In Pursuit of Risk-Informing Low-Level Waste Disposal Regulations

Clarifying certain inconsistencies in the regulations governing LLW classification and disposal would make them more risk-informed and consistent with current disposal site operating practices.

By David James, Thomas Kalinowski, and Phung Tran

In a strategic assessment[1] of practices and obligations toward the management of low-level radioactive waste, the U.S. Nuclear Regulatory Commission placed high priority on two (out of seven) tasks that are of particular interest relating to the disposal of nuclear power plant–generated radioactive wastes. These are to, first, update the Branch Technical Position (BTP) on Concentration Averaging and Encapsulation and, second, develop the Guidance Document on Alternate Waste Classification (*Code of Federal Regulations*, Title 10, Part 61.58). The Electric Power Research Institute (EPRI) addressed the first item in "An Evaluation of Alternative Classification Methods for Routine Low-Level Waste from the Nuclear Power Industry," published in 2008 (Report 1016120). EPRI presented highlights of this study to the NRC in a meeting in June 2008 and provided the study[2] itself to the NRC in January 2009. The second of these items will be addressed in work planned for this year.

Alternate waste classification as a viable waste management pathway has evolved from application and use of 10 CFR 61.[3] From the direction provided in the Low-Level Radioactive Waste Policy Act of 1980, 10 CFR 61 aimed to promulgate regulations for a series of regional disposal sites. In support of the regulations, the NRC theorized model sites representing four distinct U.S. regions with varying populations, annual rainfall, transportation distances, etc. Using the anticipated source terms for radioactive generators that would be using the respective sites, the NRC then modeled the impacts on various population groups such as facility operators, waste transporters, people living along transportation routes, and persons living in the vicinity of the site.

There were four basic considerations to the NRC's evaluation:

- Protection of occupationally exposed workers and the public during operation of the facility.
- Long-term environmental protection.
- Protection from an inadvertent intruder.
- Modest impact of regulatory changes on disposal costs and disposal site operations.

Prior to 10 CFR 61, there were no specific requirements for stabilization or for segregation of unstable wastes. Wastes were emplaced in unlined trenches with minimal cover. The NRC study determined that some of the wastes required additional protection, including deeper disposal and specific stabilization. Rather than implement a blanket requirement for cover depth and stability (this was considered to be overly burdensome to operating disposal sites and there wasn't adequate justification for the added protection), the study recommended that lower activity wastes be disposed of without stabilization under two meters of cover. The unstable waste must be segregated from the higher activity wastes. This led to the three-tier classification system identified in 10 CFR 61.55.

The current classification criteria define generic values that envelop the conditions that may be encountered at various disposal sites. If a proposed disposal site could demonstrate that the protection levels provided in 10 CFR 61.55 would be met through site selection, the classification system would assure safe operation without having to conduct detailed design evaluations for the proposed facilities. Furthermore, a standardized system of classification would reduce confusion for the generator and for the disposal site operator. The generator would not have to be concerned with varying disposal requirements, and the disposal site operator would immediately know how to disposition each package.

The classification system offers convenience; however, it is not "risk-informed." The NRC defines the phrase "risk-informed decision making" as follows[4]:

> A "risk-informed" approach to regulatory decision making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to health and safety.

It is unclear from this broad definition how a risk-informed approach would apply to the issue of waste classification. Most of the radionuclide concentration limits provided to establish waste class are based on exposures to a hypothetical subsistence intruder who excavates into the site, exposing the waste, and constructs a foundation for a house. The intruder remains to build the house, spread the excavated material, maintain gardens, and grow livestock for food and milk on the site. Fundamentally, the intruder analysis is a deterministic analysis. That is, the scenario is not evaluated as a risk of occurrence; it's assumed that it will happen. The intruder scenario is also completely dependent on the specific disposal model (unstabilized waste, thin 2-m cover) used in developing the concentration limits.

Because risk-based analyses could not be conducted on the large universe of potential disposal sites envisioned in 10 CFR 61, this opens the prospect of site-specific evaluation and the setting of site-specific disposal conditions:

> **§ 61.58 Alternative Requirements for Waste Classification and Characteristics.**
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> The Commission may, upon request or on its own initiative, authorize other provisions for the classification and characteristics of waste on a specific basis, if, after evaluation of the specific characteristics of the waste, disposal site, and method of disposal, it finds reasonable assurance of compliance with the performance objectives in subpart C of this part.

This provision would allow an applicant to redefine concentration limits corresponding to a specific site and disposal configuration as long as the general performance requirements of 10 CFR 61 are met (i.e., 25 millirems per year whole body, 75 mrem/year to thyroid, and 25 mrem/year to any other organ).

While the 10 CFR 61.58 provision stands out in the regulation, it has not been used to develop an alternative disposal criterion for any commercial disposal site development. Classification in accordance with 10 CFR 61.55 is required for transfer of radioactive wastes per App. G of 10 CFR 20. Agreement states potentially licensing a disposal site currently must treat compliance with 10 CFR 61.55 as a "matter of compatibility."[5] Effectively, the regulation provides a conservative framework for disposal but provides little credit or incentive to develop a more engineered facility. Nevertheless, few of the proposed or developed disposal sites followed the disposal model in 10 CFR 61, preferring instead to increase protection beyond what was required.

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What is Low-Level Waste?

Low-level waste is legally defined as waste that is not "high-level radioactive waste, spent nuclear fuel, or byproduct material."[6] This begs the larger question, "What is low-level waste—really?"

Because LLW is defined by exclusion, a starting point would be to identify what is not LLW. High-level waste (which is not LLW) is waste that requires "permanent" isolation such as provided in geologic structures.[7] LLW, one would therefore assume, is waste that does not require permanent isolation and would in some defined period of time render itself harmless (within the context of other environmental risks). Historically, it has been assumed that sufficient isolation of this waste could be achieved with near-surface burial. The Low-Level Radioactive Waste Policy Act (LLWPA) and 10 CFR 61 were constructed around this premise. In fact, the main purpose of the LLWPA was to delegate responsibility for LLW disposal under the assumption that it was acceptable for near-surface disposal. The act tasked the NRC with classifying which radioactive waste is LLW.

Table I lists what is commonly considered to be LLW and what is commonly considered to be not LLW. It should be noted that some of the "not" LLW may also be acceptable for near-surface disposal subject to a specific determination of the suitability and the conditions of disposal. Because these are not LLWs in the context of the LLWPA, acceptance for disposal would be determined by the relevant disposal authority. Disposal classification in accordance with 10 CFR 61 for any of the "not LLW" would be generally irrelevant.

Defining what is LLW is a fundamental first step in setting reasonable standards for disposal site protection objectives. A working definition offered here, consistent with guidance published by the International Atomic Energy Agency and adopted by other nations utilizing near-surface disposal, is the following:

> Low-level waste: Waste that is above clearance levels, but with limited amounts of long-lived radionuclides. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near-surface facilities. This class covers a very broad range of waste. LLW may include short-lived radionuclides at higher levels of activity concentration and also long-lived radionuclides, but only at relatively low levels of activity concentration.[8]

By this definition, all LLW would be suitable for near-surface disposal, providing a minimum of 500 years of isolation. This is generally adequate isolation for all of the non-fuel-bearing wastes generated at nuclear power plants. However, since there is no bounding definition of LLW, any material not specifically included in the list of items identified as HLW is LLW. For example, depleted uranium, which is almost pure U-238, is not considered by-product material because it is not identified as such in the Atomic Energy Act and is not included in the list of waste not suitable for near-surface disposal. By default, therefore, it is LLW. For those radionuclides listed in 10 CFR 61 that affect classification of nuclear power plant LLW, Fig. 1 shows the risk imposed by the industrywide

Table I
LLW and Not-LLW

Not Low-Level Radioactive Waste	Low-Level Radioactive Wastes
● Spent Nuclear Fuel ● Wastes resulting from the reprocessing of spent nuclear fuel ● By-product Material ○ Mill tailings 11e(2)* ○ Waste incidental to fuel manufacturing 11e(2) ○ Discrete source of Ra-226 ○ Accelerator wastes ○ Other sources developed from NARM ● TRU Wastes—wastes containing concentrations of TRU not exceeding 10 CFR 61 disposal limits ● Greater than Class C Wastes ● Chemically Hazardous LLRW Wastes (Mixed Wastes) ● NORM, Naturally Occurring Radioactive Material ● Some Sealed Sources ● *Exempt Waste*	● Nuclear Power Plant–Generated Wastes (excluding Nuclear Fuel) ○ Process wastes (resins, filter materials, DAW) ○ Expendable hardware ○ Decommissioning wastes including most activated hardware ● Government ○ Dry solids ○ Trash ○ Absorbed liquids ○ Biological ○ Solidified chelates ○ Sealed source ● Industrial Generated Wastes ○ Miscellaneous solids and absorbed liquids ○ Solidified oils ○ Resins and filter wastes ○ Biological wastes ○ Discarded manufactured products ● Hospitals and Medical Facilities ○ Laboratory wastes ○ Biological ● Academic ○ Laboratory wastes ○ Dry solids ○ Biological

* "Mill tailings and waste incidental to extraction and concentration for source material content would be defined as byproduct material," *The Atomic Energy Act of 1954,* Public Law 83.

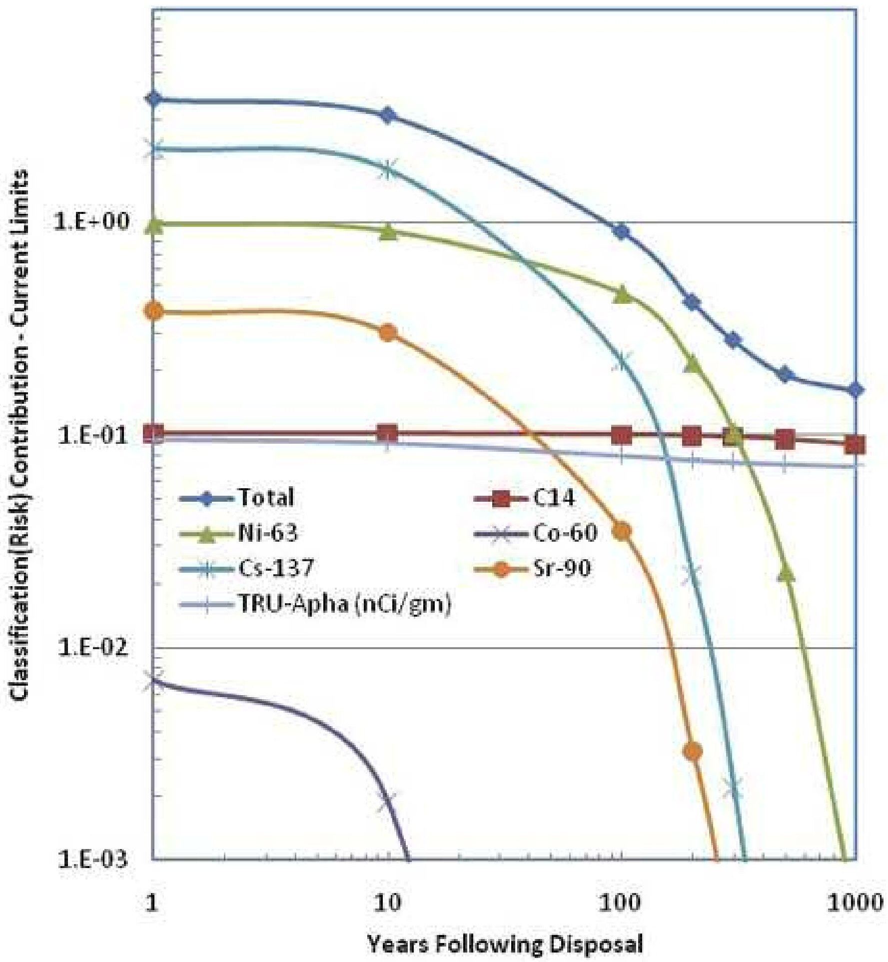

Fig. 1. Relative risk versus time for classification-limiting radionuclides.

source term if all of the waste and activity is disposed of under current requirements as Class A waste. By contrast, depleted uranium exposures would be dominant after the first 100 years and continue to increase.

Regulatory Actions Prompted by the Depleted Uranium Issue

The Advisory Committee on Nuclear Waste (ACNW) suggested that the NRC use the site-specific performance assessment provision of 10 CFR 61.58 to develop a risk-informed basis for LLW disposal. Both the ACNW and the NRC staff generally believed that a permanent change to 10 CFR 61 would not be on the table. However, because of the unique challenges posed by the need to dispose of large volumes of depleted uranium, further regulatory clarification was needed. As a by-product of the enrichment process, for each kilogram of enriched uranium at 2.8 percent U-235, roughly 40 kg of depleted uranium is produced. The NRC issued a finding in January 2005 that depleted uranium should be classified as LLW.[9] This determination was driven by the law affecting the privatization of the US Enrichment Corporation, which required the DOE to take responsibility for depleted uranium if it was determined to be LLW. Since there is no disposal limit established for U-238, its allowable content in LLW is unlimited. So not only is the material LLW, it is also Class A LLW and subject to the least restrictive disposal criteria. The LLWPA and the later Amendments Act did not specifically identify depleted uranium as by-product material or as waste at all, allowing it to fall into the LLW category.

While it may be appropriate to look for a near-surface solution for depleted uranium, it was not originally envisioned in the disposal limits defined in 10 CFR 61.55. In response to this incongruence, the NRC has proposed a change to 10 CFR 61.55 requiring a site-specific evaluation pertaining to the disposal of depleted uranium (the only operating disposal site that could potentially receive this material is the EnergySolutions site at Clive, Utah). To assess the public response to this proposal, the NRC hosted two public meetings in September 2009, one in Washington, D.C., and one in Salt Lake City. Nuclear industry opponents maintained that the waste should be treated as greater than Class C, that a completely new performance assessment should be conducted, and that any change should be subject to a full environmental impact statement (EIS). Some industry sources also expressed concern because they would be commercially impacted by any changes to the regulations.

Effectively, the argument pertaining to depleted uranium opens more issues concerning the relevance of concentration limits in 10 CFR 61. Current performance assessment methodologies focus on the inventory in the disposal site rather than localized concentrations. The concentrations limits are viewed as an artifact of a process defined for implementing the LLWPA. They have little bearing on current disposal practices or risks related to particular disposal activities and are not correlated with total inventory for a disposal site. That said, treating depleted uranium as Class A LLW muddies the water when trying to establish a coherent definition. The suggested change to 10 CFR 61.55 would add a footnote requiring a site-specific evaluation for the disposal of significant amounts of depleted uranium. Given an appropriate disposal venue and disposal depth, depleted uranium can be safely disposed of in a near-surface facility.

Blending and Waste Classification

In 2006, with the looming restricted use of the Barnwell disposal site, EPRI sponsored a project to examine the overall classification of LLW generated by the nuclear power industry. The examination determined that the bulk of the wastes (and activity) could be disposed of as Class

Disposal sites licensed to receive Class A materials are evaluated to the Class A limits. There is no inherent commitment for the site operator to limit the disposal to some arbitrarily lower capacity criteria. There is an inherent commitment on the part of the regulators to allow operation to proceed in accordance with the license.

A waste with no change in the regulations and a small change in the implementation of the guidance documents. Both the industry and the NRC view onsite storage of wastes as the least desirable outcome of the Barnwell restrictions. It should come as no surprise, therefore, that once Barnwell operations were restricted, more emphasis would be placed on optimizing the production of disposable wastes.

As noted earlier, the ACNW had previously identified the averaging criteria as an area that needed further consideration with respect to risk. In SECY-2007-180, "Strategic Assessment of Low-Level Radioactive Waste Regulatory Program," the committee cited the need to make the criteria more risk-informed and the need to make the underlying rationales more self-evident. The industry argued that before the issuance of the averaging guidelines,[10] the restrictions did not address any protection requirement beyond that associated with discrete sealed sources. EPRI published a report in 2008[2] that investigated the basis for the BTP. The study found that the limiting conditions for 10 CFR 61 disposal were based on excavating a volume of material that would comprise 50 to 100 large containers, which would obviate any benefit from restricting averaging below the container level. Basically, it was argued that there was no basis or benefit to be gained from restricting averaging of flowable materials below that referred to in the 10 CFR 61 Draft EIS (DEIS) as the intruder volume (wherein it is assumed that the intruder excavates, by hand, the foundation of a house. The dimensions are 10 x 20 m and 3 m in depth). By allowing averaging over a larger volume of materials, nearly all of the wastes generated in power plants would be eligible for Class A disposal. EPRI presented this preliminary finding to the NRC in late 2006. The meeting, organized by the Nuclear Energy Institute (NEI), was heavily attended by NRC staff as well as utility representatives representing nearly the entire operating fleet of reactors. That meeting was followed up by two additional meetings held in NEI offices in 2007 and 2008 that focused more particularly on the averaging rules. The EPRI final report was made available to the NRC and to the general public through the NRC and through EPRI.[11]

The idea of relaxing the averaging rules stimulated commercial competition. EnergySolutions moved quickly to promote the development of a blending service where flowable wastes (particularly resins and filter media) would be centrally collected, mixed, and classified prior to disposal at their site in Utah. The proposed practice is not specifically addressed in NRC regulations or guidance and, therefore, is not specifically precluded. However, neither is it specifically allowed. In its application for a facility permit in Tennessee, EnergySolutions needed assurance from the NRC that it would not be in violation of NRC requirements. Because of the ambiguity in how the regulations may be interpreted, the NRC has held public discussions on this issue and is preparing a recommendation to the commission for a finding on the issue.

The blending service proposed by EnergySolutions promised to reduce the stored volumes of LLW at nuclear power plants by eliminating a significant share of routinely generated operational waste currently classified as Class B and Class C. This prompted other waste processors to propose alternate processing or storage/disposal options. Studsvik[12] suggested an alternative waste processing option for utilities with no Class B and Class C disposal capability that would include a thermal treatment process and solidification of the resultant waste. The wastes, which would be blended and classified on the basis of the final waste mixture, would be sent to Waste Control Specialists (WCS) for storage. Studsvik would take title to the blended wastes to address the issue of attribution and would provide in their pricing a protected fund to pay for ultimate disposal. A secondary issue associated with this is that the WCS license opens the door for them to reserve a small percentage of their volume capacity for out-of-compact wastes.

The discussion that has developed between EnergySolutions and Studsvik/WCS options has been the recent focus of discussions related to the BTP. The NRC held individual meetings with the two sides on December 14 and 15, 2009, at which each was allowed to make its case in a public meeting. At a joint public meeting on January 14, 2010, both sides were again represented along with industry representatives and advocacy groups.

Both of the proposals involve receiving material from a number of generators and blending the materials within some limits for classification. The volume reduction of higher activity materials requires the addition of lower activity materials to maintain classification limits. The processes themselves are not much different. Studsvik argues that its process puts the highly concentrated waste into a stable waste form that is safer in the disposal environment, and because it is Class B or C, it will be placed in a more restrictive disposal configuration. The EnergySolutions process would distribute that activity over a larger volume that would be inherently less hazardous than the concentrated waste. Furthermore, when the total activity is taken into consideration, the overall average concentration does not proportionately increase public risk since additional protective measures are automatically taken for higher activity Class A wastes.

All of the disposal sites require intruder protection of Class A materials that approach the Class A limits. Such protection includes stabilization to guarantee 300 years of isolation or deeper disposal, or both. WCS plans to dispose of all LLWs including Class A wastes in the same facility without distinction. In this case, classification has no particular distinction or relevance except as to how it is treated commercially. EnergySolutions will place the waste in its containerized waste facility, which includes both increased cover and structural support that would act as intruder barriers.

Table II
Summary of Incremental Barrier Costs For Facility Design and Operation*

	Additional Disposal Costs (1980)	
Type of Barrier	\$/m^3	\$/ft^3
No barrier	0	0
Thicker cap—3 m of soil	1.59	0.05
Thicker cap—3 m of compacted clay	10.89	0.31
Layered waste disposal	37.73	1.07
Slit trench (10 percent of waste)	91.49	2.59
Caisson disposal (10 percent of waste)	216.45	6.13
Walled trench (10 percent of waste)	256.09	7.25
Walled trench (100 percent of waste)	160.99	4.56
Grouting—cement	60.46	1.71
Grouting—low-strength cement	46.86	1.33
Engineered intruder barrier	59.17	1.68
Intermediate-depth burial	53–159	1.50–4.50
Mined cavity	327–654	9.26–18.52
Ocean disposal	710–2200	20.11–62.31
Space disposal	2 000 000.00	56 600.00

*Table S.7 from NUREG-0782, Vol. I.

To focus back on the BTP, the main driver, as stated by the NRC,[13] is to ensure protection of the inadvertent intruder. This is a cornerstone of 10 CFR 61. With regard to the materials at issue, these will always be disposed of in an intruder protected configuration. The issue would be important only if the waste were disposed of in least protected configuration (i.e., unstabilized with 2 m of cover). EPRI research indicated that for resin wastes generated in nuclear power plants, approximately 85 percent (by volume)[14] of the Class B and C wastes can be accommodated in this type of facility without additional protection.

Key considerations with respect to the industry position on concentration averaging as defined in the NRC BTP are as follows:

- Overall disposal risk is determined by the total activity in the disposal site, not the concentration in any given volume of material (package or portion of a package).
- According to the intruder scenarios used to define the classification limits, the intruder would excavate up to 200 m^3 of material, which would be mixed with soil. This is equivalent to 50–60 large liners of waste. Such an excavation would obviate any benefit gained by the averaging constraints. Homogeneity of waste inside a package is not a factor in the intruder scenario.
- Disposal sites licensed to receive Class A materials are evaluated to the Class A limits. There is no inherent commitment for the site operator to limit the disposal to some arbitrarily lower capacity criteria. There is an inherent commitment on the part of the regulators to allow operation to proceed in accordance with the license.
- Blending of radioactive materials is not dilution in the context of the EPA dilution prohibition (or the BTP). Concerns related to dilution pertain to release to pathways directly exposing the public.

Issues with 10 CFR 61

The NRC, through recommendations from the Government Accountability Office and the ACNW, has opened a discussion on 10 CFR 61. Such a discussion understandably brings out competing interests and arguments. Establishing a rational, technically correct, and economically viable disposal policy provides a better foundation for progress, even if all of those weighing in do not agree with it. However, there are some issues with the 10 CFR 61 classification system that should be addressed.

Misapplication of Generic Rules

The NRC effort to develop regulations for the disposal of LLW was a landmark effort. The studies and the regulations established a framework that served as a model for the rest of the world. Aspects of the regulation are reflected in every program outside of the United States that followed. However, generic rules intended to apply to everything generally don't particularly apply to anything. Technical analysis indicates that the performance objectives defined in the regulations could be met with a more flexible approach, based on the final waste and disposal environment.

Cost/Benefit Off Target

The cost/benefit analyses performed to justify the disposal model for 10 CFR 61 do not reflect current disposal reality. When originally conducted, disposal site operating costs were the driving factor. Overall disposal costs were assessed to be on the order of $223/m^3 ($6.32 per cubic foot). A number of alternative disposal technologies were considered in the original DEIS.[15] The incremental costs associated with these technologies are shown in Table II.

Because of the disposal costs, the regulations focused on minimizing the amount of waste subject to additional barriers, so that the bulk of the volume would be disposed of with no added barrier. Only a small volume, less than 10 percent, would then be subject to the additional cost. If we took the $6.32/ft^3 as the average disposal cost at the time of preparation of the DEIS, it would be equivalent to paying approximately $60/ft^3 today (assuming 10 percent annual interest). This compares with $400–$500/ft^3 average disposal cost today (more than $3000/ft^3 for some wastes). Furthermore, short of the most extreme measures, most of the enhanced barriers are in current use at the disposal sites, despite the fact that no benefit is credited.

Individual Nuclide Limits Inconsistent with Dose Conversion Factors

Using fixed activity limits in a regulation does not promote the use of improved technical knowledge (coming from either direction). Dose conversion factors and risk assessment factors have changed significantly since 10 CFR 61 was issued. The use of the more recent International Council on Radiation Protection 72[16] and Federal Regulation Guide 13[17] dose and risk factors would result in considerably different activity concentrations. Both Ni-63 and Sr-90, which are often found to control classification for nuclear power plant LLW, would have significantly higher disposal limits under the 10 CFR 61 model.

The DEIS emphasized the importance of tracking certain highly mobile radionuclides that would readily be carried in groundwater. These included H-3, C-14, Tc-99, and I-129. Dose and risk factors used now for these nuclides are much different than those used in 1980.

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