OPERATING LIMIT EVALUATION FOR DISPOSAL OF URANIUM ENRICHMENT PLANT WASTES

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Operating Limit Evaluation for Disposal of Uranium Enrichment Plant Wastes

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Introduction

PGDP is one of two government-owned, contractor-operated uranium enrichment facilities within the U.S. Department of Energy (DOE) complex. As an industrial facility, activities at PGDP generate substantial amounts of waste that are intended for disposal in a solid waste landfill permitted by the Commonwealth of Kentucky in accordance with provisions of Subtitle D of the Resource Conservation and Recovery Act (RCRA). A proposed solid waste landfill at Paducah Gaseous Diffusion Plant (PGDP) will accept wastes generated during normal plant operations that are considered to be non-radioactive. However, nearly all solid waste from any source or facility contains small amounts of radioactive material, due to the presence in most materials of trace quantities of such naturally occurring radionuclides as uranium and thorium. In addition, activities at the PGDP involving the handling and processing of uranium in various isotopic abundances can result in the addition of small amounts of radioactive material to waste that otherwise would be intended for disposal in a solid waste landfill. Such incidentally contaminated waste containing very low levels of radioactive material is quite different, with regard to its potential impacts on public health and the environment, from the kinds of low-level radioactive waste generated directly from operations, which are intended for disposal in dedicated facilities for low-level radioactive waste in accordance with DOE requirements in Order 5820.2A (DOE 1988).

The rationale for allowing waste materials which are slightly contaminated with radioactive material to be sent to a solid waste landfill include the following. First, in many wastes with low levels of contamination, the presence of radionuclides which resulted from activities at the facility would be virtually indistinguishable from background levels that would occur in the absence of any such activities. Second, if the limits on allowable quantities of radionuclides in solid waste are set sufficiently low, the resulting effects on public health and the environment from disposal in a landfill would be negligible, particularly in comparison with the corresponding effects due to the ubiquitous natural background of radiation.

This paper describes an evaluation of operating limits, which are protective of public health and the environment, that would allow waste materials containing small amounts of radioactive material to be sent to a new solid waste landfill at PGDP. The operating limits are expressed as limits on concentrations of radionuclides in waste materials that could be sent to the landfill based on a site-specific analysis of the performance of the facility (Lee et al. 1995). These limits are advantageous to PGDP and DOE for several reasons. Most importantly, substantial cost savings in the management of waste is achieved (Boo 1995). In addition, certain liabilities that could result from shipment of wastes to a commercial off-site solid waste landfill are avoided. Finally, assurance that disposal operations at the PGDP landfill are protective of public health and the environment is provided by establishing verifiable operating limits for small amounts of
radioactive material; rather than relying solely on administrative controls. The operating limit determined in this study has been presented to the Commonwealth of Kentucky and accepted as a condition to be attached to the operating permit for the solid waste landfill.

Performance Objectives for Landfill Disposal

Subtitle D of RCRA provides for the disposal of non-radioactive wastes without providing a definition of the term “non-radioactive.” For wastes with naturally occurring radionuclides, “non-radioactive” most certainly must allow for the presence of some radioactivity. Since the objective of establishing a meaningful operating limit is to protect public health and the environment, performance objectives were identified to determine acceptable disposals of waste with small amounts of radioactive material.

No general regulatory policy as yet exists that is expressed in terms of negligible dose for exposed individuals or populations that could be used to exempt a wide variety of practices or sources, including disposal of any waste, from regulatory requirements for radioactive material. However, regulatory requirements for acceptable disposals of radioactive waste are available. For DOE, these requirements are specified in DOE Order 5820.2A (DOE 1988). This Order limits an inadvertent intruder at 100 years after disposal to chronic exposures of 1 mSv/yr (100 mrem/yr) effective dose equivalent, and to acute exposures of 5 mSv (500 mrem) effective dose equivalent. Exposures to off-site individuals due to atmospheric releases are limited to 0.1 mSv/yr (10 mrem/yr) effective dose equivalent. The dose limit for the general public is 0.25 mSv/yr (25 mrem/yr) effective dose equivalent from all pathways, and groundwater resources are to be protected consistent with existing regulatory requirements. The performance objective for protection of groundwater resources is usually interpreted as compliance with standards for radioactivity in public drinking water supplies established by the EPA in 40 CFR 141.

The performance objectives for off-site individuals and inadvertent intruders for low-level radioactive waste disposal described above are not directly applicable to disposal of slightly contaminated waste in a solid waste landfill, because upper bounds on negligible dose that would be appropriate for disposal of waste which is essentially unregulated in regard to its radioactivity content should be substantially less than limits on acceptable dose that are appropriate for disposal of waste which is carefully regulated for its radioactivity content (NCRP 1993). With regard to the protection of groundwater resources, the requirements of 40 CFR 141 do provide upper bounds on negligible dose for waste disposal, because this standard is applied to community water systems and is extended to groundwater protection at the edge of a disposal facility.

The performance objectives for solid waste disposal used to define the operating limit for this investigation include the following:

- For off-site individuals, a limit on effective dose equivalent from direct consumption of contaminated water of 0.04 mSv/yr (4 mrem/yr).
For inadvertent intruders onto the disposal site, a limit on effective dose equivalent from all exposure pathways involving direct intrusion into solid waste in the disposal facility of 0.04 mSv/yr (4 mrem/yr).

These radiological performance objectives assume that all other requirements for disposal of waste in a solid waste landfill (e.g., RCRA requirements) are met. These limits were chosen based on the following rationale.

The off-site performance objective for exposures of off-site individuals was based on the presumption that releases of radionuclides from the disposal facility to the environment will occur primarily by groundwater transport, and on the proposed revisions of EPA standards for radioactivity in public drinking water supplies in 40 CFR 141 (EPA 1991). In addition, based on previous analyses for the Oak Ridge and Savannah River sites (ORNL 1994, MMES 1994), the dose from all exposure pathways is dominated by the dose from the drinking water pathway only. If the solid waste landfill is operated consistent with RCRA requirements, which include covering of the waste with uncontaminated soil, atmospheric releases should be of no concern. Furthermore, releases to surface water should be in concentrations less than concentrations in groundwater. By having a performance objective for inadvertent intrusion that is equivalent to the performance objective for groundwater resource protection, the potential exposures to any individual would be negligible. Drinking water standards for radionuclides clearly define an upper bound on negligible risk, because there is no requirement to reduce levels of radioactivity below the standards even if it would be cost-effective to do so. Thus, the performance objective for off-site individuals, when extended to an inadvertent intruder, provides a reasonable basis for establishing negligible risk from the disposal of slightly contaminated wastes.

These performance objectives were applied to each radionuclide that is potentially present in PGDP wastes in a site-specific analysis of disposal facility performance to determine the maximum concentration in wastes that would be consistent with the performance objectives. For each radionuclide, the more restrictive concentration limit in the waste, based on the analyses for the drinking water pathway for off-site individuals and for exposures of inadvertent intruders is selected as the limit for that radionuclide. These concentration limits are then used to define an operating limit.

**Disposal Facility Description**

PGDP is located on a 1385 ha (3423 ac) federal reservation near Paducah, Kentucky, and 5 km (3 miles) south of the Ohio River. Surface soils are underlain by loess, Pliocene-Pleistocene continental deposits, Tertiary and Cretaceous sediments, and Mississippian bedrock. The major aquifer in the area is confined by a Tertiary clay layer that is hydraulically connected to the Ohio River. An overlying unconfined aquifer recharges the major aquifer. The major aquifer is at a depth of about 15 m (50 ft) near the site of the solid waste landfill. The thickness of the major aquifer is about 9 m (30 ft), with the unconfined aquifer having a variable thickness that is about 3 m (10 ft). The hydraulic conductivity of the unconfined aquifer is about 1 m/d, and the major aquifer is about 100 m/d. The site is drained by two minor tributaries of the Ohio River. One
tributary is ephemeral without the addition of PGDP discharges. The average discharge of the two creeks is 0.18 m³/s (6.3 ft³/s), including PGDP discharges that amount to more than 85% of the total discharge.

Waste materials to be disposed of at the solid waste landfill include soils, wood, concrete, roofing, construction debris, and sanitary wastes. As a uranium enrichment facility, PGDP wastes may be contaminated with uranium with varying assays. Other isotopes possibly present in wastes in smaller amounts include ⁹⁹Tc, ²³⁰Th, ²³²Th, ²³⁷Np, ²³⁸Pu, ²³⁹Pu, and ²⁴¹Am. Other radionuclides of potential concern are not known or not suspected to be in wastes at PGDP.

The solid waste landfill is expected to have a total capacity of 1,200,000 m³ (1,600,000 yd³), with an average disposal rate of 6000 m³/yr (8000 yd³/yr). The landfill will be operated by constructing ten cells, with each cell expected to be filled over a period of 20 years. The wastes are to be compacted and covered with excavated soils in a ratio of 1:1 of waste to soil. The final cover for the landfill will be installed at the completion of the operating period of the landfill.

Analysis of Performance

Transport of radionuclides from the solid waste landfill was analyzed using a site-specific application of the FTWORK code developed by GeoTrans (1990a). The model was adapted to provide sufficient resolution for the new solid waste landfill and to represent the transport of contamination from the landfill to a future off-site receptor. The consideration of inadvertent intrusion was performed as part of the analysis of performance to address possible exposures of such individuals from disposals at the landfill. Each of these aspects of the analysis is discussed below.

Source term

To determine the source term for the analysis of contaminant transport in groundwater, the landfill was subdivided into parts, which were filled in succession over time. The model assumed that the waste was emplaced uniformly over each part at a constant rate during its 20-year period of operation, and covered at closure to reduce infiltration. The cover and liner of each part were assumed to remain intact for a period of 30 years after cover installation. The hydraulic conductivity of the cover and liner were assumed to increase exponentially with a decay constant of 0.1 per year approaching that of local soils. Site recharge of 12 cm/yr was assumed to infiltrate into the waste during the period of operations, decline to 10% of the site recharge as a result of the performance of the cover and liner, and increase exponentially afterwards to the site recharge value. Leachate was generated at a constant rate defined by the distribution coefficient of each radionuclide in the waste. The leachate generated during the operations period was assumed to be collected by the leachate collection system. All leachate generated after emplacement of the cover was assumed to infiltrate into the soils and to be transported to groundwater.
The source term model assumed that radioactive decay could be accounted for at the end of the calculation based on the travel time of the parent radionuclide in groundwater. Solubility limits for radionuclides were not considered, because concentrations of contamination are likely be low. Additionally, wastes were assumed to be contaminated uniformly such that a uniform distribution within the waste mass could be considered. Finally, radionuclides were considered individually in this analysis.

Groundwater flow and mass transport

The finite-difference code FTWORK (GeoTrans 1990b) was used for modeling groundwater and contaminant transport. The geologic strata were represented as a four-layer, variable thickness composite, that were calibrated to field data. The head distribution was calibrated to the available monitoring data, with distribution coefficients for the wastes and soils selected from PGDP site evaluations.

Dose estimation

Estimates of dose for the consumption of contaminated groundwater were developed in the form of annual effective dose equivalents per unit concentration of radionuclides based on the consumption of 730 L/yr of contaminated water from the contaminated source, and the ingestion dose conversion factors for each radionuclide of concern. Exposures of inadvertent intruders were assumed to occur according to the agriculture-homesteader scenario (ORNL 1994, MMES 1994). The scenario dose conversion factors are estimated as the sum of the pathway dose conversion factors for the different exposure pathways. For the agriculture-homesteader scenario, an inadvertent intruder was assumed to arrive at the site immediately after the end of active institutional controls, and to construct a house directly on top of the landfill such that the foundation extends into the wastes. Waste materials were assumed to be indistinguishable from native soil, and to be exhumed in the construction of the house and mixed with native soils in a vegetable garden. The pathways that were assumed to occur were ingestion of vegetables grown in contaminated soil, direct ingestion of contaminated soil, external exposure to contaminated soil, and inhalation of contaminated soil.

Results of Analysis

The results of the analysis of the facility were used to determine concentrations in waste that would satisfy the performance objectives for disposal for protection of off-site members of the public and inadvertent intruders. The more restrictive concentration for each radionuclide was considered to be the concentration limit. The concentration limits were then used in conjunction with existing regulatory guidance to define an operating limit for the solid waste landfill.
Source term and groundwater results

The contaminant flux to groundwater during the operating period and institutional control period was controlled by the performance and degradation of the liner and the cover. The flux of contaminants reached a peak value and decreased with time. This peak occurred after institutional control ended because of the credit given to the liner and cover in the analysis.

The calculated maximum concentrations at the PGDP plant boundary are shown in Fig. 1 for each radionuclide considered. The dependance of the maximum concentration on the distribution coefficient ($K_d$), which defines the partitioning of contamination between the soil or waste and water, can be clearly seen.

![Fig. 1. Graphs for calculated maximum concentration versus time at the Paducah Gaseous Diffusion Plant boundary for radionuclides with various $K_d$ values.](image)

Dose analysis results

The results of the dose analysis were calculated including the contributions from radiologically significant short-lived decay products, which were assumed to be in activity equilibrium with the parent radionuclide. The agricultural scenario dose conversion factors for the radionuclides of concern to waste disposals at PGDP were obtained from the performance assessment for a low-level radioactive waste disposal facility at the Savannah River Site (MMES 1994). The
concentration limits of each radionuclide in waste were determined for the groundwater pathway and the inadvertent intruder that would satisfy the performance objective of 4 mrem annual effective dose equivalent. For the groundwater pathway, these concentration limits were based on the maximum concentration in groundwater at any point in time. For the inadvertent intruder, the concentration limits were based on the exposure at the end of active institutional control. The concentration limits were calculated using an assumed waste density of 0.6 g/cm³. The results are presented in Table 1.

Table 1. Concentration limits in pCi/g determined from the groundwater-contamination analysis at the plant boundary and the intruder-exposure analysis at the landfill.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Intruder-exposure</th>
<th>Groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>⁹⁹Tc</td>
<td>610</td>
<td>560</td>
</tr>
<tr>
<td>²³⁰Th</td>
<td>610*</td>
<td>11000</td>
</tr>
<tr>
<td>²³²Th</td>
<td>1.9*</td>
<td>1300</td>
</tr>
<tr>
<td>²³⁴U</td>
<td>610</td>
<td>61*</td>
</tr>
<tr>
<td>²³⁵U</td>
<td>37*</td>
<td>64</td>
</tr>
<tr>
<td>²³⁶U</td>
<td>670</td>
<td>64*</td>
</tr>
<tr>
<td>²³⁸U</td>
<td>170</td>
<td>64*</td>
</tr>
<tr>
<td>²³⁷Np</td>
<td>13.</td>
<td>0.38*</td>
</tr>
<tr>
<td>²³⁸Pu</td>
<td>200*</td>
<td>170,000b</td>
</tr>
<tr>
<td>²³⁹Pu</td>
<td>170*</td>
<td>200</td>
</tr>
<tr>
<td>²⁴¹Am</td>
<td>120*</td>
<td>1900b</td>
</tr>
</tbody>
</table>

*More restrictive limit.

bLimit based on long-lived decay products ²³⁴U for ²³⁸Pu and ²³⁷Np for ²⁴¹Am.

Interpretation of results

Table 1 provides a quantitative basis for establishing an operating limit for the solid waste landfill. Simply applying the lowest concentration limit for each isotope, however, does not address the assumptions incorporated into the calculations, the uncertainties, waste compositions, and the existing regulatory guidance. Additionally, requiring the concentration of all isotopes of concern to be measured for all wastes is not practical. For an operating limit to be effective, a practical means for certifying wastes that is consistent with the analysis of performance is needed.

The analysis of performance assumes that all wastes have an average concentration of each nuclide considered but does not consider the presence of uncontaminated materials typically
present in wastes. Dilution of wastes with uncontaminated materials is likely to reduce concentrations of materials in the landfill by a factor of about two. This conservatism is balanced by the possible increase in density from compaction of wastes, which should be about the same order of magnitude. The analysis does not conserve mass between exposures of inadvertent intruders and the transport of contamination in groundwater. For the intruder calculations, no contamination is assumed to migrate. This assumption introduces additional conservatism. Each radionuclide was analyzed independently. Mixtures were not considered but most certainly will be present in the wastes. The application of the sum-of-fractions rule for mixtures is a conservative approach to handling mixtures, because of the differing time of arrival of each isotope (Fig. 1). Other uncertainties are present in the modeling of the site and the transport of contamination. These uncertainties have been minimized by the extensive use of site data to calibrate and verify the transport model's performance.

Existing regulatory guidance includes the U.S. Nuclear Regulatory Commission Branch Technical Position Paper on the Disposal or On-Site Storage of Thorium and Uranium Wastes from Past Operations (NRC 1981), which allows for the disposal of enriched uranium with concentrations less than 30 pCi/g without restrictions on the disposal of wastes. Applications for disposal are examined on a case-by-case basis, subject to a site specific review of the proposal for disposal. Other regulatory guidance available from EPA (1994) and NRC (NRC) for cleanup of residual radioactivity at contaminated sites includes a dose limit of 15 mrem/yr. These proposed standards are much higher than the performance objective used in this analysis and have yet to be applied.

The operating limit for the solid waste landfill was set using the NRC Branch Technical Position Paper value of 30 pCi/g uranium for disposal without further restrictions. This limit is substantially less than the concentrations presented in Table 1. When applied to wastes that are typical of PGDP waste streams that are likely to be disposed of in the landfill, the presence of radionuclides other than uranium are sufficiently low that the application of the 30 pCi/g operating limit for uranium provides reasonable assurance that all nuclides in wastes will be less than the concentration limits in Table 1 after applying the sum-of-fractions rule for mixtures.

Conclusions

The operating limit study was presented to the Commonwealth of Kentucky for acceptance as a condition on the operating permit for the solid waste landfill. The operating limit of 30 pCi/g uranium was accepted. The acceptance of the operating limit will allow DOE to realize enormous savings in the disposal of slightly contaminated wastes in the solid waste landfill. The method for certifying wastes for disposal to ensure that the 30 pCi/g uranium operating limit is met is under development and will be submitted to the Commonwealth of Kentucky prior to landfill operations. The 30 pCi/g uranium operating limit will ensure that the performance objectives will be achieved in landfill operations and represents a reasonable operating limit that can be applied to landfill operations.
References


U.S. Nuclear Regulatory Commission. Disposal or onsite storage of thorium or uranium wastes from past operations. Federal Register; 46, 52061; 1981.