A REGULATORY ANALYSIS OF INCIDENTAL WASTE

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ABSTRACT[*]

Spent nuclear fuel and vitrified high-level waste (HLW) have been selected as the main candidates for disposal at the proposed deep geologic repository at Yucca Mountain (YM), Nevada. The question remains: what should be done about the components, residuals, and side streams from reprocessing of spent nuclear fuel? In general, reprocessing involves dissolving spent nuclear fuel. Subsequent chemical processing can then be used for selective removal of fissile material for reuse and other needed isotopes. The associated waste stream is a solution of fission products and other radioactive elements. By definition, from the Nuclear Waste Policy Act of 1982, as amended, both the supernate and sludge resulting from reprocessing of spent nuclear fuel are classified as HLW. In other words, wastes from reprocessing are classified by source, and not by risk to human health or the environment. At the Department of Energy's (DOE) Savannah River Site, the supernates and sludges from reprocessing, and from production of weapons-grade fissile material, are stored in 51 underground tanks until they can be separated and processed. The supernate is treated to remove fission products, and the remaining low-activity liquid is then made into saltstone and disposed of onsite. The removed fission products are combined with the HLW sludges and vitrified at the Defense Waste Processing Facility for eventual disposal at YM. Thus, the supernate stream, originally classified as HLW, is separated into an HLW fraction, and an incidental or low-level waste (LLW) fraction.

Wastes can be determined to be incidental if they meet three criteria provided as guidance by the U.S. Nuclear Regulatory Commission (NRC), (1) "...wastes have been processed (or will be processed) to remove key radionuclides to the maximum extent that is technically and economically practical"; (2) "...wastes will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration limits for Class C low-level waste as set out in 10 CFR Part 61"; and (3) "...wastes are to be managed, pursuant to the Atomic Energy Act, so that safety requirements comparable to the performance objectives set out in 10 CFR Part 61, Subpart C are satisfied." The performance objectives of 10 CFR Part 61 include protection of the general population, protection of an inadvertent intruder, protection of workers, and stability of the disposal site. Similar criteria have been issued by DOE in DOE Order 435.1, "Radioactive Waste Management."

These three criteria have been applied in a number of cases. NRC has been involved in review of several applications, including low-activity waste removed from HLW tanks at Hanford, low-activity waste removed from tanks at Savannah River, disposal of West Valley supernate waste, and closure of HLW tanks at the Savannah River Site.

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[*] This paper does not necessarily reflect the views or position of the U.S. Nuclear Regulatory Commission or the U.S. Department of Energy.

BACKGROUND [1]

In the mid 1940's the Manhattan Project pursued several different paths toward the creation of an atomic weapon. Two paths were the enrichment of uranium, and the production and separation of plutonium. For each of the two paths there were different obstacles. The difficulty in creating an enriched uranium weapon was in the enrichment process itself. The plutonium weapon required the creation and separation of an element not found in nature. Both paths were pursued and both weapon types were ultimately used. The enrichment of uranium was performed through several different mechanisms (e.g., gaseous diffusion, thermal diffusion, gas centrifuge and electromagnetic). Since fissionable uranium occurs naturally, the enrichment process only involved the processing of natural uranium. Therefore, the enrichment of natural uranium did not involve the handling of transuranic (TRU) waste or fission products. However, the production of plutonium in large scale required the bombardment of uranium targets with neutrons. This was usually accomplished in a production reactor. Once the uranium targets or nuclear fuel had been irradiated for a sufficient amount of time the plutonium would be chemically separated from the spent fuel or irradiated targets. As a result of the plutonium production process TRU waste and fission products were created.

Originally only Hanford used chemical separation to obtain plutonium, but the Savannah River Site (SRS) soon began chemical separation operations. The Oak Ridge National Laboratory (ORNL) also experimented with chemical separations for the removal of plutonium but these processes were confined to uranium targets such that limited amounts of fission products were involved. Both Hanford and SRS reprocessed spent nuclear fuel and uranium targets and thereby built up large inventories of fission products. The Idaho National Engineering and Environmental Laboratory's (INEEL) major function was the recovery of enriched uranium from spent naval nuclear fuel. The different types of material reprocessed may play a vital role in how the waste products are handled.

HISTORY OF HIGH-LEVEL WASTE LEGISLATION

As nuclear reactors began to operate, a new type of radiation hazard emerged. Never before had such enormous quantities of fission products been produced. The fission products were incorporated into the nuclear fuel "burned" in the reactor. As mentioned before, some reactors were not built for power generation but to produce man-made elements such as plutonium or americium. The targets used in production reactors were made from depleted uranium and as a result had fewer fission products than fuel used in power reactors or fuel used in production reactors. Therefore, early in the reactor programs two different waste forms emerged, high-level waste (HLW) and TRU waste. It wasn't until 1970 that the Atomic Energy Commission defined HLW. The definition is part of 10 CFR Part 50; it states that HLW are "those wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from the subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels [2]." This definition was used primarily to define the different waste streams at reprocessing plants. Spent nuclear fuel was not addressed in the definition of HLW in the 1970 version of 10 CFR Part 50. It wasn't until the Marine Protection, Research, and Sanctuaries Act of 1972 that spent nuclear fuel was included in the definition of HLW. In 1980, yet another definition of HLW was provided in the West Valley Demonstration Project Act (WVDPA). The definition for HLW in the WVDPA was comparable to that in Appendix F of 10 CFR Part 50, with the additional statement that HLW also includes "such other material as the Commission designates as high level radioactive waste for the purposes of protecting the public health and safety [3]." Yet another definition of HLW was provided in the Nuclear Waste Policy Act of 1982, as amended (NWPA). The HLW definition in the NWPA, reads "[t]he term 'high-level radioactive waste' means - (A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in the reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (B) other highly radioactive material that the Commission, consistent with existing law, determines by rule requires permanent isolation [4]." The NWPA also fails to define spent nuclear fuel as HLW, and instead defines it as "fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing [4]." The U.S. Nuclear Regulatory Commission (NRC) definition of HLW in 10 CFR Parts 60 and 63 is consistent with the NWPA definition, but includes spent nuclear fuel [5], [6].

Although this is not a complete history of HLW legislation, it does provide enough background to allow an observer to note that the definition of HLW has never had any quantitative basis. A vaguely quantitative definition is provided in the NWPA. These HLW definitions focus upon the source of the material or waste, and not the risk to human health or the environment. HLW continues to be defined based on source.

WASTE CLASSIFICATION

Beginning in the late 1980's the cold war began to weaken and aging defense nuclear facilities required decontamination and decommissioning. For example, at SRS the HLW tanks are currently being taken out of service and closed. The HLW contained in the 51 underground tanks from the two reprocessing canyons (H and F canyons), is currently being removed and vitrified at the Defense Waste Processing Facility. Because of the method used to reprocess spent nuclear fuel and production targets at SRS, the 51 HLW tanks contain several different types of wastes: sludge, supernate, and saltcake. The low-activity fraction from supernate and saltcake will be removed, treated, grouted, and then disposed of as low-level waste (LLW) following an incidental waste determination. The high-activity fraction will be vitrified. Following treatment, the supernate and saltcake represent a much smaller hazard to the environment and public health than spent nuclear fuel or HLW sludge. It is clear from this practice that some wastes resulting from reprocessing can be shown to be incidental to the process. Currently there are no laws or regulations that define incidental waste. However, both the Department of Energy (DOE) and the NRC recognize incidental waste as a byproduct of reprocessing operations. DOE defines incidental waste in DOE Order 435.1 "Radioactive Waste Management." [7] NRC has guidance that permits wastes to be determined to be incidental if they meet the following three criteria: (1) "...wastes have been processed (or will be processed) to remove key radionuclides to the maximum extent that is technically and economically practical"; (2) "...wastes will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration limits for Class C low-level waste as set out in 10 CFR Part 61"; and (3) "...wastes are to be managed, pursuant to the Atomic Energy Act, so that safety requirements comparable to the performance objectives set out in 10 CFR Part 61, Subpart C are satisfied." [8], [9] The DOE and NRC criteria are similar, and both allow either the Secretary or Commission to authorize alternate waste classification criteria. In addition, Order 435.1 permits some incidental waste to be managed as TRU (a classification NRC does not use). The rationale behind the incidental criteria is to allow waste classification to be determined by a quantitative (risk) measure. Therefore, a waste stream that doesn't meet the incidental criteria and is not considered for alternative waste classification will retain its original waste classification (e.g. HLW). In essence an incidental waste determination is based on how a particular waste performs, compared to LLW or TRU waste acceptance criteria. Criterion One simply requires that the waste meet as low as reasonably achievable (ALARA) standards. ALARA requires that the waste is treated to the maximum extent possible both technically and economically. Criterion Two states that the waste must be in a suitable form and meet the LLW waste concentration limits in 10 CFR 61.55. Finally, Criterion Three states that the waste must not represent a greater risk to the public, workers, or environment than LLW. Similar criteria are included in DOE Manual 435.1-1 for TRU waste.

INCIDENTAL WASTE REVIEW PROCESS

In 1996, DOE-SRS asked the NRC to provide technical support in determining whether or not the residual waste remaining in HLW tanks at SRS, following bulk waste removal, could be considered incidental. The NRC performed a similar determination at Hanford regarding supernate and saltcake removed from HLW tanks, using the aforementioned three criteria to respond to the DOE-SRS request.

Criterion One

To evaluate Criterion One, the NRC staff looked at the way SRS was removing sludge from the HLW tanks. SRS has proposed waste removal from the tanks by three mechanisms. The first process is bulk waste removal. Once most of the waste has been removed, multiple cycles of water washing will be performed. Depending on the inventory of radionuclides left in the tank following water washing a third option may or may not be applied. At the SRS the HLW is in an alkaline form such that the sludge precipitates out and settles on the bottom of the tank. To remove waste remaining following water washing, the sludge must be solubilized. Oxalic acid washing was chosen as the third removal option. Oxalic acid washing will dissolve the sludge and provide increased mobility for removal through pumping. To determine whether Criterion One was met or not, a cost benefit determination was done to evaluate the amount of waste removed, cost of removal, and reduction in risk resulting from the removal. Staff determined that oxalic acid cleaning may be technically practical, but is not economically practical for use in all tanks. Therefore, the decision on oxalic acid washing can be based on the type of waste in each tank. If a tank contains large amounts of sludge, oxalic acid washing is likely to be necessary to meet performance objectives. If a tank mainly contains supernate, oxalic acid washing is not expected to be required. NRC staff agrees that the SRS methodology appears to meet Criterion One.

Criterion Two

Criterion Two states that the waste must be in a stable form, and must meet Class C concentration limits as defined in 10 CFR Part 61. At SRS the HLW tanks are going to be filled with three layers of grout. The first layer of grout will be a reducing grout that will help reduce the solubility of radionuclides that could leach into the ground water. The second layer is used to provide protection against subsidence, and the third layer will be a strong grout used as an intruder protection barrier. The tank grouting also provides for an excellent waste form that is significantly better than what would be expected at a typical LLW burial site. NRC considers that the stability requirement can be met by the grouted waste tanks.

Alternative Waste Classification Criteria

In most of the tanks at SRS the residual heel would meet Class C concentration limits with the application of concentration averaging [10]. Concentration averaging allows credit for mixing of waste with stabilization material. That is, the concentration of radionuclides in the waste can be averaged over the volume of the waste plus the stabilization material, not just over the volume of the waste. In the HLW tanks at SRS, the reducing grout is the only layer to mix with the residual waste, therefore, concentration averaging will be used only with this layer.

Fourteen of the 51 HLW tanks at SRS will require only bulk waste removal and water washing, with concentration averaging, to meet the Class C limits. The remaining 37 tanks would require chemical cleaning via oxalic acid washing to meet Class C concentration limits with concentration averaging. Some of the 37 tanks would require extensive cleaning to meet the limits.

The DOE-SRS methodology therefore relies on alternative considerations for the classification of the waste, rather than planning to use oxalic acid cleaning in all tanks to meet Class C concentration limits. In particular, DOE-SRS relies on its plans, described above, to solidify the waste in layers of grout, some 30 feet below the surface of the ground; further, DOE-SRS relies on the site which is considered stable. Finally, DOE-SRS relies on its plans to clean the remaining 37 tanks, using oxalic acid only to the extent necessary to meet the performance objectives of Part 61 (see discussion below under Criterion Three), and not to the extent necessary to meet Class C concentration limits. These alternative considerations – waste form, method of closure and stability of the site – are viewed by DOE-SRS as providing comparable protection for an inadvertent intruder to that which would be provided if the waste met Class C limits. Protection of an inadvertent intruder was used as the primary performance measure when the Class C concentration limits were developed [11].

The DOE-SRS methodology does not assure waste is Class C in accordance with Criterion Two. However, the DOE-SRS methodology relies on an approach that is similar to that in 10 CFR 61.58 of the Commission’s regulations which provides for alternative considerations for classification "if after evaluation, of the specific characteristics of the waste, disposal site, and method of disposal, [the Commission] finds reasonable assurance of compliance with the performance objectives of [10 CFR Part 61] Subpart C [9].” As discussed below, DOE-SRS has provided information showing the DOE-SRS methodology will meet the performance objectives of Part 61. Further, DOE-SRS’s methodology relies on the presence and stability of the waste form and the depth of the waste to protect the inadvertent intruder. The NRC considers that although the Class C concentration limits cannot be met for all tanks, if DOE-SRS removes tank waste to the maximum extent that is technically and economically practical, and meets performance objectives consistent with those specified for disposal of LLW, the tank closure methodology should provide adequate protection of public health and safety and the environment.

Suggested Alternative Concentration Limits

Although NRC agreed with DOE-SRS's incidental waste determination based on Criteria One and Three, NRC has suggested that DOE-SRS develop concentration limits, in essence a site-specific alternative to the Class C concentration limits [12]. These limits would bound the closure analysis and provide a firm benchmark for satisfactory cleaning of the tanks, particularly the handful of tanks that cannot meet Class C concentration limits even with application of concentration averaging.

As part of our analysis we formulated a set of concentration limits, developed from the draft and final environmental impact statements [11], [13] for 10 CFR Part 61. NRC has taken a position of risk-informed performance-based regulation. This is a significant departure from classifying waste based on source or concentration. The definition of HLW is not based on risk or performance. In contrast, however, the LLW concentration limits were developed based on dose standards. The concentrations given in Table 1 and Table 2 of 10 CFR 61.55 were determined by dose modeling. These concentrations are the maximum concentrations that would prevent a total effective dose equivalent (TEDE) greater than 5 mSv/yr (500 mrem/yr) to an inadvertent intruder at 500 years after closure, when engineered barriers are assumed to fail. An important aspect of this dose standard is that the dose limit is applied at 500 years. Therefore, the concentrations given in Tables 1 and 2 of 10 CFR 61.55 allow for decay. The one exception is alpha emitting transuranic nuclides with half-lives greater than five years.

All 51 tanks at SRS are expected to meet Class C concentration limits for all radionuclides in Table 2 of 10 CFR 61 (short-lived radionuclide limits). The tanks that cannot meet Class C concentration limits are the tanks with the largest TRU inventory. The concentration limit for alpha emitting TRU in 10 CFR 61.55 is 100 nCi/g (3700 Bq/g). The 100 nCi/g (3700 Bq/g) value was based on the average value of expected TRU content for typical LLW streams, and not on a limiting intruder dose of 5 mSv/yr (500 mrem/yr). The Final Environmental Impact Statement (FEIS) for 10 CFR Part 61 states that the 100 nCi/g TRU (3700 Bq/g) limit would give an inadvertent intruder a dose, 500 years after closure, of 0.08 to 1.7 mSv/yr (8-170 mrem/yr) to the bone. The rule (10 CFR 61) does not provide radionuclide specific TRU limits because such limits would require that waste intended for burial be subject to alpha or gamma spectroscopy for isotopic analysis. This type of analysis was deemed too burdensome. As a result, the 100 nCi/g (3700 Bq/g) limit does not apply to a single isotope but instead to all alpha emitting TRU isotopes. This is an important distinction, because DOE-SRS has already characterized the tank inventories, and could therefore apply specific TRU limits without requiring extensive alpha or gamma spectroscopy.

In addition, the 100 nCi/g (3700 Bq/g) limit for all alpha emitting TRU does not account for decay, and therefore assumes that a given concentration of Pu-238 would represent the same temporal hazard as that of Pu-239 at any time post closure. Most TRU waste is long lived, but Pu-238 and Am-241 are relatively short-lived (86 years and 458 years, respectively). At SRS, these are the radionuclides of greatest concern with respect to the Class C concentration limits. The FEIS determined the radionuclide specific TRU limits for an intruder at 500 year post closure for a dose standard of 5 mSv/yr (500 mrem/yr). Table I in this article documents the TRU radionuclide specific limits as determined in the FEIS for 10 CFR Part 61.

Table I: Concentration limits for alpha emitting TRU isotopes (from the FEIS for 10 CFR 61). [13]

Concentration Limits for Alpha emitting TRU Isotopes (nCi/cm^3)		
Isotope	**Class A**	**Class C**
Np-237	4.1	41
Pu-238	28	6800
Pu-239 & Pu-240	10.4	105
Pu-242	11	110
Am-241	7.9	140
Am-243	6.6	68
Cm-243	62	78,000
Cm-244	540	41,000

The Class C concentration limits for all radionuclides discussed in the FEIS differ from the Class C concentration limits provided in the Draft Environmental Impact Statement for Part 61 (DEIS) by a factor of ten. The DEIS neglected to account for mixing with dirt that the Class C waste would be subject to while as it was brought to the surface in an inadvertent intruder scenario. As stated in the FEIS, Class C waste must be buried at a depth of five meters. When this minimum depth of burial is accounted for, the concentration limits for Class C waste were increased by a factor of ten. This logic can also be applied to the residual tank waste at SRS. The minimum depth of burial for the residual waste at SRS is 30 feet, or approximately 10 meters. Therefore, an additional factor of ten dilution can be allowed for all radionuclides in Tables 1 and 2 for residual tank wastes, for tanks at least five meters below the surface.

Site-specific concentration limits for the residual tank waste at DOE-SRS could be set as follows, providing the performance objectives are met:

> No radionuclide concentration shall exceed ten times the value specified in Table 1 of 10 CFR 61.55, with the following alterations. The table shall be revised to include the specific TRU limits from the FEIS, rather than the general 100 nCi/g limit for all alpha emitting TRU. In addition, no radionuclide concentration shall exceed the value specified in Table 2 Column 3 in 10 CFR 61.55. The procedure established in 10 CFR 61.55(a)(7) shall be followed such that the sum of the fractions for all [altered] Table 1 radionuclides shall not exceed ten, and the sum of the fractions for all Table 2 radionuclides shall not exceed one. The administration of an alternative waste classification would not supercede the need to meet all aspects of Criterion One and Criterion Three.

Criterion Three

Criterion Three requires that the stabilized waste meet performance objectives similar to those provided in 10 CFR 61, Subpart C, specifically protection of the public, protection of an inadvertent intruder, protection of workers, and site stability. The NRC staff evaluation of DOE-SRS's methodology for meeting the third criterion was relatively straightforward. To show compliance with Criterion Three, DOE-SRS provided a performance assessment (PA) for closure of HLW tanks at the F-tank farm. The PA showed that no inadvertent intruder (resident farmer) would be expected to receive a TEDE greater than 5 mSv/yr (500 mrem/yr), and no member of the public would be expected to receive a yearly TEDE greater than 0.25 mSv (25 mrem). Although not originally included in the PA, DOE-SRS also performed an extensive uncertainty analysis and a sensitivity analysis in response to NRC staff requests. Following these additional analyses, the maximum drinking water dose to a member of the public was calculated to be approximately 0.019 mSv/yr (1.9 mrem/yr) and approximately

1.30 mSv/yr (130 mrem/yr) to an intruder. DOE anticipates drinking water to be the largest contributor to total dose which indicates that both public and intruder doses should be well within the regulatory limits.

DOE-SRS will meet the worker protection standard in 10 CFR 61.43 through the use of DOE regulations, 10 CFR Part 835, which are comparable to those administered by NRC through 10 CFR Part 20.

For the fourth performance objective, "Stability of the disposal site after closure," the information indicates the site stability of the tank farm and HLW tanks will be provided from the grout used to immobilize the residual waste. Over 30 feet of grout will be added to each tank, and no active maintenance for the tanks will be needed once the grouting process has been completed.

Based on its review of the PA and supplementary information provided during its review, we conclude that there is reasonable assurance that the HLW tanks closed according to the DOE-SRS methodology can meet Criterion Three.

CONCLUSIONS

NRC has concluded that although the Class C concentration limits cannot be met for all tanks, if DOE-SRS removes tank waste to the maximum extent that is technically and economically practical, and meets performance objectives consistent with those specified for disposal of LLW, the tank closure methodology should provide adequate protection of public health and safety and the environment. The incidental waste determination, unlike the HLW definition, is a risk-informed, performance-based approach. The DOE-SRS methodology for considering residual tank waste as non-HLW using the incidental waste determination, and the NRC staff review were similarly based on risk analysis and performance assessment.

DOE-SRS intends to evaluate and pursue the alternative waste classification process specified by 10 CFR 61.58 in support of high-level waste tank system closure activities. DOE-SRS will work closely with DOE-Headquarters to address this alternative process with regard to DOE Order 435.1 requirements and the requirements of the National Environmental Policy Act.

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