

LANDFARMING OF MUNICIPAL SEWAGE SLUDGE AT OAK RIDGE, TENNESSEE

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ABSTRACT

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The City of Oak Ridge, Tennessee, has been applying municipal sanitary sludge to sites comprising 90 ha on the U.S. Department of Energy (DOE) Oak Ridge Reservation (ORR) since 1983. Approximately 13,000,000 L are applied annually by spraying sludge (2 to 3% solids) under pressure from a tanker. Under an ongoing monitoring program, both the sludge and the soil in the application areas are analyzed for organic, inorganic, and radioactive parameters on a regular basis. Organic pollutants are analyzed in sludge on a semiannual basis and in the soil application areas on an annual basis. Inorganic parameters are analyzed daily (e.g., pH, total solids) or monthly (e.g., nitrogen, manganese) in sludge and annually in soil in application areas. Radionuclides (Co-60, Cs-137, I-131, Be-7, K-40, Ra-228, U-235, U-238) are scanned daily during application by the sewage treatment plant and analyzed weekly in composite sludge samples and annually in soil. Additionally, data on radioactive body burden for maximally exposed workers who apply the sludge show no detectable exposures. This monitoring program is comprehensive and is one of the few in the United States that analyzes radionuclides. Results from the monitoring program show heavy metals and radionuclides are not accumulating to harmful levels in the soil application areas.

INTRODUCTION

The City of Oak Ridge, Tennessee, has been applying municipal sanitary sludge to land on the DOE ORR since 1983 under an agreement with DOE and the Tennessee Department of Environment and Conservation (TDEC). Previous work on the benefits of this sludge application to sycamore (*Platanus occidentalis*) and loblolly pine (*Pinus taeda*) on the ORR showed that even a single dose application of sludge resulted in a long-term (>10 year) positive

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growth and biomass (Van Miegroet et al. 1991). The majority of the nutrients were retained in the upper soil, with a significant increase in the total and available nitrogen. This benefit lasted several years after the sludge application, in contrast to another experimental plot where inorganic nitrogen was leached away within a few months of application (Van Miegroet et al. 1991).

Other researchers have shown the benefits of land application of municipal sludge. For example, McNab and Berry (1985) found that three species of pine seedlings planted in soil amended with dried sludge produced approximately 3 X more tree biomass and 8% more wood as a percentage of total tree weight when compared to trees grown in soil amended with inorganic fertilizer. Peterson and coworkers (1984) grew poplars in a greenhouse environment and compared poplars grown in sludge-amended soil with those grown in ammonium nitrate fertilized soil. The poplars grown in the sludge-amended soil grew faster than those grown in soil amended with inorganic nitrogen. Peterson et al. (1984) also showed that the trees grown in sludge-amended soil did not accumulate more of any nutrient or heavy metal than those grown with inorganic nitrogen.

The City of Oak Ridge sewage treatment plant receives wastewater from both domestic and industrial sources. The land application consists of spraying sludge (2 to 3% solids) under pressure from a tanker at a rate of approximately 10 metric tons/ha. Nine sites comprising 90 ha have been used by the city: four sites comprising 28 ha have been closed following land application, and five sites comprising 63 ha are still active application sites. Currently, 2 to 6 loads per day (40 to 120 loads/month) of sewage sludge are trucked in a 20,000-L tanker truck to the application sites and transferred to a 5,300-L field vehicle for surface spray application. Approximately 13,000,000 L/year are applied, resulting in a thin layer of sludge on surface vegetation.

Sewage sludge typically contains both natural and human-made radionuclides. Because there are currently no applicable federal sludge radioactivity standards, conservative radionuclide limits for ORR sludge application have been established (DOE 1994). These limits require that

the resulting average concentration of uranium and other radionuclides with longer decay periods in the receiving soil will not generally exceed 2X background. In addition, to ensure long-term acceptability of the Oak Ridge sludge application program, a risk-based model for determining acceptable radionuclide concentrations in sludge has been established.

Industrial customers of the City of Oak Ridge sewage treatment plant include a DOE facility and several private companies that use radioactive materials. These customers must meet U.S. Nuclear Regulatory Commission (NRC) regulations governing sewage discharges to municipal treatment plants from NRC licensees; however, radioactive materials coming from medical facilities, such as the local hospital, currently do not have to meet the same program limits as other standard industrial customers. Because radionuclides may become concentrated in the sludge during the treatment process, the municipal sludge has been monitored for radionuclides in addition to other federal- and state-mandated components.

Although there are no federal requirements to test sludge for radionuclides, both the sludge and the landfarm areas on the ORR are part of an ongoing monitoring program. The radiological content of municipal sludges is of concern to the NRC and the U.S. Environmental Protection Agency (EPA); however, DOE's local monitoring program is one of the few programs in the United States that analyzes radiological content in sludge (GAO 1994). The data compiled from this comprehensive program provide the opportunity to monitor any potentially harmful buildup of metals and radionuclides over a long period of time.

METHODS

The City of Oak Ridge, in cooperation with DOE, analyzes organic, inorganic, and heavy metal parameters in digested sewage sludge and sludge application site soils in compliance with 40 CFR 503.10-503.18, the State of Tennessee Land Application Approval (LAA), and the City of Oak Ridge National Pollutant Discharge Elimination System (NPDES) Permit #TN0024155. LAA inorganic parameters in sludge (such as pH, total solids percent and percentage of volatile

solids) are monitored daily (City of Oak Ridge 1994). Other LAA inorganic parameters in sludge include ammonia, nitrate, nitrite, inorganic nitrogen, total Kjeldahl nitrogen, organic nitrogen, manganese, potassium, and phosphorus, which are analyzed monthly (City of Oak Ridge 1994). Heavy metals in sludge are analyzed monthly, and toxic organic compounds are analyzed twice a year by both EPA methods 8270 and 8080 (City of Oak Ridge 1994). Radionuclides (Co-60, Cs-137, I-131, Be-7, K-40, Ra-228, U-235, U-238) are analyzed weekly in composite sludge samples, and sludges to be hauled and applied on the ORR are scanned daily. Soils from sludge application sites are analyzed annually for organic, inorganic, heavy metal, and radioactive chemicals.

Three City of Oak Ridge employees at the sewage treatment plant have the potential for occupational exposure to the sludge, either at the treatment plant or during spraying operations. All have been employed at the plant since the land application of the sludge has been in operation. They have been monitored for exposure to radionuclides through whole body counts and urinalysis (DOE 1994).

RESULTS

Table 1 shows the highest levels of heavy metals detected in the sludge in 1993 and compares them with the federal limits under 40 CFR 503.13. In all instances, the heavy metal concentrations in the sludge were well below the federal ceiling limits for these compounds. Chlordane (0.55 $\mu\text{g}/\text{kg}$) was the only organic contaminant reported above the detection limit in the sludge in 1993 (City of Oak Ridge 1994).

Table 2 shows the radionuclide levels in the municipal sludge from 1988 to 1993. The concentrations of naturally occurring radionuclides such as ^{7}Be , ^{40}K , and ^{226}Ra have remained relatively constant throughout the reporting period. Concentrations of radionuclides that are a result of nuclear testing fallout (^{60}Co and ^{137}Cs) dropped between 1988 and 1993. Uranium entering the sewage treatment plant has dropped dramatically since 1988 and is thought to be the

result of improved practices on the part of local industrial customers. The increased use of medical isotopes by Oak Ridge Methodist Medical Center is seen in the 6-fold increase in ^{131}I from 1988 to 1993.

Table 3 shows the cumulative radionuclide loading at five application sites that are currently active. Although it appears that radionuclides are accumulating to some extent at some sites (e.g., ^{137}Cs is twice as high at the Scarboro Road application site than in the adjacent reference site), there is little or no difference between radionuclide concentrations at the application sites and adjacent reference sites for most radionuclides reported. Radionuclides do not appear to concentrate and accumulate at the application sites.

Whole body counts and urinalysis of the three municipal workers showed no detectable radioactivity from occupational exposure to sludge. Quantitative risk assessment using standard methods in compliance with DOE Order 5400.5 and standard EPA methodologies (EPA 1989 and EPA 1991) has shown no appreciable risks to these workers who would be maximally exposed to the sludge (DOE 1994).

DISCUSSION

Land application of municipal sludge is a viable option for beneficial reuse of the organic nutrients and nitrogen contained in the sludge. Studies have shown that sludge application increases timber yields (Sopper & Kerr 1980, Van Miegroet et al. 1991, Chapman-King et al. 1990, McNab & Berry 1985, and Peterson et al. 1984), and land application can be a cost-efficient alternative for final disposal (DOE 1994).

There are both practical limits and regulatory limits to the amount of sludge that can be applied to a land area. Practically, excess nitrogen is harmful. There are legal constraints on both the daily and cumulative application of both nutrients and heavy metals. DOE has established conservative loading limits that are below those established by federal law (DOE 1994). Because there are no standard loading limits for radionuclides, buildup of these

compounds is of concern to the public. Extensive monitoring of the land application areas on the ORR has shown that buildup of radionuclides from municipal sludge is not occurring.

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Caption List:

TABLE 1. City of Oak Ridge highest heavy metal levels for 1993 vs. 40 CFR 503.13 ceiling concentration limits.

TABLE 2. Historical radiological characterization of Oak Ridge sanitary sewage sludge (selected radionuclides).

TABLE 3. Cumulative radionuclide loading on active sludge land application sites.

Key Words:

municipal sludge, sewage sludge, landfarm, land application, 40 CFR 503.13, beneficial use, heavy metals, radionuclides

**TABLE 1. City of Oak Ridge highest heavy metal levels for 1993 vs.
40 CFR 503.13 ceiling concentration limits.**

Heavy Metal	Highest Detected Sludge Level in 1993 ^a	40 CFR 503.13 Ceiling Concentration Limits ^a
Arsenic	25.1	75
Cadmium	15.1	85
Chromium	185	3000
Copper	544	4300
Lead	95	840
Mercury	16.2	57
Molybdenum	33.8	75
Nickel	51	420
Selenium	20.9	100
Zinc	2070	7500

(a) All levels are in mg/kg dry weight.

TABLE 2. Historical radiological characterization of Oak Ridge sanitary sewage sludge (selected radionuclides)

Radionuclide	Half Life	Source(a)	Average Concentration, pCi/g dry weight					
			1988	1989	1990	1991	1992	1993
⁷ Be	53.6 d	1	1.2	1.5	1.7	1.6	1.3	1.7
⁴⁰ K	1.28×10^9 y	1	7.0	6.8	7.2	5.9	5.1	5.8
⁶⁰ Co	5.27 y	2,4	5.3	2.5	3.3	0.9	0.8	0.6
¹³¹ I	8.04 d	5	6.8	8.5	5.9	9.7	17	42
¹³⁷ Cs	30.2 y	2,4	2.0	1.3	2.7	1.4	0.5	0.6
²²⁶ Ra	5.8 y	1	0.6	0.9	1.2	0.7	0.7	0.9
U - total	4.5×10^9 y	1,2,3	140	50	30	25	23	13(b)
U-235 assay			0.32%	0.51%	0.71%	0.80%	0.90%	0.8% (b)

(a) (1) Natural radionuclide, (2) nuclear reactor, (3) uranium industry, (4) nuclear testing fallout, and (5) medical radionuclide.

(b) Based on gamma spectroscopy; prior year total uranium by neutron activation, U-235 assay by mass spectroscopy.

TABLE 3. Cumulative radionuclide loading on active sludge land application sites.

Selected Radionuclide	Cumulative Radionuclide Loading on Indicated Site, pCi/g									
	Hayfield #1		Hayfield #2		High Pasture		Watson Rd.		Scarboro Rd.	
	Ref(a)	Total(b)	Ref	Total	Ref	Total	Ref	Total	Ref	Total
Potassium-40	3.0	2.7	3.0	4.8	3.1	4.1	11.2	7.4	4.0	3.8
Cobalt-60	0.01	0.05	0.01	0.01	bld	0.06	bld	0.01	bld	0.03
Srontium-90	0.07	0.12	0.07	0.19	0.12	0.14	0.15	0.17	0.18	0.17
Technetium-99	0.01	0.01	0.01	0.05	0.04	0.08	0.06	0.09	bld	0.04
Cesium-137	0.54	0.57	0.54	0.77	0.47	0.45	0.54	0.59	0.48	0.81
Uranium-total	2.8	3.6	2.8	3.2	2.3	3.4	3.0	2.9	2.4	3.2

(a) Assumed background radiation for given site based on radioanalysis of soil taken from adjacent site not used for sludge; bld signifies radionuclide measurement below level of detection.

(b) Radionuclides found in top 15 cm of application site soil by lab radioanalysis of samples taken in 1992 and 1993, values include background.