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CRITICALITY SAFETY CONSIDERATIONS FOR LOW-LEVEL-WASTE FACILITIES

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INTRODUCTION

The nuclear criticality safety for handling and burial of certain special nuclear materials (SNM) at low-level-waste (LLW) facilities is licensed by the U.S. Nuclear Regulatory Commission (NRC). Recently, Oak Ridge National Laboratory (ORNL) staff assisted the NRC Office of Nuclear Material Safety and Safeguards, Low-Level-Waste and Decommissioning Projects Branch, in developing technical specifications for the nuclear criticality safety of ^{235}U and ^{239}Pu in LLW facilities.[1] This assistance resulted in a set of nuclear criticality safety criteria that can be uniformly applied to the review of LLW package burial facility license applications. These criteria were developed through the coupling of the historic surface-density criterion[2,3] with current computational techniques[4] to establish safety criteria considering SNM material form and reflector influences. This paper presents a summary of the approach used to establish and to apply the criteria to the licensing review process.

REVIEW OF SURFACE-DENSITY APPROACH

The surface-density approach uses the relationship between the mass of fissile material per unit base area (i.e., surface density) in a critical, air-spaced plane array of discrete units and the critical mass per unit area of a uniform slab of the same material. The approach is to develop a limit for the allowable fissile mass per unit area (generally taken perpendicular to the axes of the arrayed units) such that a planar array of the most reactive units planned for the array will remain safely subcritical. A basic requirement for the application of the surface-density technique is that the fraction of the unit mass divided by the bare critical mass of the same material must be 0.3 or less. Given the nature of long-term placement or burial of LLW (i.e., the potential for package and contents settling), the surface density specifications for allowable fissile material masses per unit area must be applied to the level base area upon which the waste containers rest (e.g., the floor area of the storage area).

CONSIDERATIONS FOR AND RESULTS OF THE SURFACE-DENSITY APPLICATION

The melding of the surface-density spacing criteria with well-established computational tools and data was used to demonstrate the safe burial of LLW materials in packages (burial of loose bulk LLW materials was outside the scope of this application). Considerations for and results of the surface-density application included the following:

1. Allowable single-package mass limits were derived to ensure that the mass fraction critical will be 0.3 or less for various materials.
2. Material density and light water moderation effects were determined such that the most limiting surface density ranged from 35 to 50 g/L for ^{235}U systems and 20 to 25 g/L for ^{239}Pu systems.
3. Unit height and height-to-diameter (H/D) ratios were examined. H/D ratios between 1.0 and 2.5 resulted in the most limiting surface densities for both ^{235}U and ^{239}Pu systems.
4. Reflector materials (e.g., light water, concrete, wet SiO_2 and dry SiO_2). A dry silicon dioxide reflector at a density of 1.9 g/cm^3 provided the most restrictive allowable surface densities by a factor of about 2 less than for full water reflection.
5. Reflector off-sets (e.g., in contact with units and off-set 6 inches) produced no discernable effect, as expected from theory for reflected infinite homogeneous slabs.
6. Isotopic compositions (e.g., ^{235}U wt % of 100, 90, 80, and 10, ^{239}Pu wt % of 100, 80, and 76). Because of the limited influence of the "fast-fission effect" in the diluted and reduced density fissile materials in LLW, the presence of ^{238}U and ^{240}Pu tends to increase the allowable surface density.
7. Due to the selection of optimum moderation for the fissile material in the LLW calculational model further addition of moderators (e.g., 12-gauge or 1/4-in.-thick carbon-steel or 1/4-in.- or 1-in.-thick lead, and wet and dry SiO_2) between the units resulted in equal or less-reactive arrays.
8. For ^{235}U-contaminated LLW bulk carbon, dilution of ^{235}U results in a minimum reduction of the allowable ^{235}U surface density value such that the total mass of carbon (graphite) present in a unit (package) should not exceed 20 times the total mass of the ^{235}U that

may be present. However, the inclusion of bulk carbon with ^{239}Pu-contaminated LLW demonstrated continued reduction in allowable surface densities. Also, the inclusion of bulk beryllium in either ^{235}U- or ^{239}Pu-contaminated LLW demonstrated the continued reduction in the allowable surface density.

9. No effect was observed in calculated results between triangular-pitch and square-pitch arrays having identical surface density values.

10. A typical total calculational uncertainty of about 0.053 was assumed, and evaluated surface density was reduced by about 20% to ensure subcriticality.

SUMMARY

The following table summarizes operational limits derived from the surface-density application.

Summary of operational areal density limits for fissionable material in LLW[a]

Fissile material type (wt %) of fissile nuclide	Maximum mass of fissile nuclide per package	Maximum fissile nuclide areal density[b]	Maximum bulk carbon areal density[b]
≤ 100 wt % ^{235}U	350 g ^{235}U	94 g $^{235}U/ft^2$	1880 g C/ft^2
≤ 10 wt % ^{235}U + ≥ 90 wt % ^{238}U	350 g ^{235}U	174 g $^{235}U/ft^2$	3480 g C/ft^2
≤ 100 wt % ^{239}Pu	225 g ^{239}Pu	52 g $^{239}Pu/ft^2$	c
≤ 76 wt % ^{239}Pu + ≥ 12 wt % ^{240}Pu + ≤ 12 wt % ^{241}Pu	225 g ^{239}Pu + 35 g ^{241}Pu	(51 g ^{239}Pu + 8 g $^{241}Pu)/ft^2$	c

[a] For a given fissile material type, all three limits (i.e., grams fissile nuclide per container, fissile nuclide areal density, and bulk carbon areal density) must be ensured.

[b] The areal density in kg/m^2 can be obtained by multiplying the g/ft^2 values by 0.010763.

[c] Packages with bulk carbon are outside the scope of these suggested criteria and must be considered on a case-by-case basis.

REFERENCES

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