EPRI Takes on Low-Level Waste Disposal Issues

By Phung Tran and David James

Since late 2006, EPRI has been investigating alternatives to the current criteria for low-level waste disposal classification.

When it was announced that the Barnwell waste disposal facility would finally close its doors to out-of-compact waste at the end of June 2008, the Electric Power Research Institute (EPRI) began steps to help affected nuclear power plants prepare for this eventuality. These steps included technical developments aimed at revisiting issues surrounding storage of low-level waste at plant sites to assure safe, viable long-term storage and reexamining the regulatory framework for LLW disposal classification criteria to promote more cost-effective waste disposal options, as well as reducing volumes of Class B and C waste through process improvements. Specifically, the U.S. Nuclear Regulatory Commission, in response to the Low Level Waste Policy Act of 1980 (LLWPA), introduced "Licensing Requirements for Land Disposal of Radioactive Waste," *Code of Federal Regulations* (CFR) Title 10, Part 61. This set of regulations defined generic disposal requirements for regional disposal facilities anticipated in the act. Included in the disposal requirements was a classification scheme in which wastes would be disposed of with increasing protection requirements depending on activity concentrations. These were defined as follows: Class A, requiring minimum protection; Class B, requiring stabilization in addition to the minimum protection requirements; and Class C, requiring intruder protection in the form of deeper disposal.

At the time that the LLWPA was enacted in 1980, there were three operating commercial LLW disposal facilities. These were the Barnwell, S.C., disposal facility operated by Chem-Nuclear Systems Inc.; the Richland, Wash., disposal facility operated by US Ecology Inc; and the Beatty, Nev., disposal site, also operated by US Ecology. The LLWPA called for the replacement of these sites with new regional disposal sites by 1986. There was little progress initially to site new facilities, however, so Congress amended the act in 1985 to extend the operation of the existing sites until 1992 and establish milestones and penalties for the states as an incentive to complete the process.

The LLWPA as amended was not entirely successful, and no new LLW disposal sites have been established within the framework of the LLWPA. The disposal site in Beatty, Nev., was closed in January 1992 in accordance with the timetable set by the LLWPA Amendments. The Richland disposal site has remained open under the control of the Northwest Compact but is restricted to receiving LLW generated only within the states included in the Northwest and Rocky Mountain Compacts, thus currently serving only one of the nation's 104 operating nuclear power plant units. The Barnwell site also closed in 1992, but the state of South Carolina reopened the site about six months later and allowed disposal of LLW from other regions. For the last 16 years, the Barnwell disposal facility has been the only venue in the United States that provides full service disposal of LLW open to all generators.

The EnergySolutions disposal facility at Clive, Utah, opened up to Class A wastes in 2001. The site originally opened in 1988 to receive waste derived from uranium mill tailings. The first new licensed low-level radioactive waste (LLRW) disposal facility since the Barnwell site received its license in 1974, the facility developed privately outside the compact process defined in the LLWPA. The increasing volume restrictions at Barnwell, along with the lack of progress in developing new sites by the regional compacts, left a large opening for private development. While licensed by the NRC to receive all classes of LLW, the Clive facility is allowed by its State of Utah license to receive only Part 61 Class A wastes. No accommodation for disposal of Part 61 Class B and C wastes will be available after Barnwell closes.

An additional LLW disposal site anticipated to be licensed within the next year is the Waste Control Special-

Table 1 EIS Exposure Scenarios	
Accident	An accident is assumed to occur during burial site operation, which results in a release of airborne particulate contamination. Such accidents could include a fire or container rupture.
Intruder construction	A person is assumed to intrude into the site during the surveillance period and construct a house or small building. During the construction activity, the intruder is exposed to direct radiation from the waste as well as airborne particulate radiation caused by excavation in the facility.
Intruder agriculture	A person is assumed to intrude into the site for agricultural purposes. In this scenario, the intruder is subject to direct radiation and exposure by inhalation, as well as exposure from ingesting food grown on the site.
Leaching and migration with well access	In this long-term exposure scenario, it is assumed that the radioactivity in the site is transported to an aquifer, and a well drawing water from the aquifer is used for drinking water and crop irrigation. Exposures are derived from ingestion of the water and food grown from the irrigated crops, along with direct and inhalation exposures.
Leaching and migration with open-water access	This scenario is very similar to the case with well access except that an additional dose pathway is concluded for ingestion of fish.
Surface transport of exposed waste	It is assumed that the trench cap has eroded or collapsed, leaving the waste exposed. Runoff from the site carries contamination into surface waters. Dose pathways are identical to the case of leaching and migration.
Atmospheric transport of exposed waste	Supposing that waste has become exposed, particulate matter is carried by the wind to cause human exposure. In this case, the dose pathways are similar to the accident case except that exposures are assumed to be chronic rather than acute.
Intruder drilling	A well is drilled down through the waste material, and the contaminated soil is brought to the surface, where it could result in exposures to the driller's helper and individuals residing near the mud pit.

ists (WCS) disposal site near Andrews, Tex. This site, which was privately developed as a hazardous-waste site, had independently applied for a license to operate as an LLW disposal site. When efforts by the state of Texas to promote an alternative site were abandoned, the WCS site was adopted by the state as the alternative compact site. When the site is licensed, it will be available only to Texas generators, along with those from its compact partner, Vermont.

The EPRI LLW Disposal Classification initiative began with the simple observation that the regulatory criteria provided in 10 CFR 61 had been developed almost 30 years ago as a generic licensing basis for regional disposal facilities. The NRC was directed under the LLWPA to develop these criteria and based them on knowledge, technology, and practices in use at the time. Since then, no new facilities have evolved from this act, and current disposal practices utilized at the current operating sites provide more stringent protective barriers than originally envisioned in the Environmental Impact Statement (EIS) for 10 CFR 61. EPRI, working with the Nuclear Energy Institute (NEI), determined that a thorough review of the bases for 10 CFR 61 and other guidance governing LLW disposal was warranted so as to pursue and encourage more cost-effective waste disposal options.

Initial Investigation

Since late 2006, EPRI has been investigating alternatives to the current U.S. disposal classification criteria, which are governed by 10 CFR 61. Along with the regulations, the NRC provided interpretative guidance for complying with the regulation through LLW branch technical positions (BTPs). EPRI performed a review of the original EIS on 10 CFR 61 ("Licensing Requirements for Land Disposal of Radioactive Waste," Draft EIS on 10 CFR 61, NUREG-0782, Sept. 1981) to gain a deeper understanding of the technical bases and concentration limits included in the regulation. Table 1 lists exposure scenarios examined in the EIS.

While all of the scenarios are important for establishing the overall safety of the disposal site, the prospect of an inadvertent intruder circumventing the protective measures built into the disposal technology presented the most restrictive protection basis. The concentration limits defined in 10 CFR 61 were developed on the basis of the intruder-agriculture and intruder-construction exposure scenarios. It was assumed in the evaluations that the disposal technology in vogue at the time (i.e., unstabilized waste with 2 meters of cover) was a reasonable basis for creating the intruder scenarios. The radiation ex-

posures were calculated on the basis of average concentrations with the premise that the waste would not be distinguishable from normal soil. The intruder would presumably excavate a quantity of the waste to construct a personal residence and plant a garden in the excavated waste that would be mixed with soil from the trench cap during the excavation. Although not specifically evaluated in the EIS, if the waste could be distinguished from soil, it would represent a deterrent from further excavation and limit the intruder exposure. No particular attention was given in the EIS to distribution of activity in the waste stream. It was assumed in the development of this criterion that the activity was uniformly distributed through the waste at the concentration limit. Variations from this hypothesis generally resulted in reducing intruder exposures. Specific scenarios applicable to each of the radionuclides with 10 CFR 61 concentration limits are listed in Table 2.

Table 2
Basis for 10 CFR 61 Limits

Radionuclide	Scenario	Dose Pathway
Process Wastes		
H-3	Intruder-Agriculture	Food Uptake
C-14	Intruder-Agriculture	Food Uptake
I-129	Intruder-Agriculture	Food/Inhalation
All transuranics	Intruder-Construction	Inhalation
Co-60	Intruder-Agriculture	Direct Gamma
Ni-63	Intruder-Agriculture	Food Uptake
Sr-90	Intruder-Agriculture	Food Uptake
Cs-137	Intruder-Agriculture	Direct Gamma
Activated Metals		
Ni-59	Intruder-Agriculture	Direct Gamma
Ni-63	Intruder-Agriculture	Food Uptake
Nb-94	Intruder-Agriculture	Direct Gamma
C-14	Intruder-Agriculture	Food Uptake

The EIS identified LLW in its entirety as being suitable for near-surface disposal. Subsequent concentration limits defined in 10 CFR 61, however, in addition to the averaging constraints of the BTP, combine to partition this broad category into subclassification schemes (i.e., Class A, Class B, and Class C). An unintended consequence of this partitioning is that states may choose to license sites by class, thereby orphaning some portion of the stream.

Prior to the development of the BTP on concentration averaging, NRC positions related to 10 CFR 61 did not specifically constrain averaging. The 1983 BTP on classification allowed averaging of nuclide concentrations over volume for radionuclides whose concentration limit was defined in curies per cubic meter or averaging over weight for radionuclides whose concentration limit was defined in nanocuries per gram. The development of the "averaging" BTP was prompted in part by the NRC's concerns related to loss of control of discrete high-activity items, as witnessed in Brazil in 1987. Fundamentally, the BTP constrains averaging of discrete waste streams to a factor of 10 above and below the average (factor of 1.5 for "key-gamma" radionuclides). Because the difference between Class A and Class C disposal for long-lived radionuclides is also a factor of 10, the BTP limits the extent to which Class C waste could be averaged with Class A waste. The BTP forces the exclusion of lower activity materials from the averaging calculation for the determination of waste classes. This results in fewer Class A packages and more Class B and C packages. The BTP constraints on averaging obviate the benefit that distribution of activity and dispersal in the disposal environment would have on the average concentration in the disposal site and therefore on exposures to the inadvertent intruder.

Averaging over anything less than the disposal package is probably not justified on the basis of the way in which the exposure scenarios were constructed. To reach the intruder dose scenarios, it has to be assumed that the radioactivity is in a form that is indistinguishable from the soil and that it is completely dispersed in the local zone. The intruder protection basis was determined from the total excavated volume. The actual dose to the intruder is independent of the distribution of activity in the excavated material because the probability of being in proximity to any volume increment would be the same. An early study (V. C. Rogers, "The Siting and System Performance of Low-Level Waste Disposal Facilities," Waste Management 1982, Tucson, Ariz.; RAE Report to EPRI, RAE-7-3, July 1981) performed in the time frame of development of 10 CFR 61 recognized that for long-lived radionuclides ultimate protections of the general public were achieved principally by dilution as a barrier for ultimate exposure. Therefore, concentrating the radioactivity into a smaller volume may actually be contrary to the objective of maximum public protection. Furthermore, disposal economic trends over several decades indicate minimal to nonexistent economic advantages in disposal facility fees for concentrating waste activity.

As a result of the preliminary investigation, EPRI identified two regulatory initiatives. The first was to revise the BTP to allow broader blending of compatible waste types. The second was to amend 10 CFR 61.55 to allow for an alternative disposal criterion based on site-specific hydrogeological characteristics and end land use scenarios. For example, isotopes whose concentrations are governed by the food uptake pathway for facilities located on nonarable sites should be exempted in the calculation to determine classification at that site. If there is no viable

mechanism for agriculture, the scenario should be excluded from consideration. It may become necessary in the future to completely revise the LLW classification scheme in 10 CFR 61 to better reflect modern disposal technology and updated science on health impacts from radiation exposure and to provide more alignment with international disposal standards.

Understanding the Industry LLRW Source Term

Work subsequently undertaken by EPRI and the NEI focused on developing a better understanding of the LLW source term from nuclear power plants and examining how the BTP averaging constraints impact disposal options. In 2007, EPRI gathered data from operating nuclear power facilities on volumes and activities of waste shipped. Data were primarily gathered from plant shipping records. A total of 42 facilities, representing 65 out of 100 operating nuclear power plant units, responded to the survey. The data included volumes, weights, radioactivity breakdowns by radionuclide, disposal date, disposal stream, and waste classification. A total of 10 000 package records were collected covering the period from January 2003 through March 2007. Disposal streams were identified in accordance with the NRC categories defined for the Manifest Information Management System ("Instructions for Completing NRC's Uniform Low-Level Radioactive Waste Manifest," Rev. 2, NUREG/BR-0204, July 1998; see also http://mims.apps.em.doe.gov/). For evaluation purposes, the streams were consolidated into four groups, including homogeneous wastes (comprising resins, charcoal, and other filter media), mechanical filters, dry active waste (DAW), and activated metals. Activated metals, which accounted for approximately 85 percent of the total activity of wastes, were not specifically considered in the averaging scenarios. (Classification of activated metals is controlled primarily by short-lived radionuclides. Disposal of irradiated components, while generally suitable for near-surface disposal, should be evaluated on a case-by-case basis for the disposal site in question.) A breakdown of the volumes of the remaining wastes is shown in Fig. 1. Overall, the industry generates about 1 million cubic feet of these types of wastes per year, with the volume evenly split between the two dominant plant types. Boiling water reactors (BWRs), on average, generate about 50 percent more volume per unit. DAW constitutes about 90 percent of the volume, resins about 9 percent.

The corresponding distribution by activity is shown in Fig. 2. While resins and filters constitute only about 10 percent of the volume, they account for more than 99 percent of the activity. Again, excluding activated metals, the industry generates about 28 000 Ci per year, with BWRs contributing about 18 000 Ci and pressurized water reactors the remaining 10 000 Ci. BWRs per unit generate about four times as much activity.

Based on the survey, Class A wastes account for almost 99 percent of the total volume of wastes. This leaves a total volume of Class B and C waste of approximately 15 000 ft^3 per year—the equivalent of one large liner per plant unit. A chart showing the volume distribution by classification is shown in Fig. 3.

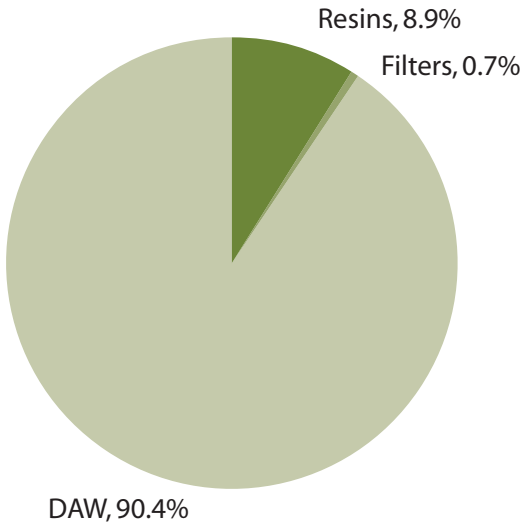

Fig. 1. Process waste distribution by volume.

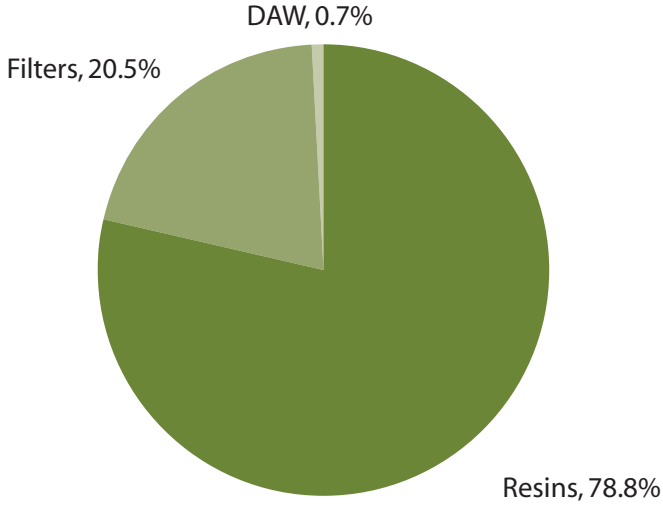

Fig. 2. Process waste distribution by activity.

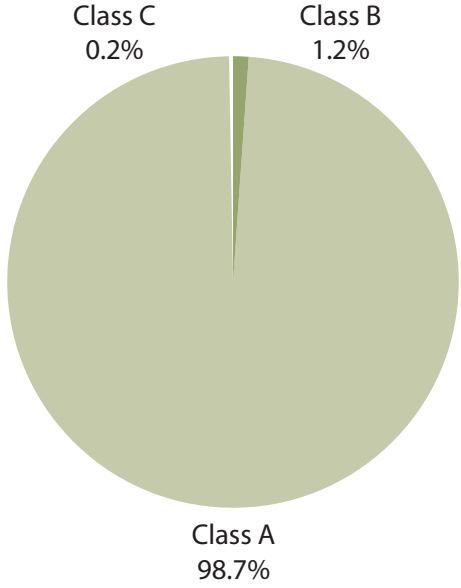

Fig. 3. Volume distribution by classification.

Figure 4 focuses again on activity distribution by classification. Class A wastes account for about 35 percent of the total activity. Class B wastes account for more than half. Surprisingly, the total reported activity in Class C wastes is less than that of the Class A wastes. In the case of the Class B wastes, classification is driven by the short-lived radionuclides, in particular Cs-137 and Ni-63. In the case of Class B wastes, it is also true that concentrations of long-lived radionuclides are below the Class A limits.

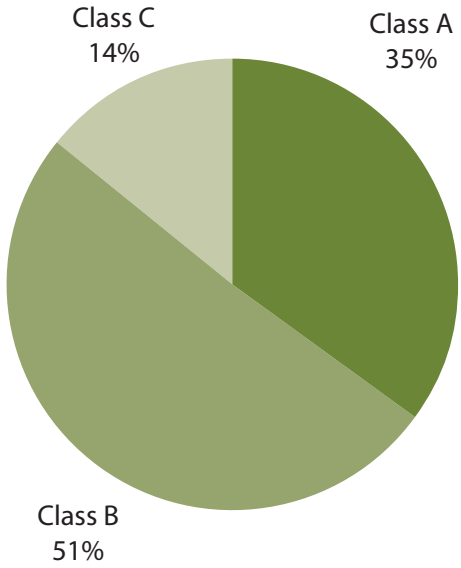

Fig. 4. Activity distribution by classification.

Implications of a Broader Averaging Approach

If we look at the overall classification of the waste tabulated in the EPRI survey, the weighted average classification basis is about 10 percent of the Class A limit for Part 61 Table 2 and only about 1.4 percent of the Class A limit for Part 61 Table 1. Assuming that a representative collection of this material is placed in the disposal site, all of the public protection parameters would be met. This scenario assumes averaging over all of the wastes without consideration of stream or who would generate it. Because this waste, in bulk, meets Class A limits and would be eligible for Class A disposal as defined in 10 CFR 61, the streams themselves could be treated as Class A by definition.

If a more modest approach is followed, however, in which the generation is evaluated on the basis of individual streams, this "streamwide" averaging is limited to a factor of 10, and the allowed averaging volume is 152 m^3 as defined in the EIS intruder-construction scenario, the majority of the waste in each waste stream would still qualify for Class A disposal. This type of averaging approach would assume that waste packages would be placed contiguously in the disposal site through a coordinated shipping campaign to assure that Class A limits were maintained in the disposal site during the process. Alternatively, the averaging could be achieved through processing to assure that concentration limits are met at the package level. Figure 5 shows the cumulative classification for ion exchange resins generated over a four-year period and constrained by BTP averaging discussed previously. This stream accounts for around 80 percent of the activity in the process wastes. Following the BTP averaging criteria, the minimum activity included in the averaging calculation cannot be more than a factor of 10 lower than the average activity. In addition, the average activity

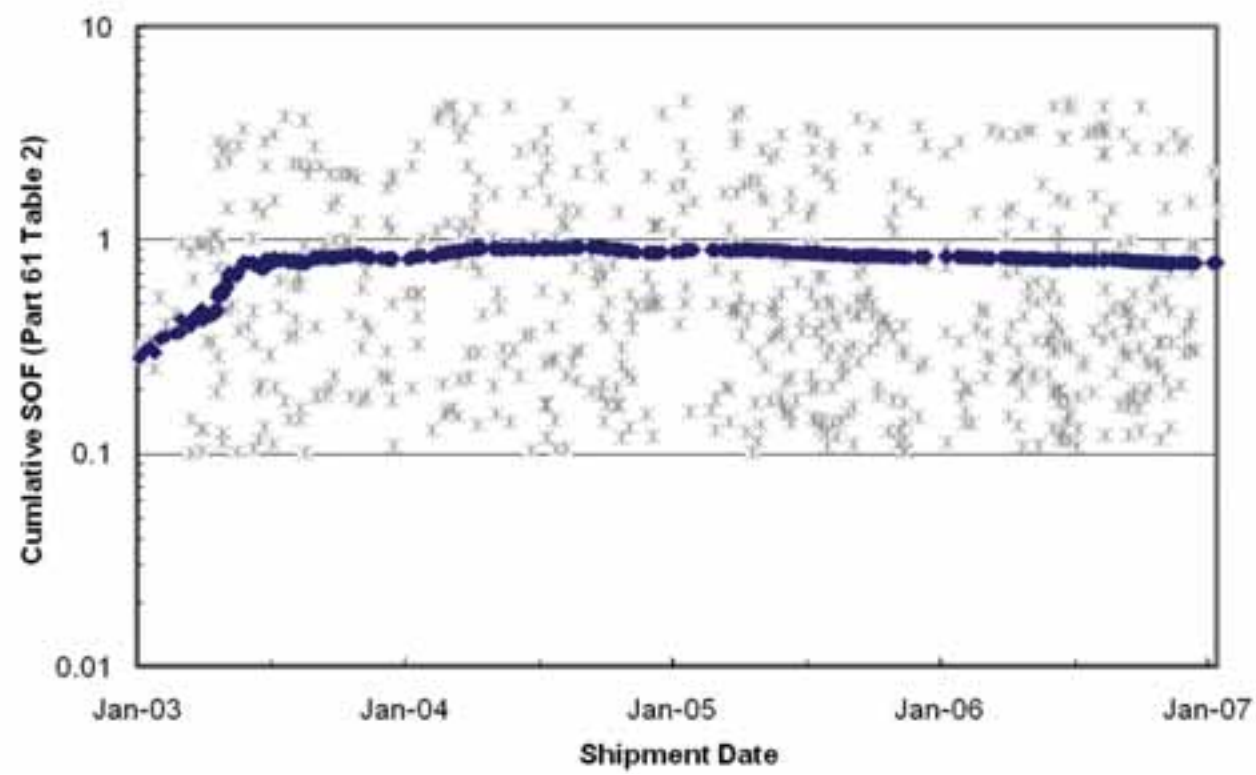

Fig. 5. All resins, cumulative classification, BTP averaging.

cannot exceed the Class A limit on a sum-of-fractions (SOF) basis.

Using the SOF as the index, a maximum SOF was determined to be approximately six times the Part 61 Table 2 Class A limit. The solid line in Fig. 5 represents the cumulative average classification value. The asterisk points represent individual SOF values for each of the packages.

Streamwide BTP averaging would primarily impact the amount of waste characterized as Class B. Figure 6 demonstrates the impact on volume. Effectively, the proposed practice would increase the amount of resin waste characterized as Class A by about 8000 ft^3 per year. To put this in perspective, the industry currently generates about 87 000 ft^3 per year, of which 75 000 ft^3 is disposable as Class A. The disposable volume would increase to 83 000 ft^3 leaving only about 5000 ft^3 for onsite storage. This would be a two-thirds reduction in the amount of storage required. Streamwide BTP averaging would reduce the amount of activity stored onsite by about 55 percent. Assuming that risk is related to the gross quantity of activity, a 55 percent reduction of risk could be achieved without changing 10 CFR 61 and without explicitly changing the branch technical position on averaging.

Two of the major initiatives in EPRI's current research plan follow directly from the NRC's strategic assessment: first, provide input and supporting analysis to support the NRC review of the Branch Technical Position on Concentration Averaging, and second, provide input and supporting analysis to the NRC for the development of a design guide for implementing a 10 CFR 61.58 design analysis for developing site-specific disposal classification and characterization bases.

A Need for More Risk-Informed Regulations

In 2005, the NRC's Advisory Committee on Nuclear Waste (ACNW) issued a white paper on the need for an updated framework for LLRW regulations ("History and Framework of Commercial Low-Level Radioactive Waste Management in the U.S.," ACNW White Paper, Dec. 2005; reissued as NUREG-1853, Jan. 2007). The ACNW suggested that the NRC revisit some of the 10 CFR 61 bases to develop a more risk-informed approach. The NRC responded with a strategic assessment published in October 2007 that identified the need to revisit the BTP on averaging and to develop guidance for implementing an alternative system of classification as allowed under 10 CFR 61.58 ("Strategic Assessment of U.S. Nuclear Regulatory Commission Low-Level Waste Regulatory Program," SECY-2007-180, Oct. 2007). Earlier in 2007, Commissioner Gregory Jaczko addressed the attendees of the EPRI International LLW Conference in Connecticut and indicated the NRC's interest in resolving LLW disposal issues, expressing particular interest in industry efforts to confront these issues and develop strategies for resolution. Central to the NRC strategic assessment is a response to the observation made by the ACNW that the current regulations—10 CFR 61—are not sufficiently risk-informed. The NRC itself, in a response to the Government Accountability Office (GAO), went further in saying that in addition to not being risk-informed, the regulations were neither reliable nor cost-effective and the time was right to begin exploring alternatives (Letter from Luis A. Reyes, NRC, to Robin Nazarro, GAO, May 25, 2004). A common theme throughout the strategic assessment was the need to make the LLW program more risk-informed. The bases for the regulatory limits in Part 61 were derived from deterministic intruder scenarios that were not risk

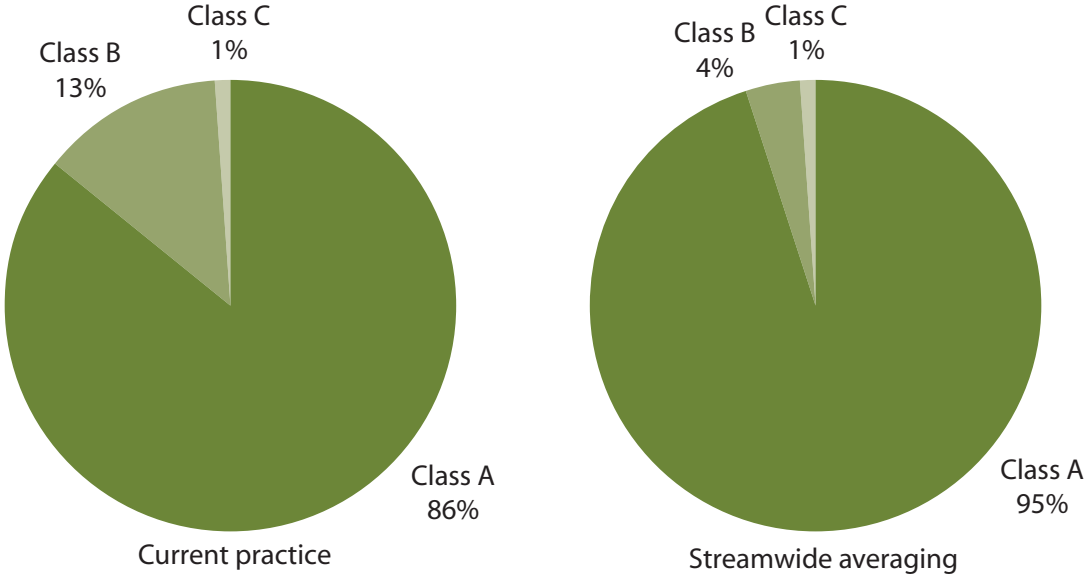

Fig. 6. Impact of streamwide averaging on Class A waste volume totals for ion exchange resins.

tested. As a result, the limits defined in Part 61 tended to be overly restrictive in the determination of disposal requirements.

EPRI's Continuing Research Program

Two of the major initiatives in EPRI's current research plan follow directly from the NRC's strategic assessment: first, provide input and supporting analysis to support the NRC review of the Branch Technical Position on Concentration Averaging, and second, provide input and supporting analysis to the NRC for the development of a design guide for implementing a 10 CFR 61.58 design analysis for developing site-specific disposal classification and characterization bases. Interwoven in the supporting analyses developed toward these initiatives is the development of a risk-informed basis and examination of collateral impacts, as well as examination of costs and benefits, as applicable. The overall objective is to minimize the accumulation of Class B and C wastes from plant sites and to pursue more cost-effective and reliable disposal options. Other tasks included in these investigations are (a) to develop a better understanding of the underlying bases for 10 CFR 61 disposal criteria, (b) address potential issues related to nonutility wastes, and (c) investigate the impacts of employing other disposal models such as the International Atomic Energy Agency disposal scheme, along with updated International Commission on Radiological Protection dose conversion factors.

Both the ACNW and the NRC believe that reforms including increased availability of disposal capacity can be achieved within the existing framework provided by 10 CFR 61.58. Another longer term initiative not specifically addressed in the current research program or in the actions of the NRC may be the promotion of change to the regulation itself. ■

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