approach to clarify and simplify

[16]See Figure 1: Conceptual illustration of the waste classification scheme (IAEA, 2009), "Classification of Radioactive Waste," accessed April 9, 2017, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf.

the current system for managing low-activity waste[17] by converting it to a risk-informed system. The tiered approach, which identified a set of options in order of increasing complexity, resources, and time, acknowledged that changes to regulations would likely take many years and would require coordination among many federal and state agencies.

The report also found that current laws and regulations for low-activity wastes provide adequate authority for protection of workers and the public (FINDING 1) (see National Research Council, 2006, Appendix A). However, the current system of managing and regulating low-activity waste—as described partially above—is complex (FINDING 2). The report's summary notes that classification systems are becoming more complex as unanticipated waste streams are identified. Indeed, this is one of the motivating factors for the current workshop.

The report further found that certain categories of low-activity wastes have not received consistent regulatory oversight and management (FINDING 3) and that current regulations for low-activity wastes are not based on systematic consideration of risk (FINDING 4). These last two findings pertain primarily to uranium and thorium mill tailings, naturally occurring radioactive material (NORM), and technologically enhanced radioactive material (TENORM). TENORM can contain significant concentrations of radioactive materials. NORM and TENORM wastes are not generally regulated by federal agencies; moreover, their regulation by the states is inconsistent.

The National Academies also published a workshop summary that is relevant to LLW management and disposal: *Best Practices for Risk-Informed Decision Making Regarding Contaminated Sites—Workshop* (National Research Council, 2014), funded by DOE. This workshop explored long-term remediation decisions for contaminated sites based on sustainability principles (balancing between the environmental, societal, and economic goals) rather than purely risk-based or regulation-based approaches.

The National Academies report *Waste Forms Technology and Performance* (National Research Council, 2011) provided guidance on improving current methods for processing radioactive wastes and producing waste forms for disposal. The report found that laws and regulations governing DOE wastes do not establish specific requirements for waste form performance in disposal systems, therefore allowing DOE flexibility in the selection of waste forms.

[17]The 2006 committee intended the term "low-activity waste" (LAW) to be more inclusive than LLW, which has a specific definition through the NWPA. DOE often uses the term LAW to describe lower-activity fractions of tank waste; National Research Council (2006) did not use the term in that sense.

D.5 CASE STUDIES AND EXAMPLES OF CHALLENGING LOW-LEVEL WASTES

The following five case studies will be discussed during the workshop. They represent instances in which an appropriate and acceptable disposal pathway was found for the LLW involved. The presentations on the first day of the workshop will consider these case studies in greater detail, with an eye to drawing lessons for other challenging waste streams for which clear disposal pathways do not currently exist or which are potentially not optimal.

Case Study 1: Separations Process Research Unit Tank Waste Sludge

In the early 1950s, research on plutonium and uranium separation techniques such as PUREX and REDOX[18] was performed at the Knolls Atomic Power Laboratory's[19] (KAPL's) Separation Process Research Unit (SPRU). Radioactive liquid and sludge wastes resulting from the research were stored in seven tanks located onsite. The separations research ended in 1953, and the liquids were retrieved from the tanks in the 1960s, but the sludge wastes remained in the tanks. DOE completed solidification of the sludge and removal of the tanks from KAPL in 2014.[20] The cleanup required coordination among several organizations: DOE, its contractor (URS Corporation), the Office of Naval Reactors (the site's landlord), and WCS. WCS accepted the tank sludge waste and the remediated tanks at its LLW disposal facility in Andrews, Texas.

Case Study 2: Disposal of Low-Level Radioactive Waste at the NNSS

The secure shallow-land burial (to 24 feet [7.3 meters] below ground surface) in the Area 5 Radioactive Waste Management Site at the NNSS accepts LLW, MLLW, and classified waste[21] from more than 25 different sites within the DOE Complex. Per agreement with DOE, Nevada's Division of Environmental Protection (NDEP) participates in the review of waste

[18]REDOX (reduction oxidation) and PUREX (Plutonium and Uranium Recovery by Extraction) are processes for separating plutonium and uranium from irradiated fuel and targets.

[19]The Knolls Atomic Power Laboratory is located in upstate New York. It is a research and development laboratory for the U.S. Navy Nuclear Propulsion Program.

[20]"EM's SPRU Celebrates Waste Removal Success, Safety Milestone," accessed February 24, 2017, http://energy.gov/em/articles/em-s-spru-celebrates-waste-removal-success-safety-milestone.

[21]DOE Order 435.1-1 defines classified waste as "Radioactive waste to which access has been limited for national security reasons and cannot be declassified shall be managed in accordance with the requirements of DOE 5632.1C, *Protection and Control of Safeguards and Security Interests*, and DOE 5633.3B, *Control and Accountability of Nuclear Materials*."

profiles proposed for disposal at the NNSS and in the review of the NNSS Waste Acceptance Criteria.

NDEP's perspectives on the variation in certain key criteria with the broad spectrum of LLW reviewed for disposal at the NNSS will be presented at the workshop, including:

- isotope half-life duration;
- radionuclide activity concentrations as compared to concentrations shown by the existing site performance assessment to meet site performance objectives; and
- plutonium equivalent gram activity.

NDEP will also review general measures that have been taken by DOE, the state of Nevada, and others to address stakeholder concerns associated with transportation and disposal of this LLW.

Case Study 3: Canada: Port Hope Area Initiative

The Port Hope Area Initiative (PHAI)[22] is focused on the cleanup of approximately 1.2 million cubic meters of historic low-level radioactive waste currently stored across sites within the municipality of Port Hope. These wastes, primarily contaminated soil, resulted from radium and uranium refining activities in the 1930s through the 1950s. Construction of a long-term waste management facility (an engineered above-ground mound) is under way. Its location will be within an existing LLW management facility. Waste at the existing site and specified wastes from other sites in Port Hope will be placed in the above-ground mound.[23]

Case Study 4: Canada: Deep Geologic Repository for Low- and Intermediate-Level Waste

Canada does not have an operating disposal facility for low- or intermediate-level wastes (L&ILW).[24] Each waste generator is responsible for

[22]The PHAI Management Office is a tripartite organization involving Atomic Energy of Canada Limited, Natural Resources Canada, and Public Works and Government Services Canada (PWGSC). This office is responsible for carrying out the LLW disposal and cleanup projects in the Port Hope area.

[23]"Port Hope Area Initiative," accessed February 24, 2017, http://www.phai.ca/en/home/default.aspx.

[24]Canadian definitions of low- and intermediate-level wastes are different from U.S. definitions. Current Canadian definitions were adopted in 2008 and are consistent with the IAEA GSG-1 classification system (IAEA, 2009). Canada previously recognized three classes of waste: nuclear fuel waste, uranium mining and milling waste, and low-level waste—the latter defined similarly to the U.S. definition as wastes not included in the first two categories.

the long-term management of their wastes. A new L&ILW disposal facility, a deep geologic repository, in Kincardine (Ontario) is currently undergoing licensing. Ontario Power Generation (OPG), a major Canadian utility and nuclear waste generator, owns and operates the site on which this repository will be built. The repository will be located on an existing nuclear site—the Bruce Nuclear Power Generating Station, adjacent to OPG's Nuclear Waste Management Organization facility. The repository will have a reference depth of 680 meters and has a potential waste capacity totaling approximately 200,000 cubic meters. The municipality of Kincardine is a willing volunteer host for the facility. The hosting agreement specifically excludes the possibility of disposing of used reactor fuel in the facility.

Case Study 5: France: Very LLW and Intermediate LLW Facilities

The management and disposal of LLW in France differs in important ways from approaches used in the United States, even though the waste characteristics are similar in both countries. The French approach considers the physical characteristics of the waste and its hazard, based on half-lives and activities of radionuclides, in determining treatment and disposal options. The French classification makes a distinction between:

- very short-lived, short-lived, and long-lived waste, and
- very low-, low-, intermediate-, or high-level waste (VLL, LL, IL or HL waste).

Approximately 96 percent by volume of nuclear waste in France is VLL and LL short- and long-lived waste and IL short-lived waste. This waste contains less than 0.1 percent of the overall waste activity. Conversely, approximately 4 percent of France's waste by volume is IL long-lived waste and HL short- and long-lived waste containing more than 99.9 percent of the activity.[25]

France has two disposal facilities of relevance to the current workshop. For waste that has a very low-activity level (between 0 and 100 becquerels per gram [Bq/g] or 0 to 2.7 nanocuries per gram [nCi/g]), the waste is managed at the ANDRA CSTFA (Centre de stockage des déchets à très faible activité) disposal facility located in the Aube district, southeast of Paris.[26] This facility has been operational since 2003 and is the first disposal facility in the world for this type of waste. Low- and intermediate-level short-lived

[25] "ANDRA: Waste Classification," accessed February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification-1605.html.

[26] "ANDRA: Very-low-level waste," accessed February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/very-low-level-waste-1607.html.

waste, such as waste related to maintenance (i.e., clothes, tools, gloves, filters) and the operation of nuclear facilities (i.e., residues from the treatment of gaseous and liquid effluents) has been disposed of at the ANDRA CSFMA (Centre de stockage des déchets à faible et moyenne activité et à vie courte) waste disposal facility since 1992.[27] France currently does not have a facility to dispose of low-level long-lived waste but plans to commission a repository by 2019.[28] Cigéo, a geological disposal facility for intermediate- and high-level and long-lived waste, is expected to be commissioned in 2025.

D.6 CHALLENGING LOW-LEVEL WASTE STREAMS

As noted previously, challenging LLW streams lack clear or have potentially non-optimal disposition pathways. They will be discussed during the breakout sessions on the second day of the workshop.

GTCC and Commercial TRU Waste Exceeding 100 nCi/g

There are three types of GTCC waste considered in DOE's final environmental impact statement analysis (DOE, 2016): Activated metals (generated from the decommissioning of nuclear reactors including core shrouds and core support plate), sealed sources, and other waste (contaminated equipment, debris, scrap metal, filters, resins, soil, and solidified sludge). The combined GTCC LLW and GTCC-like waste inventory is projected to be about 12,000 cubic meters (~420,000 cubic feet) and will contain a total activity of about 160 million curies (MCi); about 75 percent of this waste is commercial GTCC LLW and 25 percent is DOE-owned GTCC-like LLW.[29]

DOE evaluated five alternatives in the final environmental impact statement for the disposal of the GTCC LLW and DOE-owned GTCC-like waste (DOE, 2016). As noted previously, the preferred alternative for the disposal of GTCC LLW and GTCC-like waste is land disposal at generic commercial facilities and/or disposal at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

[27] "ANDRA: Low and intermediate level short-lived waste," February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/short-lived-low--and-intermediate-level-waste-1609.html.

[28] "ANDRA: Low-level long-lived waste," February 24, 2017, https://www.andra.fr/international/pages/en/menu21/waste-management/waste-classification/low-level-long-lived-waste-1616.html.

[29] "Supplement to Greater-Than-Class C (GTCC) Low-level Radioactive Waste and GTCC-like Waste Inventory Reports," accessed February 24, 2017, http://www.gtcceis.anl.gov/documents/docs/Supplemental-Inventory-Report.pdf.

Sealed Sources

Sealed sources are used in industry, medicine, research, and oil exploration. Some examples include cobalt-60 for medical therapy; cobalt-60 and cesium-137 for bulk irradiation (e.g., medical equipment and food); americium-241/Be for well logging (e.g., for petroleum exploration); and iridium-192 and cobalt-60 for industrial radiography. Disused or unwanted sealed radiation sources range in activity from micro- to kilo-curies; these sources meet USNRC's definition for Class C or GTCC LLW. They can cause acute radiation effects in humans and serious contamination incidents if not managed properly (Cuthbertson et al., 2014).

Clearance or Exempt Waste and Low-Activity Waste

Waste that has very low activity levels is referred to as "clearance" or "exempt" waste by the IAEA (IAEA, 1996). The United States does not have a clearance or exempt classification category. The activity level of this type of waste falls into the lower end of the USNRC Class A designation. This type of LLW may occur in very large volumes. Examples include lightly contaminated wastes generated from decommissioning of nuclear facilities at DOE and civilian sites and from site cleanup activities, including debris, rubble, construction materials, and soils.

Incident Waste

These are wastes resulting from a nuclear incident,[30] for example a severe nuclear accident or nuclear or radiological terrorist attack. Examples of incident wastes include agricultural materials and soils, concrete, asphalt (roads), rubble, debris, metal, activated components, emergency responders' equipment, and cleaning materials. There is potential for very large amounts of waste with low- to high-levels of radioactivity, depending on the type of incident.

Depleted Uranium (DU)

DU waste is a created through the enrichment of uranium, for both commercial and defense applications. DU is unique in its disposal requirements because the activity (and exposure risk) of DU increases with time

[30]Section 11q of the AEA defines a nuclear incident as "any occurrence, including an extraordinary nuclear occurrence, within the United States causing, within or outside the United States, bodily injury, sickness, disease, or death, or loss of or damage to property, or loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, or other hazardous properties of source, special nuclear, or byproduct material."

due to the ingrowth of decay products. Most DU exists as a hexafluoride (DUF_6) and must be converted to DU oxide (e.g., DU_3O_8) for disposal.

Small quantities of DU are currently being disposed of as a Class A waste. However, more than 1 million metric tons (MT) of DU (up to 800 kMT DU at Paducah and Portsmouth and ~300 kMT commercial DU) will require disposal.

There are currently two LLW disposal facilities that are authorized to dispose of uranium oxide: WCS in Texas and the NNSS. A third site, EnergySolutions in Utah, is seeking a permit to authorize disposal of DU in its Class A LLW disposal facility. DOE is currently preparing a supplemental environmental impact statement to analyze the environmental impacts of DU oxide disposition.[31] A USNRC staff review (USNRC, 2008) concluded that existing regulations need to be amended to ensure that commercial DU is disposed of safely.

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Appendix E

Biographies of Panelists and Speakers

LISA EDWARDS is the senior program manager for the Nuclear Chemistry, Radiation Safety and Used Fuel/HLW Management Programs at the Electric Power Research Institute (EPRI). Before joining EPRI in 2006, Ms. Edwards had more than 18 years of experience in commercial nuclear utilities at Duane Arnold, Comanche Peak, Cooper, and St. Lucie. She received her USNRC Senior Reactor Operator license in 2001. She has extensive experience in both solid and liquid radioactive waste processing and management. Ms. Edwards received a B.S. in chemistry from Cornell College, Mount Vernon, Iowa, where she was elected to Phi Beta Kappa and graduated magna cum laude.

MIKLOS (MIKE) GARAMSZEGHY is a chemical/nuclear engineer with more than 35 years of experience in the research, design, and operation and planning of radioactive waste management facilities. He is currently design authority and manager of technology assessment and planning at the Canadian Nuclear Waste Management Organization (NWMO), a utility-owned consortium that has a federal government mandate to develop and implement a program for the long-term management of used nuclear fuel. He has contributed to numerous International Atomic Energy Agency (IAEA), Organisation for Economic Co-operation and Development-Nuclear Energy Agency (OECD-NEA), and International Association for Environmentally Safe Disposal of Radioactive Materials (EDRAM) reports, as well as international peer reviews and projects for more than 30 years, dealing with varied aspects of radioactive waste, advanced fuel cycles, and used nuclear fuel management. He is a past chair of the Canadian Standards

Association N292 technical committee (which deals with radioactive waste standards); current chair of the Canadian Advisory Committee for the ISO TC-85/SC-5 technical committee (which deals with nuclear fuel cycle and waste standards); current Canadian representative on ISO TC85/SC5/WG5 (Waste Characterization); the ISO representative on the IAEA's Waste Safety Standards Committee (WASSC); a member of the Canadian government's External Advisory Panel on Gen-IV reactors; and serves on the technical program advisory boards for several international conferences dealing with radioactive waste management. He holds BASc and MASc degrees in chemical/nuclear engineering from the University of Toronto (Canada) and is a registered professional engineer in Ontario (Canada).

MELANIE PEARSON HURLEY has more than 25 years' experience at the Department of Energy in regulatory compliance and oversight, and program and project management. She has worked in the environmental discipline for the past 35 years in local, state, and federal government agencies. Mrs. Hurley joined the Office of Environmental Management in 2009 after 18 years with the former DOE Office of Environment, Safety and Health (now Environment, Health, Safety and Security). She is currently a headquarters liaison in the Office of Field Operations for the eight Environmental Management Consolidated Business Center Projects. Mrs. Hurley has a B.S. in biology from Virginia Polytechnic Institute and State University and a masters in administration from Central Michigan University.

LAWRENCE "RICK" JACOBI, JR. is the owner and principal consultant at Jacobi Consulting. He is an experienced nuclear industry executive with more than 40 years of front-line experience in project management, licensing, and handling of radioactive material, environmental sciences, legal and regulatory matters, and governmental and media affairs. As a licensed nuclear engineer, health physicist, and member of the State Bar of Texas, Mr. Jacobi provides technical assistance to a variety of nuclear and radiological facilities including waste disposal companies, industrial users, uranium miners, transportation companies, oil and gas exploration and production companies, and investment companies who are seeking an expert opinion on the acquisition of nuclear facilities. He offers hands-on technical assistance in the licensing, construction, operation, and decommissioning of nuclear and radiological facilities, including expert guidance on radiation risk assessment, licensing and permitting of nuclear facilities, environmental assessments, nuclear facility closure and decommissioning plans, radiological and nonradiological environmental monitoring programs, and nuclear facility operating procedures. Mr. Jacobi is an internationally recognized expert on the management of radioactive waste storage, processing, and disposal facilities. He has a B.S. and M.Sc. in nuclear engineering from Texas A&M University and a J.D. from South Texas College of Law.

SCOTT KIRK recently joined BWX Technologies and serves as the director of regulatory affairs for its Technical Service Group. In this capacity, Mr. Kirk provides guidance on a variety of regulatory affairs matters, focusing on radioactive waste management. Prior to his employment with BWX Technologies, Mr. Kirk served as the vice president of licensing and regulatory affairs for Waste Control Specialists during the past 10 years, working on disposal options for complex waste streams such a large quantities of depleted uranium and Greater-Than-Class C low-level waste. Mr. Kirk was also employed by Nuclear Fuel Services and served as the principle liaison with USNRC for more than 10 years. He was responsible for obtaining licensing approval for processing highly enriched uranium for the U.S. Naval Nuclear Propulsion Program and a major nuclear-nonproliferation program for DOE. Mr. Kirk was recently selected by the Southeast Compact Commission for Low-Level Radioactive Waste Management as the recipient of 2017 Richard S. Hodes M.D. Honor Lecture Award for his contributions and innovations in the field of radioactive waste management. He has a M.Sc. in environmental health from East Tennessee State University and a B.S. in geology and physics from Appalachian State University. He is certified in the comprehensive practice of health physics by the American Board of Health Physics.

GREG LOVATO is deputy administrator at the Nevada Division of Environmental Protection (NDEP), where he oversees the Mining, Environmental Cleanup, Waste Management, and Federal Facilities programs. He started his career in at U.S. Environmental Protection Agency (EPA) Region 9 as an environmental engineer working on cleanup, brownfields, and hazardous waste permitting projects in Nevada and California, including 3 years at NDEP in Carson City and 6 years at the Los Angeles Regional Water Quality Control Board. Mr. Lovato holds a B.S. in civil engineering from Stanford University and a B.A. in management-engineering from Claremont McKenna College. Mr. Lovato is a licensed professional engineer (civil) in Nevada and California.

THOMAS E. MAGETTE has more than 30 years' experience managing and conducting nuclear safety, licensing, siting, and environmental assessment programs for energy generation and transmission, national defense, and radioactive waste disposal facilities. He served as the director of the Nuclear Safety Division in DOE's Office of New Production Reactors and was the manager of nuclear programs for the Maryland Power Plant Research Program. His experience covers a wide spectrum of the nuclear industry, including operating reactors, decommissioning, decommissioning funding, transportation, low-level radioactive waste, spent nuclear fuel, and import-export of radioactive material. Mr. Magette currently manages nuclear consulting offerings for PricewaterhouseCoopers (PwC) Capital Projects and Infrastructure in the United States. Mr. Magette holds B.S. and M.S. degrees in nuclear engineering from the University of Tennessee and is a registered professional engineer in Maryland and Virginia.

WILLIAM "WILL" NICHOLS' professional experience as a water resources engineer has focused on hydrology, environmental site characterization, fate and transport modeling, pathway and exposure modeling, uncertainty and sensitivity analysis, integrated risk assessment, probabilistic modeling and simulation, and software quality assurance. He has applied his expertise to help solve problems of national importance in the areas of Resource Conservation and Recovery Act (RCRA) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), remedial investigations and feasibility studies, radioactive waste disposal facility licensing, National Environmental Policy Act (NEPA) reviews, and environmental impact statement development. Mr. Nichols' expertise has been applied in support of environmental restoration, dose reconstruction for legacy radioactive waste practices, and demonstration of compliance with applicable waste disposal regulatory requirements. He received a B.S. and M.S. from Oregon State University.

ANDREW ORRELL is the section head for Waste and Environmental Safety at the International Atomic Energy Agency (IAEA) where he is responsible for the development and promulgation of internationally accepted standards, requirements, and guides for the safe management of radioactive waste and spent fuel, decommissioning, remediation, and environmental monitoring. In addition, Mr. Orrell oversees the planning and execution of support to the IAEA Member States for the implementation of the IAEA Safety Standards and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Prior to joining the IAEA, Mr. Orrell was the director of nuclear energy programs for Sandia National Laboratories. With more than 25 years of professional experience in nuclear fuel cycle and radioactive waste management for the U.S. and several international programs, Mr. Orrell is versed in the complex interdependencies between nuclear energy development, waste management, decommissioning, remediation, and disposal. Mr. Orrell routinely advises government and industry leaders on the technical and policy implications for radioactive waste management, including repository development and licensing, national policy development and regulation, site characterization and safety case development, storage, transportation, and the securing of public confidence.

GÉRALD OUZOUNIAN has been the international director for ANDRA, the French national radioactive waste management agency, since October 2006. Previously, he served as the deputy director for the scientific department at ANDRA for 16 years. He was also in charge of modelling policy and of its implementation in ANDRA. In these functions, he has prepared and implemented studies for low- and intermediate-level activity waste disposal and for used nuclear fuel and high-level waste management, including strategic studies and scientific and technical assessment of the different options. Dr. Ouzounian is a member of the Nuclear Energy Agency's Radioactive Waste Management Committee and the IAEA's Waste Technology Committee. He received a Ph.D. from the Paris University.

DANIEL "DAN" B. SHRUM has worked for EnergySolutions for 19 years. He is the senior vice president for regulatory affairs at EnergySolutions and is responsible for the overall corporate environmental, radiation safety, quality assurance, and security culture, obtaining and updating EnergySolutions numerous permits and licenses, and ensuring that the regulations are followed at all facilities. He has more than 24 years of professional experience including investigations and remedial actions at numerous CERCLA and RCRA sites in Utah, North Dakota, Alaska, and California. Mr. Shrum has designed and installed monitoring well compliance and groundwater extraction systems and has conducted and interpreted aquifer test data for many groundwater investigations. He has successfully managed field teams conducting site characterizations, remedial investigations, and treatability studies. He is experienced in all aspects of drilling and monitoring well completion methods, appropriate air, soil, and groundwater sampling protocol, and quality assurance/quality control procedures. Mr. Shrum has authored or co-authored many soil and groundwater work plans and sampling protocols in addition to investigation reports. Mr. Shrum's academic experience emphasized the geology, hydrogeology, and geochemistry of the several mountain systems in Utah and Idaho.

TEMEKA TAPLIN is the federal program manager for the Off-Site Source Recovery Program within the National Nuclear Security Administration's Office of Radiological Security. During her 5 years of federal service she has worked on numerous radiological security programs dealing with disused, unwanted, and orphaned radiological sources. Under her tenure, thousands of radiological sources have been recovered for final disposition or brought back under regulatory control. She also works with national laboratories and university partners to build educational programs that will increase the number of radiation security experts for the next generation. Ms. Taplin has an M.H.P. and is a graduate of Texas A&M University.

DOUG TONKAY is the director of the Office of Waste Disposal within the Department of Energy's Office of Environmental Management (EM). He manages staff responsible for a portfolio of EM mission activities, including strategic planning and disposal policy for DOE LLW/mixed LLW, a share of the DOE's LLW Federal Review Group, disposition planning for depleted uranium, and planning for Greater-Than-Class C LLW disposition. During his 25-year career at DOE he has worked on a variety of assignments in low-level radioactive waste and transuranic waste management. He also leads the U.S. interagency working group implementing activities for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and is also the U.S. country coordinator for two IAEA projects. He earned B.S. and M.Sc. degrees in nuclear engineering from the Pennsylvania State University.

MARK YEAGER is environmental health manager in the Division of Waste Management with the South Carolina Department of Health and Environmental Control. He began his career in 1980 in the Department's Radiological Laboratory while attending the University of South Carolina. In addition to conducting environmental monitoring at the state's various fixed nuclear facilities, Mr. Yeager performed environmental monitoring and sample analyses at the Energy Solutions/Chem-Nuclear Systems LLW disposal facility located in Barnwell, SC. In 1987, Mr. Yeager transferred to the state's Agreement State program as an onsite inspector at the Barnwell facility. He is currently the program's senior health physicist and inspector. Some of his achievements within the field of radioactive waste management and transportation include: contributing member of the Conference of Radiation Control Program Director's (CRCPD's) E-26 Committee on Radioactive Material Transportation; active member and former chairperson of the CRCPD's E-5 Committee on Radioactive Waste Management; providing technical assistance and regulatory oversight to the EPA and U.S. Navy during the radiological decommissioning of the Charleston Naval Shipyard; providing regulatory oversight of the final decommissioning and resulting waste disposal operations of the former Carolinas-Virginia Training Reactor located in Jenkinsville, SC; assisting in the development and subsequent publication of the American National Standard Institute's *Standard N14.36: Measurement of Radiation Levels and Surface Contamination for Packages and Conveyances*; administering the state's transportation inspection program for DOE's Foreign Research Reactor Spent Nuclear Fuel Recovery Program and the Savannah River

Site/Waste Isolation Pilot Plant TRU waste disposal program; assisting in the implementation of the USNRC's initial orders and subsequent security requirements in 10 CFR Part 37 at the Barnwell Disposal Facility; and the Organization of Agreement State's representative on the USNRC's 10 CFR Part 61 Working Group.

Appendix F

Acronyms

AEA	Atomic Energy Act of 1954
ALARA	As low as reasonably achievable
ANDRA	Agence nationale pour la gestion des déchets radioactifs (National Agency for Radioactive Waste Management, France)
ANPR	Advance Notice of Public Rulemaking
BDF	Barnwell Disposal Facility
Bq/g	Becquerels per gram
BTP	U.S. Nuclear Regulatory Commission's *Branch Technical Position on Concentration Averaging and Encapsulation*
BWXT	BWX Technologies, Inc.
CANDU	CANada Deuterium Uranium reactor
CEAA	Canadian Environmental Assessment Agency
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*, known also as Superfund
CFR	Code of Federal Regulations
CIRES	Centre industriel de regroupement, d'entreposage et de stockage facility (France)
CNSC	Canadian Nuclear Safety Commission
CRCPD	Conference of Radiation Control Program Directors, Inc.
CSA	Centres de stockage de l'Aube (France)
CSFMA	Centre de stockage des déchets à faible et moyenne activité et à vie courte

CSM	Centre [de stockage] de la Manche (France)
CSTFA	Centre de stockage des déchets à très faible activité
DAW	Dry active waste
DHEC	South Carolina Department of Health and Environmental Control
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DUF_6	Depleted uranium hexafluoride
DU_3O_8	Depleted uranium oxide
EIS	Environmental impact statement
EPAct	*Energy Policy Act of 2005*
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
g/m^3	Gram per cubic meter
GSG	IAEA General Safety Guide
GSR	IAEA General Safety Requirement
GTCC	Greater-Than-Class C
HEPA	High-efficiency particulate air
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMPEP	U.S. Nuclear Regulatory Commission's Integrated Materials Performance Evaluation Program
ILW	Intermediate-level waste
KAPL	Knolls Atomic Power Laboratory
L&ILW	Low- and Intermediate-Level Wastes
LANL	Los Alamos National Laboratory
LLRW	Low-level radioactive waste
LLRWMO	Low-Level Radioactive Waste Management Office
LLRWPA	*Low-Level Radioactive Waste Policy Act of 1980*
LLRWPA amendments	*Low-Level Radioactive Waste Policy Act Amendments of 1985*
LLW	Low-level radioactive waste or low-level waste
MARSSIM	U.S. Environmental Protection Agency's *Multi-Agency Radiation Survey and Site Investigation Manual*

MLLW	Mixed low-level waste
MOX	Mixed oxide
mrem/yr	Millirem per year
mSv/yr	Milliseiverts per year
MT	metric ton
nCi/g	Nanocuries per gram
NCRP	National Council on Radiation Protection and Measurements
NDEP	Nevada Division of Environmental Protection
NEPA	National Environmental Policy Act
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
NORM	Naturally occurring radioactive material
NPP	Nuclear power plant
NPV	Net present value
NRC	U.S. Nuclear Regulatory Commission
NWMO	Nuclear Waste Management Organization
NWPA	*Nuclear Waste Policy Act of 1982*
OAS	Organization of Agreement States
OMB	U.S. Office of Management and Budget
OPG	Ontario Power Generation
OSRP	National Nuclear Security Administration's Off-Site Source Recovery Program
PAG	U.S. Environmental Protection Agency's Protective Action Guideline
PE-g	Plutonium equivalent grams
PHAI	Port Hope Area Initiative
PUREX	Plutonium and uranium recovery by extraction
PVP	Property Value Protection
RCRA	*Resource Conservation and Recovery Act*
REDOX	Reduction oxidation process
ROD	Record of decision
RTG	Radioisotope thermoelectric generator
SCATR	U.S. Department of Energy's Source Collection and Threat Reduction (Program)
SECY	Office of the Secretary (of the U.S. Nuclear Regulatory Commission)
SPRU	Separations Process Research Unit

TCLP	Toxicity characteristic leaching procedures
TENORM	Technically enhanced naturally occurring radioactive material
TRU	Transuranic
TSCA	Toxic Substances Control Act
UF	Used fuel
UF_6	Uranium hexafluoride
U_3O_8	Uranium oxide
U.S.	United States
USGS	U.S. Geological Survey
USNRC	U.S. Nuclear Regulatory Commission
VLLW	Very low-level waste
WAC	Waste acceptance criteria
WCS	Waste Control Specialists, LLC
WIPP	Waste Isolation Pilot Plant

The Proposed Ward Valley Radioactive Waste Facility: Papers Submitted to the National Academy of Sciences

October 12, 1994

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Panel on Ward Valley
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Dear Member of the NAS/NRC Panel on Ward Valley:

I believe that the enclosed material should prove useful in the deliberations of your committee. It merits your careful scrutiny.

Sincerely,

Robert Cornog, Ph.D.
[co-discoverer of tritium, 1939]

EMPIRICAL MEASUREMENT OF RADIONUCLIDE MIGRATION AT LLRW DISPOSAL SITES IN ARID LOCATIONS

Abstract: Comprehensive radiation monitoring data for the US Ecology LLRW site at Beatty, Nevada, published in the last few days, provide a unique opportunity to evaluate the validity of optimistic transport models that have been used to predict travel times to groundwater in the tens of millennia. The newly available data show gross alpha readings in groundwater in excess of action levels in eight different years, gross beta in violation of action levels seven years, and tritium in excess of action levels four years, with significantly elevated tritium (>1,000 pCi/L) but below action levels an additional four years. The data provide clear evidence that radioactive materials have migrated from the disposal trenches to groundwater, 300 feet beneath the surface, in a few decades. The presence of elevated gross alpha, gross beta, and Cobalt-60 in the groundwater, in addition to substantial tritium, rule out vapor-phase migration. These empirical observations of rapid radionuclide migration contrast sharply with predictions by Prudic (1994) for Beatty and Ward Valley using Chloride Mass Balance calculations.

Introduction

Proponents of the Ward Valley LLRW project have attempted through various theoretical models and assumption-driven calculations to demonstrate that radioactivity buried in an arid location such as the existing US Ecology facility at Beatty, Nevada, or the proposed site at Ward Valley will assertedly take tens of thousands of years to migrate through the vadose zone. These models and calculations are dependent upon a long list of controversial assumptions: that there is an upward gradient at the sites, that matric potential and other soil parameters needed as inputs for the calculations have been accurately measured, that heterogeneities in the soil profiles can be effectively ignored, that all water movement in the unsaturated zones in question can be accurately described with a simple piston-flow displacement model and that there aren't potential bypass modes such as preferred pathways or mobile/immobile phases of soil water, that (in the case of the chloride mass balance approach) chloride deposition rates over the last 50,000 years are well known and can be estimated from measurements taken in the current period far from the location in question, and so on.

The problem, of course, is that models may or may not accurately represent what occurs in the field. Furthermore, they are only as good as the input assumptions upon which they are based, and the input assumptions at work here are untested and heavily disputed. Leaving aside for the moment the question of the serious problems with the measurements (e.g., thermocouple psychrometer readings) upon which US Ecology attempts to rely, at base what exists is an almost theological dispute. By that we mean that advocates of the proposition that there is essentially no deep percolation in arid zones and that what does infiltrate migrates only over tens of millennia are being strongly challenged by skeptics, but the former belief is based to a significant degree on faith (i.e., theory). True, there are serious arguments that can be advanced to support the theory, as there are to challenge it, but theory it remains. The evolution of science, however, makes clear that theories change or are abandoned over time as more data are obtained, or as intellectual fashions in a particular field shift.

Hazardous/Radioactive Waste Disposal History One of Optimistic Initial Models Subsequently Abandoned After Facilities Fail

Indeed, this pattern of the promulgation of optimistic theory and the necessity subsequently to abandon the theory when events in the real world tragically disproved it, has been at the root of the troubled history of toxic low-level radioactive waste disposal in this country. The State of California approved the Stringfellow Acid Pits based on the fact that annual evaporation exceeded annual precipitation; 15 years later groundwater contamination was extensive and spreading, and now a court has saddled the state with a cleanup bill approaching $800 million due to inadequate review when it first approved the project (Environment Week, 1992). During much of the 1950s and 1960s, radioactive waste was dumped in 55 gallon oil drums off the east and west coasts of the United States, on the assumption that the drums would contain the radioactive materials until they had decayed and that should any be released, it would be dispersed. In the mid-1970s, however, subsequent studies found that many of the barrels were already corroding and breached, releasing radioactivity; and that the radioactivity adsorbed onto bottom sediments where they were ingested by bottom-dwelling organisms which in turn were subsequently consumed by higher species, concentrating radionuclides up the food chain (cf. Davis, 1982). Monitoring was so inefficient that responsible agencies lost track of even the locations of something on the order of half of the ocean dump sites (Hirsch, 1981).

Initial predictions for US Ecology's LLRW facility at Sheffield, Illinois, were that it would safely contain the radioactive waste for millennia; within 15 years of opening, the facility had failed and had to be closed after extensive radionuclide migration and contamination resulting from the failure to adequately characterize the site beforehand (failure to identify sand lenses and their capability of acting as fast-track migration pathways) and reliance on models that eventually were found to have substantially underestimated travel times (U.S. Congress, 1976). US Ecology's LLRW facility at Maxey Flats similarly failed, when radionuclides such as tritium and plutonium were found to have migrated offsite in as little as a decade despite initial predictions such migration would take many thousands of years (Shrader-Frechette, 1992); the failure to consider the effects of complexing agents on increased mobility and decreased soil retention were among the causes identified (Cleveland and Rees, 1981; Weiss and Czyscinski, 1981; Fowler and Polzer, 1988).

The history of the heavily contaminated Department of Energy nuclear complex strongly reinforces this same theme – initial optimistic models predicting extremely slow travel times proved by experience to be tragically wrong, as radioactive wastes have contaminated vast areas, with cleanup costs estimated on the order of $155 billion (U.S. Congress, 1991; U.S. Department of Energy, 1991). As the National Research Council (1989, p. 37) noted in its evaluation, "Virtually every facility in the weapons complex has some amount of environmental contamination within its boundaries while many also have some contamination outside the boundaries."

Models are transient, changing, readily abandoned. Radioactive contamination is, in human terms at least, permanent, and abandonment of aquifers or land are considerably more costly than subsequent abandonment of a model that turned out to be a mistake. Mistaken models can thus be extremely costly to the human enterprise and the environment in general.

Best Evidence: Has Radioactivity Migrated at Arid Sites?

It should be remembered that in the case at hand, the models and theory-based calculations are all designed to answer only one question: Can the radioactive materials proposed to be buried in unlined trenches at Ward Valley reach groundwater or the surface prior to having decayed away? The best evidence to answer that question is not the theoretical models advanced by facility proponents. Theories are, after all, merely hypothesis. Science is not the promulgation of theory – that is merely the first step. The core of science is the testing of hypothesis against hard evidence obtained from controlled experimentation.

The best evidence is thus, by definition, not theoretical models but actual data. The best data for the question at hand are those that indicate whether there has been, at arid LLRW sites, radioactive migration faster than predicted by the optimistic models of the Ward Valley project proponents. US Ecology (1990) has conceded that it has had troubles at its now-closed eastern LLRW sites involving radioactive contamination but asserts its facilities located in arid western sites (Richland, Washington, and Beatty, Nevada) have been free of such difficulties. The problems its facilities have experienced, US Ecology asserts, are due neither to its reliance on a design involving no containment (i.e., unlined trenches) nor its own track record, but rather location in humid climates (Kentucky and Illinois).

Furthermore, US Ecology has said that its Beatty site can be relied upon as an analog for Ward Valley; indeed, the company has used infiltration estimates from Beatty for its computer model for Ward Valley (License Application, Appendix, p. A-11 - A-12). Prudic (1994) has based his conclusion that it would take more than 50,000 years for radioactive material to migrate to a depth of 30 meters beneath the Ward Valley site on chloride mass balance calculations he has applied identically to both the Beatty and Ward Valley sites. The best evidence of whether he may be right would be to examine whether and how far radioactive material from the Beatty waste trenches has indeed migrated and compare that to his assertion, based on his chloride mass balance (CMB) calculations, that no movement of moisture has occurred beneath 10 meters for 15,000 years and that before that time the migration rate was only 0.2 centimeter per year (Prudic, 1994, p. 18). Evaluating actual radioactive migration at Beatty would be a good test of his even more dramatic assertions regarding the Ward Valley site, of migration rates of a mere 2-3 centimeters (cm) per 1,000 years (Prudic, 1994, p. 18).

The chloride mass balance technique utilized by Prudic is handicapped by the fundamental fact of chemistry that stable chloride is by definition *stable* (i.e., it does not decay, so its age cannot be determined by measuring how many half-lives have elapsed). A radioactive isotope, in contrast, in essence carries with it a clock by which its age can be directly measured.

Techniques based on stable chloride are further handicapped, because stable chlorine has been in existence since the earliest history of the earth, as opposed to artificial radionuclides whose existence or abundance is due to recent human activity, for example, nuclear weapons testing or wastes from nuclear reactors. Such artificial tracers carry an additional "clock" with them, as their time of origin is more or less known (e.g., 1945 or thereafter for A-bomb fallout, 1952 or thereafter for H-bomb fallout, 1962 or thereafter for wastes migrating from commercial LLRW sites). Reliance on such artificially-produced tracers makes direct estimates of travel times possible without resort to theoretical calculations highly dependent on input assumptions and the unproven validity of the model itself.[1]

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[1] It is for this reason that the tritium found beneath Ward Valley is of such significance. That tritium carries with it its own clock. Given the 12.3 year half-life of tritium, and pre-bomb tritium concentrations in precipitation that should be less than the 7 TUs currently measured there in atmosphere moisture, it must have taken something on the order of three half-lives, or ~35 years, to travel that distance. If the tritium is from bomb fallout, the same time period is at work, as the first thermonuclear bombs were detonated in the early 1950s, about 35 years before the tritium measurements were made at Ward Valley.

The simplest, and most important test of the assertions of project proponents thus would be to examine US Ecology's other arid sites as to whether there is any evidence of radionuclide migration at those facilities . Of course, those sites have been operating for only a relatively short time (~30 years) and the migration times of concern are far longer, given the longevity of many of the radionuclides buried. Thus, the absence of evidence of migration might not be determinative of the larger question, but its presence would be.

Evidence of Radionuclide Migration at Beatty

Depth to groundwater at US Ecology's Beatty site is 85 to 115 meters and mean annual precipitation is approximately the same at Beatty as at Ward Valley, 12.8 cm for the former and 11.7 cm for the latter (Prudic, 1994, p. 2). Prudic estimates that there has been no movement of water beneath 9 meters of the surface in 20,000 years and a downward percolation rate of 0.2 centimeters per year below that depth, although he asserts that that rate was probably only applicable about 20,000 years ago and current percolation rates would be even lower. Taking that rate as the current rate, however, it would take 35,000 years to travel 70 meters, the minimum depth to groundwater from the deepest Beatty waste trench, 15 meters deep [Conference of Radiation Control Program Directors (CRCPD), 1994, p. 4-8]. Clearly, if Prudic's CMB assumptions and calculations are correct, there should be absolutely no radioactive material from the Beatty waste trenches in groundwater at the site, at least not for another 35,000 years.

During his presentation before the NAS-NRC Ward Valley panel in July 1994, Prudic did not volunteer that there were groundwater contamination data from Beatty that called into question the model and calculations he was presenting. Upon repeated questioning by the panel, he eventually conceded that samples taken from a well drilled by USGS downgradient of the LLRW site were positive for tritium.

Well MR-3 was drilled in 1987 and sampled for the first and only time in August 1989, showing levels of 12.2 ± 1.9 and 6.4 ± 1.9 pCi/L (Prudic, 1993a; 1993b). This was part of a United States Geological Survey (USGS) program collecting data on groundwater quality near the Beatty LLRW site; six wells were sampled in 1989 (including the one that tested positive for tritium, well MR-3) and four separate wells were sampled in 1992 (Prudic, 1993b, p. [illegible]).

Prudic speculated (1993a, Table 4 - 1989) that the positive finding for tritium, which was confirmed by replicate analysis, might have been caused by remnant drilling fluid. This is unlikely, as he himself noted that more than 2,000 gallons of water had been pumped from the well immediately prior to sampling, and the sampling itself occurred two years after drilling. In addition, it is unclear why this problem would assertedly manifest itself only in this well, when there were other wells also monitored within 2 years of drilling (wells 600, 604, and W001).

The more reasonable interpretation that the tritium finding is valid is supported both by the fact that it was confirmed by replicate analysis and by noting the location of the well in which the tritium was found compared to those in which it was not found. Of the wells monitored by Prudic in his review, *only MR-3, the one in which tritium was found, was directly downgradient of the radioactive waste facility*. Eight were upgradient of the LLRW facility, and one (W001) was off to the side. Only MR-3 was downgradient of the LLRW site. (See map from Prudic, 1993a, on p. 7 of this report.)[2] If one were going to find radioactive contamination, it would be in MR-3, which is indeed precisely where it was found. The other wells, upgradient, serve as controls, demonstrating that the tritium found in MR-3 appears tied to the waste facility.

Upon repeated prodding by the NAS-NRC panel, Prudic conceded there was other evidence of radioactive contamination having reached groundwater at Beatty, in addition to his own measurements discussed above. After many years in which there were no monitoring wells, either on the LLRW site or downgradient from it, in 1982 US Ecology drilled two wells on the LLRW site itself, one (301) just inside the upgradient boundary and one (302) just inside the downgradient boundary (see map on p.7). From the time of the opening of the LLRW facility in 1962 until wells 301 and 302 were added, only the site supply well was monitored[3] (CRCPD, 1994, p. 4-15). The site well is in the buffer zone outside the LLRW facility boundary and upgradient of it (see map).

The very first sample taken from the new downgradient well (302) found extremely elevated tritium levels – 410,000 ± 10,000 pCi/L (Administrative Record, 1993, p. 123-00190 - 123-00191). This is more than 20 times the U.S. Environmental Protection Agency (EPA) Safe Drinking Water standard for tritium[4] (EPA, 1976, p. 155) and 200 times the Beatty facility's

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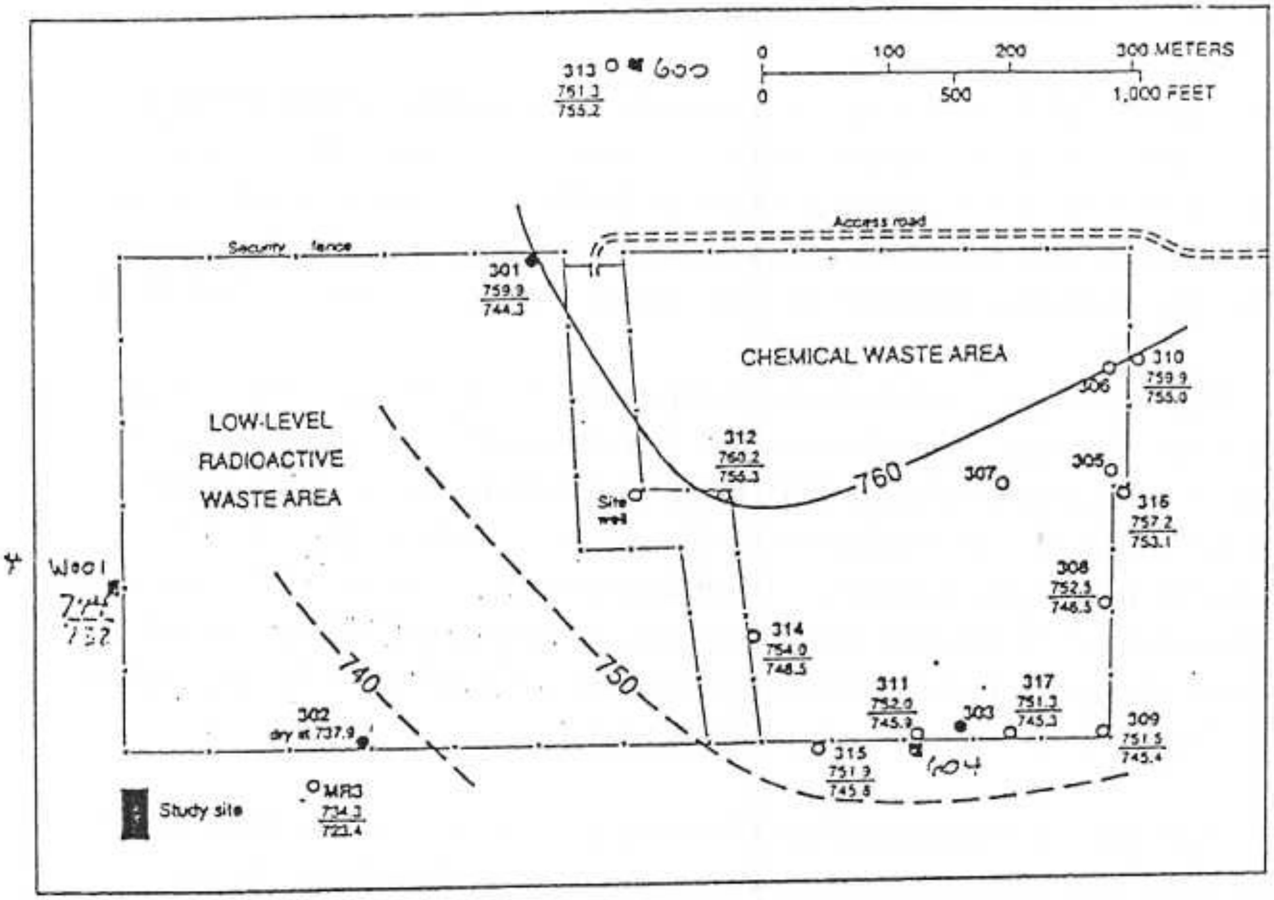
2 Prudic monitored the site well, and wells MW 313, 314, 315, 316, 600, 604, 311, W001, as well as MR-3. (Prudic, 1993a). It is difficult to understand the purpose of sampling wells almost all of which are upgradient of the facility one is attempt to monitor.

3 Again, it is difficult to comprehend how a LLRW facility could be effectively monitored for such a long period via only well, one that was not even on the LLRW site and which was upgradient of it.

4 A higher standard employed by the U.S. Nuclear Regulatory Commission for tritium in effluents from nuclear facilities (10 CF 20 Appendix B) is sometimes cited for comparison purposes, but the more restrictive EPA standard is controlling for concentrations in water supplies.



Base from US Ecology, Inc., 1990.

EXPLANATION

——750 — — GROUND-WATER LEVEL CONTOUR — Shows altitude of water levels as determined from monitoring wells. Contour interval is 10 meters. Dashed where approximately located. Datum is sea level

313 ○ 761.3 / 755.2 GROUND-WATER MONITORING WELL — Three-digit numbers and "MR3" are well identifications. Number above line is water-surface altitude, in meters, for December 1988. Number below line is well-bottom altitude, in meters. Datum is sea level. Water level at well MR3 measured by U.S. Geological Survey; all other wells measured by US Ecology, Inc.

FIGURE 3.--Waste-desposal areas showing location of monitoring wells and approximate altitude of ground-water levels in December 1988. Solid circles indicate wells for which geophysical logs are available.

New wells drilled during 1990, and water samples collected in December 1992.

Source: Prudic, 1993a
(handwritten note is from Prudic)

action level (CRCPD, 1994, p. 4-10). Tritium was also found in upgradient well 301, but in levels generally considerably lower than those found in the downgradient well. The discovery of tritium contamination via the opening of the new wells led to increased frequency of monitoring. Tritium continued to be found in the wells, at significant levels, month after month, although the concentration appeared to decline over the next two years. The data are reproduced in **Table 1**.

Prudic (1993b, p. 2) says that well 302 "reportedly" went dry in August 1983 and has been dry since that time, however it is clear from the data that measurements of groundwater continued through the end of January 1985, so if the well went dry, it would appear to have occurred after January 1985. Fischer (1992, p. 7) reports well 302 as dry in December 1988. In any case, the available data indicate elevated tritium in the downgradient well (302) for virtually all of the more than 2-year period, 1982 through 1985, for which data are available, as well as lower but still significant tritium levels in upgradient well 301 on half a dozen occasions during the 1 1/2 years for which measurements are available for it.

The California Department of Health Services (DHS) has dismissed the tritium findings, claiming they were "greater up-gradient than down-gradient," that the readings allegedly occurred only in 1983, and that "there was no recurrence" (DHS, 1993, p. 27). In particular, DHS has stated, "There has been no tritium detected in Beatty wells in 1991 or the recent past." As we have shown above, and will show in more detail below, each of these assertions is incorrect. The tritium findings were repeated samples, essentially monthly, from 1982 into the end of 1984. There is no evidence of subsequent measurements showing no tritium from 1985 on; in fact, Prudic and Fischer claim the downgradient well went dry, and when USGS put in a new well downgradient, quite near well 302, the only measurements from it, in 1989, were also positive for tritium. Furthermore, as shall be shown below, in addition to Prudic's measurement in well MR3 in 1989, other measurements at Beatty found elevated readings 100 times higher than Prudic's in 1989 and, in 1991 as well. Lastly, the well (302) with the very high tritium readings from 1982 through 1984 was downgradient, not upgradient as DHS asserted (see map, above), precisely where one would most expect elevated levels. The well downgradient from the LLRW trenches was an order of magnitude higher than the well on the upgradient portion of the facility, a clear indication that the contamination was indeed coming from the trenches. DHS does say that investigations by US Ecology and the State of Nevada were "not able to ascertain the specific cause" of the contamination (DHS, 1993, p. 27).

Table 1. Beatty, Nevada, Well Water Sampling Results

Well	Date Sampled	Tritium, pCi/L	Analyzer
301	* 6-28-82	0.0 ± 1,000	Eberline
	* 9-09-82	24,000 ± 1,000	Eberline
	* 10-26-82	< 1,000	Teledyne
	* 2-03-83	200 ± 70	Teledyne
	* 3-03-83	< 2,000	Teledyne
	3-30-83	< 200	EAL
	3-30-83	< 200	USGS
	4-07-83	< 200	USGS
	7-11-83	< 200	USGS
	7-11-83	< 220	EPA
	7-11-83	< 200	EAL
	8-02-83	0 ± 200	EAL
	8-22-83	500	CEP
	9-02-83	500	CEP
	9-30-83	500	CEP
	10-27-83	300 ± 200	EAL
	11-30-83	< 200	EAL
	12-21-83	0 ± 200	EAL
	1-26-84	0 ± 200	EAL
302	* 10-26-82	410,000 ± 10,000	Eberline
	* 2-03-83	48,900 ± 3,000	Teledyne
	* 3-03-83	65,200 ± 6,520	Teledyne
	3-11-83	50,100	EPA
	3-30-83	30,700	USGS
	3-30-83	31,000	USGS
	4-07-83	30,000	USGS
	5-03-83	46,700	EPA
	5-03-83	47,000 ± 2,000	EAL
	6-03-83	13,000 ± 600	EAL
	6-29-83	11,000 ± 600	EAL
	7-11-83	10,000	EAL
	7-11-83	18,200 ± 900	EAL
	8-02-83	13,200 ± 700	EAL
	8-22-83	< 500	CEP
	9-30-83	2,800 ± 750	CEP
	10-27-83	5,800 ± 300	EAL
	11-30-83	4,200 ± 200	EAL
	12-21-83	3,000 ± 300	EAL
	1-26-84	3,600 ± 200	EAL
	3-02-84	2,900 ± 100	EAL
	4-14-84	2,100 ± 200	EAL
	5-31-84	1,600 ± 200	EAL
	6-29-84	1,000 ± 200	EAL
	7-31-84	1,000 ± 200	EAL
	8-30-84	1,400 ± 200	EAL
	9-27-84	800 ± 200	EAL
	10-30-84	500 ± 200	EAL
	11-30-84	300 ± 200	EAL
	12-28-84	500 ± 200	EAL
	1-31-85	0 ± 200	EAL

* Samples collected and analyzed by US Ecology contractor. Rest of samples collected by State and analyzed by different agencies or contractors.

Source: Ward Valley Administrative Record, 123-00190 to 123-00191.

There have been suggestions that the contamination found in the groundwater during the 1982-1984 period may have been due to sabotage by a disgruntled employee. While this is not a particularly comforting an explanation – as sabotage is a mechanism for radionuclide transfer to and contamination of groundwater not considered in any environmental impact or safety review for either the Beatty or Ward Valley projects – the evidence makes such an explanation highly unlikely. First of all, as will be shown below, similar contamination was found in other wells before (in 1979 and 1980) and after (1985, 1989, and 1991) (CRCPD, 1994, p. 4-16; Prudic 1993a). Second, contamination was found in both the upgradient and downgradient wells, and far greater in the downgradient one. Third, the suggestion that well 302 was a dry hole and water strangely appeared in it for a time (Prudic, 1993b, p. 2), water that turned out to be contaminated, before becoming dry again, cannot explain the dropping *concentrations* of tritium in the well. The amount of water in the well could perhaps drop, if it was originally a dry hole and someone had poured contaminated water in it, but the *concentration* of tritium in that water should remain essentially constant over the two years of measurements. Prudic (1993b, p. 2-3) agrees that the drop in concentration eliminates the sabotage possibility as a reasonable explanation.

The 12.3 year half-life of tritium cannot explain the drop in concentration in Well 302 from 410,000 pCi/L on October 26, 1982, to 47,000 pCi/L in May 1983, not to 1,400 pCi/L in August 1984. Tritium leaking from particular degrading waste packages from the waste trenches, migrating down to groundwater, and then traveling downgradient in the aquifer *can* readily explain the data, and is in fact the only reasonable explanation. The data present a picture of a contamination front passing the monitoring well, with tailing concentrations traveling behind. Subsequent releases from the trenches can have the same effect, and the measurements of elevated tritium before and after the 1982-1984 findings paint the same picture – a leaking facility, with leachate reaching and contaminating the groundwater beneath it.

Indeed, despite US Ecology's efforts at the NAS-NRC Ward Valley panel meeting in June to explain the tritium findings away as potential sabotage, its monitoring reports for Beatty conclude that *the most probable cause for the presence of tritium in ground water is migration down to the ground water from the disposed waste* (CRCPD, p. 4-15 and 4-34, citing US Ecology's annual monitoring reports).

It may be argued by Ward Valley/Beatty defenders that the tritium somehow reached the groundwater 300 feet below the surface via gas phase migration and is not indicative of potential solute travel. It is essentially impossible to show a mechanism for gas phase migration that would result in tritium concentrations in groundwater 300 feet below, 20 years after the facility opened, resulting in levels of over 400,000 pCi/L. Furthermore, as will be discussed below, elevated gross alpha, gross beta, and cobalt-60 levels in groundwater demonstrate that the contamination is not just by tritium but by other radionuclides that cannot travel as a gas and must travel as a solute.

On November 21, 1984, the Nevada Department of Human Resources (State of Nevada, 1984) cited US Ecology for violating its license, in particular the requirement "that when the concentrations of radioactive material in water samples are found to be above action levels (30 picocuries per liter for alpha and 90 picocuries per liter for beta) the Division will be notified." The citation stated:

> Contrary to the above requirement, during this inspection it was learned that the company had been notified on October 18, 1984 of analyses of two water samples that had radioactive materials in concentrations above the action levels and the Division had not been notified.

A 1987 inspection report by the State of Nevada noted that wells 301 and 302 "have shown elevated levels of gross alpha and beta, and tritium in the past" (State of Nevada, 1987). The gross alpha and beta contamination indicate solute contamination. Tritium alone could be arguably vapor phase, but not elevated gross alpha and gross beta.[5]

Additional Monitoring Data, Showing Repeated Contamination at Beatty – Alpha, Beta, Cobalt-60 – in Groundwater, Unsaturated Zone Soil, and Offsite Vegetation

It is our understanding that the NAS-NRC Ward Valley panel, interested in learning whether there is any further evidence of migration of wastes from the US Ecology facility at Beatty, as a test of whether proffered models asserting no such migration could occur in arid zones, has requested from US Ecology and various regulatory bodies all such monitoring data. We understand little if any such data have as yet been received. Indeed, US Ecology asserted at the August meetings of the panel that all other monitoring data have shown no indication of any radioactivity and that they would provide all the data.

We have just received new data, dated October of this year, summarizing 30 years of monitoring at Beatty (CRCPD, 1994). The data compilation was issued by the Conference of

[5] Because of the very weak beta given off by tritium, and the analytic methods employed for gross beta scans, tritium is not included in gross beta readings and is measured and reported separately.

Radiation Control Program Directors, Inc., and prepared for it by the EG&G contractors at Idaho Falls, Idaho, who run the National Low Level Radioactive Waste Management Program for the Department of Energy.[6] CRCPD is the national organization of chiefs of state radiation protection programs. The new data demonstrate far more clearly than previous information presented to the NAS panel that radioactivity has migrated from the waste trenches at Beatty – into groundwater beneath the site (vertical migration), soil in dry wells downgradient from the site (lateral migration), and in vegetation (upward migration). The contaminants include tritium, cobalt-60, and gross alpha and gross beta contamination, demonstrating that liquid-phase solute transport is involved. The new data present a long and consistent pattern – not an isolated allegedly anomalous reading or two, as asserted by Prudic and US Ecology at the meetings of the NAS panel.

Table 2, summarizing groundwater monitoring data for gross alpha, gross beta, and tritium since Beatty opened, is taken from the CRCPD report, p. 4-16. For *eight* separate years, beginning as early as eight years after the facility first opened and continuing into the 1990s, gross alpha activity in groundwater beneath the site exceeded the Action Levels set by US Ecology and the State of Nevada, at times by more than a factor of 20. For *seven* separate years, gross beta in groundwater exceeded Action Levels, at times by an order of magnitude. Measurable tritium (in excess of 500 pCi/L) was found *8 out of the 13 years* for which there are data, ranging from 1,000 to 49,000 pCi/L.[7] By contrast, current tritium levels in rainfall are about 20-60 pCi/L. With tritium's 12.3 year half-life, no measurable tritium whatsoever should be showing up in groundwater, let alone at these high concentrations, whether from rainfall or leachate, if the Ward Valley proponents' were right that migration rates are on the order of thousands or tens of thousands of years. Whereas US Ecology and Prudic at the NAS meetings appeared to suggest there were just a couple of anomalous readings, the elevated tritium is showing up most years for which there are data. Despite suggestions of sabotage being the cause for the 1982-1984 readings, this report (p. 4-15 and 4-34), says US Ecology's own monitoring reports have attributed the tritium in groundwater to "migration from the disposed waste."

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[6] The report was prepared by the "E-5 Committee" of the Conference of Radiation Control Program Directors, Inc. The "E-5 Committee" is the Waste Management Oversight Committee.

[7] The authors of the CRCPD study (p. 4-15) reported the high tritium level found in 1982, 410,000 pCi/L ±10,000 pCi./L, in the text of their report but did not include it in their table on p. 4-16. Similarly, the highest 1983 reading reported in the Administrative Record table on p. 123-00190 is 65,200 ± 6520, higher than the value reported in the CRCPD report and with a far smaller error bar. The error margin given in the CRCPD report for the figure 49,000 ± 29,000 appears to be an error; the Administrative Record table gives the value as 48,999 ± 3,000. Likewise, the error margins reported in the Administrative Record table for 1984 are much smaller, e.g., 3,600 ± 300.

Table 2. Gross alpha, gross beta, and tritium activity in groundwater, Beatty LLRW facility, 1962-1992.

Year	Gross alpha[a] pCi/L	Gross beta[a] pCi/L	Tritium pCi/L
1962	3 ± 2	54 ± 4	no data
1963	no data	no data	no data
1964	8 ± 3	50 ± 26	no data
1965	20 ± 5	60 ± 31	no data
1966	10 ± 5	60 ± 34	no data
1967	10 ± 4	40 ± 28	no data
1968	14 ± 5	52 ± 3	no data
1969	6 ± 3	41 ± 41	no data
1970	→ **39 ± 7**	→ **94 ± 30**	no data
1971	no data	no data	no data
1972	10 ± 4	9 ± 4	no data
1973	→ **46 ± 7**	→ **549 ± 47**	no data
1974	16 ± 10	→ **132 ± 77**	no data
1975	→ **47 ± 9**	→ **173 ± 55**	no data
1976	12 ± 5	40 ± 32	no data
1977	< 3	<30	no data
1978	3 ± 2	<20	no data
1979	10 ± 5	<20	→ **3,800 ± 1,100**
1980	< 5	10 ± 4	•• **1,700 ± 900**
1981	21 ± 7	31 ± 4	0
1982	→ **710 ± 183**	→ **340 ± 49**	→ **24,000 ± 1,000**
1983	→ **140 ± 98**	→ **930 ± 150**	→ **49,000 ± 29,000**
1984	→ **63 ± 29**	→ **140 ± 24**	→ **5,000 ± 4,000**
1985	25 ± 18	26 ± 10	•• **1,100 ± 600**
1986	15 ± 9	14 ± 5	< 500
1987	no data	no data	no data
1988	→ **31 ± 11**	10 ± 3	< 500
1989	20 ± 14	30 ± 23	•• **1,548 ± 508**
1990	→ **78 ± 24**	63 ± 11	< 500
1991	10 ± 6	11 ± 5	•• **1,079 ± 551**
1992	7 ± 3	13 ± 3	< 500

Action Levels: gross alpha = 30.0 pCi/L; gross beta = 90.0 pCi/L; tritium = 2,000 pCi/L

a. Indicates highest value for each year.
→ Indicates Action Level exceeded. •• Indicates < Action Level but >1000 pCi/L H-3

Source: Conference of Radiation Control Program Directors, Inc., 1994, Environmental Monitoring Report for Commercial Low-Level Radioactive Waste Disposal Sites: Frankfort, KY, Conference of Radiation Control Program Directors, Inc., p. 4-16.

Vapor-phase migration is contradicted, both by the very high concentrations of tritium found in groundwater and by the evidence of migration of soluble radionuclides as shown by the repeated elevation of gross alpha and gross beta above action levels in groundwater. In addition, cobalt-60 was found in sediment in groundwater taken from one of the monitoring wells .[8] Cobalt-60 is an artificial isotope with a five-year half-life (in 50 to 100 years it decays to non-radioactive levels) and found in large amounts in low level radioactive waste, its presence is likewise indicative of migration of leachate to groundwater since the facility opened in 1962. Cobalt-60 has been found to migrate rapidly at other radioactive sites, particularly when in chelated form (Means and others, 1978, Killey and others, 1984).

In **Table 3**, we have reprinted the soil sample data, which, until 1984, were taken primarily from dry wells dug downgradient to monitor for possible lateral migration from the trenches (CRCPD, 1994, p. 4-21 - 3). These dry wells were normally located downgradient of the completed trenches and extended at least 10 feet below the established bottom of the trench. Two additional dry wells were located downgradient of the site itself. Note that for four years, gross alpha in the soil samples exceeded action levels. For six years, gross beta was in excess of action levels. This suggests lateral subsurface flow in the unsaturated zone, a matter raised by the Wilshire group regarding Ward Valley (Wilshire and others, 1993, p. 3-7).

In September 1984, the State of Nevada eliminated the requirement for soil sampling of the dry wells, in part because most of the soil had been removed from the dry wells during the years of sampling, leaving behind mainly rocks (CRCPD, 1994, p. 4-22). The fact that subsequent to that time, action levels for soil have not been violated would appear to be resulting primarily from the elimination of the requirement to continue sampling the dry wells where the previous violations of action levels had been detected.

In **Table 4**, the table for vegetation sampling is reproduced (CRCPD, 1994, p. 4-27). Gross beta limits were exceeded in vegetation in six different years.

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[8] The CRCPD report indicates that during some time after the very elevated tritium readings were found, at least during part of 1985 and perhaps parts of 1983 and/or 1984 (it is not clear from the text), gamma spectroscopy and fluoroscopy were performed on the suspended fraction (as opposed to dissolved fraction) taken from the water samples to attempt to ascertain contribution to gross alpha and gross beta levels resulting from naturally occurring radionuclides. Action levels were not exceeded in 1985. Furthermore, it is not clear that the artificial radionuclides of concern would be in the suspended fraction rather than the dissolved fraction. If rapid migration were resulting from chelation, the complexed radionuclides would be primarily in the dissolved fraction and thus missed. Additionally, gross alpha or gross beta levels would not fluctuate, year to year, from 10% of the Action Level to 10 times the Action Level, if the sole source of activity were naturally occurring radionuclides.

Table 3. Soil sample analysis – Beatty LLW Site.

Year	Gross alpha[a] pCi/gm	Gross beta[a] pCi/gm
1962	no data	no data
1963	no data	no data
1964	no data	no data
1965	1.9 ± 0.63	72 ± 4.4
1966	2.7 ± 1.2	73 ± 5.3
1967	1.7 ± 0.64	3.5 ± 0.34
1968	2.94 ± 0.41	5.03 ± 0.57
1969	9.5 ± 3.7	37 ± 4.1
1970	no data	no data
1971	8.9 ± 3.8	80 ± 4.9
1972	13 ± 5	→ **108 ± 32**
1973	6 ± 3	→ **110 ± 40**
1974	18.2 ± 8.2	→ **253.6 ± 111**
1975	→ **64 ± 15**	→ **614 ± 60**
1976	→ **42 ± 7.7**	→ **257 ± 28**
1977	20 ± 6.1	60 ± 24
1978	18 ± 6	60 ± 24
1979	→ **31 ± 13**	80 ± 3.1
1980	23 ± 6.1	→ **90 ± 16**
1981	→ **32 ± 9.8**	60 ± 15
1982	25 ± 6	66 ± 18
1983	24 ± 7	79 ± 4
1984	25 ± 7	52 ± 1.5
1985	16 ± 3	40 ± 17
1986	10.2 ± 1.6	9.6 ± 1.0
1987	1.3 ± 0.3	7.0 ± 0.8
1988	5.7 ± 1.1	6.6 ± 0.9
1989	9.3 ± 2.5 (wet)	21.5 ± 1.3 (wet)
1990	12.8 ± 3 (dry)	51.5 ± 7 (dry)
1991	3.5 ± 1.0 (dry)	22.0 ± 1.3 (dry)
1992	5.4 ± 2.7 (dry)	28.4 ± 2.3 (dry)

Action Levels: gross alpha = 30.0 pCi/gm; gross beta = 90.0 pCi/gm

a. Indicates highest value for each year. → Indicates Action Level exceeded.

Source: CRCPD, 1994, p. 4-23

Table 4. Vegetation sample analysis – Beatty LLW Site.

Year	Gross alpha[a] pCi/gm	Gross beta[a] pCi/gm
1962	0.73 ± 0.32	→ **126 ± 3.1**
1963	no data	no data
1964	no data	no data
1965	0.13 ± 0.04	21 ± 0.5
1966	0.9 ± 0.45	→ **110 ± 5.4**
1967	0.39 ± 0.22	8.0 ± 0.4
1968	0.16 ± 0.04	13.3 ± 0.2
1969	0.17 ± 0.12	31.3 ± 0.27
1970	no data	no data
1971	0.19 ± 0.16	2.8 ± 0.3
1972	1.4 ± 1.0	→ **722 ± 35**
1973	0.36 ± 0.32	27.2 ± 3
1974	3.8 ± 4.1	→ **420 ± 110**
1975	3.49 ± 2.2	→ **146 ± 30**
1976	9 ± 3	→ **220 ± 20**
1977	0.3 ± 0.006	39.6 ± 14.5
1978	0.7 ± 0.03	36.9 ± 9
1979	0.7 ± 0.6	29.3 ± 4.2
1980	2.4 ± 1	50 ± 5.1
1981	9 ± 4	17.6 ± 1.4
1982	2.4 ± 2	30 ± 4.9
1983	6 ± 3	55.7 ± 4.9
1984	6.3 ± 1.8	15.5 ± 2.3
1985	7.2 ± 1.3	16 ± 1
1986	0.8 ± 0.2	5.8 ± 0.2
1987	5.3 ± 2.7	77.6 ± 2.5
1988	3.2 ± 0.4	10 ± 0.3
1989	0.6 ± 0.2 (dry)	65.5 ± 8.1 (dry)
1990	3.1 ± 2.4 (dry)	16.3 ± 3.6 (dry)
1991	0.5 ± 0.2 (dry)	5.9 ± 0.3 (dry)
1992	11.4 ± 2.3 (dry)	48.9 ± 2.8 (dry)

Action Levels: gross alpha = 30.0 pCi/gm; gross beta = 90.0 pCi/gm

a. Indicates highest value for each year. → Indicates Action Level exceeded.

Source: Conference of Radiation Control Program Directors, Inc., 1994, Environmental Monitoring Report for Commercial Low-Level Radioactive Waste Disposal Sites: Frankfort, KY: Conference of Radiation Control Program Directors, Inc., p. 4-27

Table 5 reproduces tritium readings for vegetation for one time period, March 1982, taken from outside the facility boundary (CRCPD, 1994, page 4-30). The readings are extraordinary – up to 1000 pCi/ml. (These readings are questioned in the report as "not readily explained." Split samples with the State of Nevada resulted in widely divergent readings, with US Ecology saying they may possibly be related to chemiluminescence.)

Table 5. Tritium and gamma spectroscopy analysis of vegetation samples (March 1982).[a]

Location	Analysis	Concentration
200 ft. southeast of south fence in dry wash	H-3	34 ± 2 pCi/ml
	Cs-137	1 ± 0.4 pCi/gm
240 ft. southeast of south fence in dry wash	H-3	1,000 ± 100 pCi/ml
	Cs-137	1.5 ± 0.6 pCi/gm
300 ft. southeast of south fence in dry wash	H-3	630 ± 10 pCi/ml
	Cs-137	1.4 ± 0.5 pCi/gm
400 ft. southeast of south fence in dry wash	H-3	340 ± 10 pCi/ml
	Cs-137	0.9 ± 0.5 pCi/gm
320 ft. south of south fence, NE	H-3	60 pCi/ml
	Cs-137	0.8 ± 0.3 pCi/gm
320 ft. south of south fence, SE	H-3	170 ± 10 pCi/ml
	Cs-137	1.5 ± 0.4 pCi/gm
320 ft. south of south fence, SW	H-3	15 ± 1 pCi/ml
	Cs-137	0.5 ± 0.3 pCi/gm
320 ft. south of south fence, NW	H-3	11 ± 1 pCi/ml
	Cs-137	1.3 ± 0.4 pCi/gm

a. Data for other years are not available.

Source: Conference of Radiation Control Program Directors, Inc., 1994, Environmental Monitoring Report for Commercial Low-Level Radioactive Waste Disposal Sites: Frankfort, KY: Conference of Radiation Control Program Directors, Inc.

Lastly, even the direct gamma exposures measured by thermoluminescent dosimeters (TLDs) above the surface at the site fenceline are remarkable, measuring up to 1,140 mrem per quarter, or about forty times background (CRCPD, 1994, p. 4-31).

Discussion

When Prudic gave his presentation to the NAS-NRC Ward Valley panel about Beatty and his models supposedly demonstrating that no migration of radionuclides was possible at the site – and by implication, any similarly arid site – it was unfortunate that he did not volunteer the best possible data for assessing his assertions, actual measurements of leachate reaching groundwater. Similarly, it is unfortunate that his recent paper on the subject (Prudic, 1994) is likewise silent on the subject and that he hasn't published his own findings of tritium in groundwater at Beatty. Even when the NAS-NRC panel tried diplomatically to extract from him information about such data, he was reluctant to disclose it. Unfortunately, these data now appear to be but the tip of the iceberg.

It now appears that there is ample evidence of radionuclide migration from the US Ecology trenches at Beatty to groundwater 300 feet below, migration that must be in the liquid phase. This contradicts the claims of Ward Valley proponents, including Prudic, that water basically does not move in the vadose zone in arid locations, and raises very serious questions about his theoretical chloride mass balance calculations, based on idealized model assumptions (e.g., pure piston flow, uniform and well-known chloride deposition rates over long times). Prudic's chloride paper (1994) asserts moisture movement at Beatty of only a millimeter per year and even less than that at Ward Valley, purportedly taking tens of thousands of years to travel 10 meters – yet radioactive waste has reached groundwater at Beatty, 100 meters below the surface, within ten years of the facility opening.

Theoretical models have their place, but it is data that matters. Models are merely to help us assess whether radioactive material can migrate at appreciable rates in conditions of arid climates. The best possible answer to that question would be not models, but actual measurements of whether radioactive materials *have* reached groundwater. The Beatty radiological monitoring data make clear not only that it *can* happen, but that it already *has* happened.[9] In science, Theory must defer to Fact.

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9 A discussion of new evidence about contamination at US Ecology's Richland LLRW site is found in Appendix A.

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APPENDIX A

NEW EVIDENCE OF CONTAMINATION OF THE VADOSE ZONE AT THE US ECOLOGY LLRW SITE IN RICHLAND, WASHINGTON

We have recently obtained data showing elevated tritium levels (~400,000 pCi/L) in soil pore water from the vadose zone beneath US Ecology's Richland LLRW facility, strongly suggesting rapid migration in that arid site as well. Claims have repeatedly been made about Richland, similar to the claims regarding Beatty and Ward Valley, that because average annual pan evaporation potential so exceeds average annual precipitation (~6 inches at Richland), there is essentially no infiltration and recharge at the site. Those claims are in similar jeopardy as a result of vadose zone monitoring just completed.

In November 1991, US Ecology installed three wells into the unsaturated zone at its LLRW facility at Richland, located in the semi-arid region of eastern Washington State, as part of a two-year research project conducted at the request of the Washington State Department of Health. Vadose Well (VW) #101 was installed in the vicinity of waste trenches 4 and 5, and VW-102 was placed near trenches 10 and 11A. A background well (VW-100) was placed away from the disposal areas in the northwest corner of the site. A map identifying the locations of the two monitoring vadose wells and of the background control vadose well follows, as well as a completion log for VW-100 (US Ecology, 1994a). The wells extended approximately 85 feet below the surface. Silica gel packs were placed in a perforated cylinder into the bottom of the well to absorb water vapor present in the vadose zone; the vadose well was then sealed off at about the 45 foot depth (US Ecology, 1994a, p. 3; US Ecology 1994b, p. 5-141). (Potential contamination from atmospheric moisture would not be a concern, as the monitored tritium levels in the vadose wells were on the order of 400,000 pCi/L, about four orders of magnitude higher than tritium in atmospheric moisture.) Silica gel packs were replaced quarterly and the accumulated soil moisture was then monitored for tritium. Results for 1993 are reproduced in **Table A-1** from US Ecology (1994b).

The reader will readily see that tritium concentrations in the vadose zone beneath the waste trenches range as high as 4.5×10^{-4} µCi/cc (450,000 pCi/L), over 20 times the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Level. The concentrations found in the vadose zone near the burial locations average three orders of magnitude higher than at the control/background location (see **Figures A-1** and **A-2**). The control location, located about

600 feet farther from the burial trenches than the locations where the elevated tritium was found, is nonetheless still in the middle of the U.S. Department of Energy (DOE) Hanford Reservation. Therefore, the contamination found in the vadose zone near the US Ecology burial locations cannot be coming from other operations at Hanford but must be coming from the US Ecology waste trenches.

The vadose zone monitoring program was initiated at the request of the Washington Department of Health in part to verify markedly elevated tritium readings in vegetation at the US Ecology site, in particular in vegetation growing on the trench caps. The State of Washington concluded, after reviewing the vadose zone data and the vegetation data, that "there was a correlation between the two" (Washington, 1993, p. 46). Thus, there is strong evidence that tritium is migrating in substantial quantities both upwards to the surface and downward in the vadose zone fairly deep below the waste trenches.

TABLE A-1. 1993 Vadose Zone Monitoring Results From US Ecology Richland, Washington, LLRW Site.

Vadose Zone Tritium Measurements
(Units of µCi/cc)

Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Average
VW#100	1.44 ± 0.13 E-6	-2.23 ± 9.51 E-8	9.19 ± 9.39 E-8	3.77 ± 9.58 E-8	3.87 ± 2.10 E-7
VW#101	2.03 ± 0.01 E-4	2.14 ± 0.01 E-4	2.16 ± 0.01 E-4	2.39 ± 0.01 E-4	2.18 ± 0.01 E-4
VW#102	4.50 ± 0.02 E-4	4.22 ± 0.02 E-4	4.22 ± 0.01 E-4	4.05 ± 0.01 E-4	4.25 ± 0.02 E-4

Source: Palmer, A.J., and Ledoux, M.R., 1994, Annual Environmental Monitoring Report for Calendar Year 1993: US Ecology Richland, Washington Low-Level Radioactive Waste Disposal Facility: Richland, WA, US Ecology.

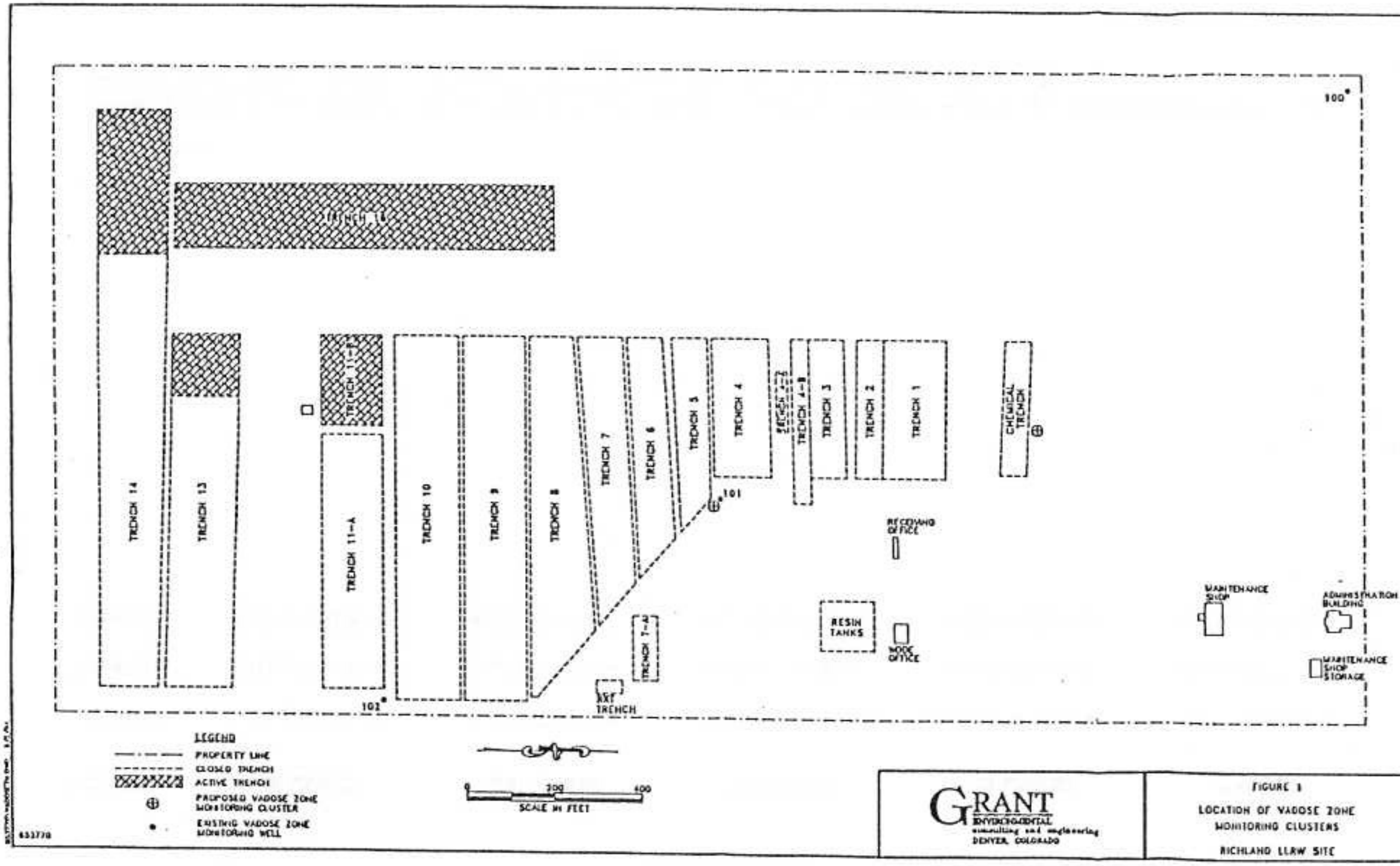

Figure A-1. Map of US Ecology Richland, Washington, LLRW facility.

MONITORING WELL COMPLETION LOG

WELL NO. VW 100

COORDINATES
NORTH: 442101.46 EAST: 2236323.45

GND ELEV:
TOC ELEV: 746.04
PROT CSG ELEV:

BEGIN DRILL: 11/ 6/91
COMPLETED: 11/ /91

CLIENT: US ECOLOGY
SITE: RICHLAND, WASHINGTON

LITHOLOGIC DESCRIPTION	DEPTH, FT	GRAPHIC LOG
	0	
	10	
	20	
	30	
	40	
TAN POORLY GRADED SILTY SAND, ANGULAR TO SUBANGULAR PARTICLES. MC= 2.34% SPT= 15-41-50 (5") SP-SM.		
	50	
GRAY POORLY GRADED SILTY SAND, ANGULAR TO SUBANGULAR PARTICLES. MC= 1.57% SPT= 8-32-50 (4") SP-SM.		
SAME AS ABOVE, MC= 1.65% SPT= 8-23-50 (4")		
	60	
TAN POORLY GRADED SILTY SAND, ANGULAR TO SUBANGULAR PARTICLES. MC= 1.64% SPT= 14-31-42-50 (3") SP-SM.		
SAME AS ABOVE, MC= 3.22% SPT= 34-48-50 (1")		
	70	
SAME AS ABOVE, MC= 2.25% SPT= 8-49-50 (3") SP-SM.		
TAN POORLY GRADED SILTY SAND, ANGULAR TO SUBANGULAR PARTICLES. MC= 2.29% SPT= 11-49-50 (2") SP		
	80	
TAN POORLY GRADED SILTY SAND, ANGULAR TO SUBANGULAR PARTICLES. MC= 2.22% SPT= 3-48-50 (1") SP.		
	90	

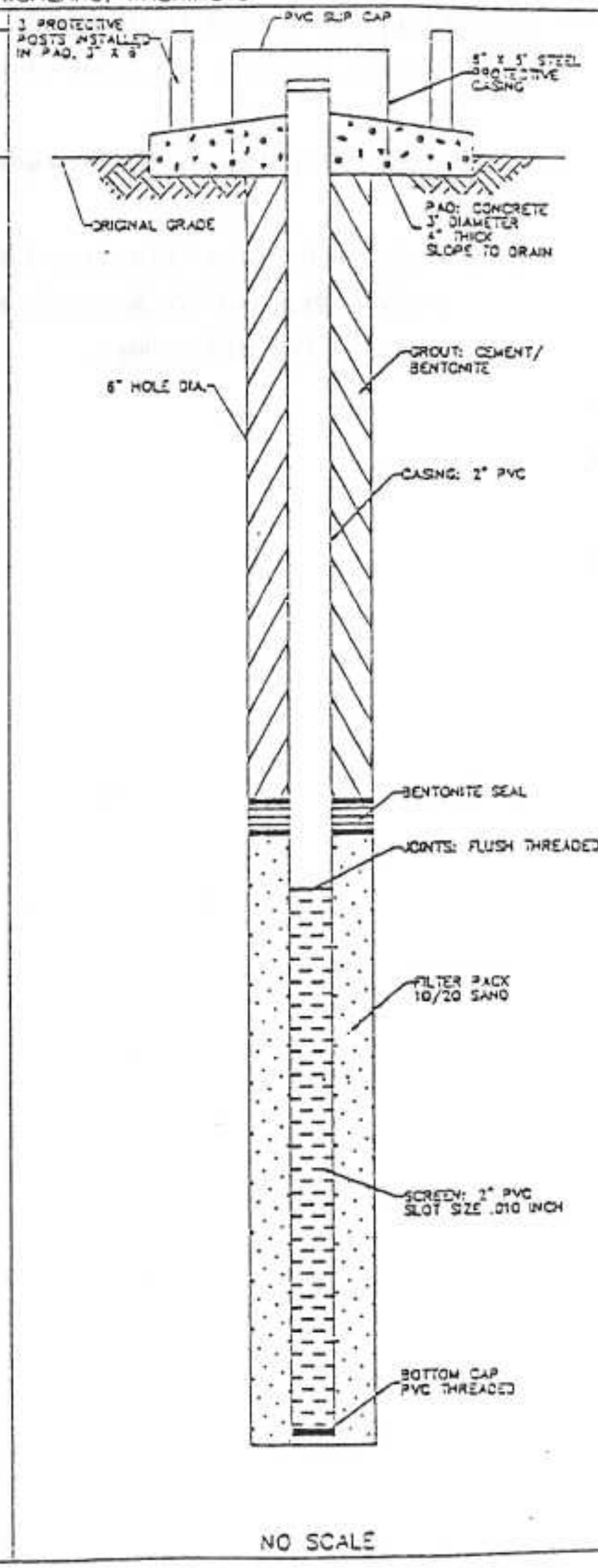

Figure A-2. Vadose zone monitoring well log.

References - Appendix A

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