Radiological Dose Assessment of NORM Disposal in Class II Injection Wells*

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ABSTRACT

Subsurface disposal of petroleum industry wastes containing naturally occurring radioactive material (NORM) via injection into Class II wells was modeled to estimate potential radiological doses to individuals consuming water from a shallow aquifer. A generic model was developed for the injection of 100,000 barrels of NORM waste containing 2,000 picocuries per liter of radium into a layered geologic system. In separate modeling runs, it was assumed that a casing failure released the entire volume of NORM into each successive geologic layer, including the shallow aquifer. Radionuclide concentrations and related potential doses were calculated for receptors located in the shallow aquifer from 0 to 20 miles downgradient of the injection well. The results indicated that even under conservative assumptions, calculated radionuclide concentrations and potential doses associated with subsurface disposal of NORM in Class II wells were below levels of regulatory concern. The preliminary results from a dose assessment of a specific project entailing injection of NORM into Class II wells support the conclusions of the generic study.

INTRODUCTION

In the past few years, the petroleum industry has adopted methods for managing and disposing of waste streams containing naturally occurring radioactive material (NORM) that are more restrictive than past practices and are likely to provide greater isolation of radioactivity. Simultaneously, many states have promulgated regulations imposing stricter standards on the management of NORM wastes. The result of these actions has been increased costs of waste management for the petroleum industry.

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DISCLAIMER

The U.S. Department of Energy (DOE) has funded a number of studies to assess the potential risks associated with various NORM disposal options, including the disposal of NORM by injection into existing, permitted Class II wells.* The results of these studies indicate that this form of disposal presents a negligible risk to the general public. In the first such study (1), potential doses resulting from underground injection of NORM were modeled by assuming a generic geologic setting. A subsequent study (2) modeled the potential doses resulting from injection of NORM into several, specific Class II injection wells that will be used for NORM disposal in a technology demonstration project. The results of these studies are presented in this paper. Greater detail regarding the methodologies, assumptions, and input parameters is contained in the referenced reports.

GENERIC STUDY

In the generic study of NORM disposal in a Class II well (1), underground injection was modeled by assuming a geologic setting of interlayered sandstone and shale deposits, the shallowest unit being a sandstone drinking water aquifer. A conservative set of assumptions was used. Separate model runs were made assuming that during injection, a casing failure caused the entire volume of NORM-contaminated waste to be injected into each geologic layer, in turn, including the drinking water aquifer. Radionuclide concentrations were calculated at a number of receptor locations in the drinking water aquifer, ranging from 0 to 20 miles (mi) downgradient from the injection site. SWIFT II (3), a three-dimensional model, was used to model the casing failures and subsequent transport of radionuclides to the downgradient receptor locations. Annual doses resulting from the radionuclide concentrations were calculated using exposure parameters recommended by the U.S. Environmental Protection Agency for maximum residential exposures (4).

Assumptions and Input Parameters

The stratigraphy modeled in the generic study consisted of six interlayered sandstone and shale units. The upper unit was assumed to be a 1,800-feet (ft) thick sandstone layer that served as a drinking water aquifer at the receptor locations. This unit was underlain by alternating shale and sandstone units, each 1,600 ft thick. The porosities of the sandstone and shale units were assumed to be 0.2 and 0.1, respectively. The units were tilted, with a slope of 0.01. The regional groundwater gradient also was assumed to

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* Class II injection wells are a specific category of injection wells used by the oil and gas industry to dispose of saltwater produced in conjunction with oil or gas, to inject fluids to enhance oil recovery, or to store hydrocarbon liquids. Class II permitting requirements are established by the Underground Injection Control Program, Part C of the Safe Drinking Water Act of 1974.

be 0.01. This gradient is large but yields conservative estimates for travel times and concentrations in the model.

To calculate the source term for the generic study, it was assumed that 100,000 barrels (bbl) of a slurry containing NORM wastes with a radium concentration of 2,000 picocuries per liter (pCi/L) were injected over a period of four days. The exposure pathway assumed that casing failure during injection released the entire volume of NORM wastes into the subsurface units. Upon release, all of the radium dissolved instantaneously. The dissolved radium was transported in the subsurface to a drinking water well, and ingestion of contaminated groundwater resulted in exposure. To calculate potential doses, it was assumed that an individual consumed 2 liters of water per day for 350 days per year.

Casing failures were simulated at three different depths within the top sandstone aquifer: one at a shallow depth (300 ft), one at the midpoint (900 ft), and one near the bottom (1,500 ft). Failures also were simulated at the midpoint of each of the underlying units at depths of 2,600 ft (shale), 4,200 ft (sandstone), 5,800 ft (shale), 9,000 ft (sandstone), and 10,600 ft (shale). Receptor points were located at a depth of 300 ft within the sandstone aquifer at distances ranging from 0 mi (i.e., coincident with the injection well) to 20 mi downgradient.

The model was run first to calculate the radium-226 and radon-222 concentrations at each of the receptor points. Additional calculations were made by assuming two domestic wells were pumping simultaneously at a rate of 14,400 gallons per day (gal/day), 0.2 and 0.5 mi from the injection site, respectively. This rate was chosen as a reasonable rate for a domestic well in a sandstone aquifer. In addition, sensitivity analyses of some of the key input parameters were conducted to assess their impact on predicted doses. Parameters chosen for the sensitivity analyses included those for which a set of definitive values could not be chosen because of variability in possible conditions (e.g., groundwater gradient or hydraulic conductivity) and those for which definitive data have not been collected but are thought to be very variable (e.g., source term concentration).

Results

Table 1 lists the concentrations of radium-226 depths and the corresponding estimated doses calculated at the three closest receptor points for the three shallowest casing failures. All of the calculated concentrations were below the current maximum allowable concentration of total radium in drinking water of 5 pCi/L, established under the Safe Drinking Water Act (5). In addition, all of the estimated doses were well below the currently accepted general public dose limit of 100 millirem per year (mrem/yr) from all sources, recommended by the International Commission on Radiological Protection (6). All of the other model runs (i.e., scenarios in which failure occurred at a depth greater than 1,500 ft or runs in which the receptor was located more than 0.5 mi away) resulted in extremely low predicted radium concentrations, at least four orders of magnitude below those presented in Table 1. (The calculated radon-222 concentrations for all scenarios were at least four orders of magnitude below those calculated for radium-226. Because these concentrations are considered to be insignificant, they are not presented in this paper.)

Receptor points at pumping wells located 0.2 and 0.5 mi downgradient had lower estimated doses because of plume dispersion. Increasing the hydraulic conductivity or gradient by one order of magnitude increased the estimated doses at the receptor points; however, the doses were still well below the currently accepted standard. Doubling the concentration of radium in the NORM slurry effectively doubled the estimated doses.

NORM DEMONSTRATION PROJECT

Through its Oil and Gas Environmental Program, the DOE is co-funding the demonstration of a new NORM treatment and disposal technology developed by BPF, Inc., that entails final disposal of the NORM via injection into Class II injection wells (7). The BPF technology is a mobile, modular system in which NORM wastes are treated and disposed of at the lease site where the NORM is stored. The technology entails dissolving the radionuclides into a liquid solution and injecting that solution back into subsurface formations, using existing permitted injection wells located on or near the lease site. The three main processes provided by the treatment modules are (1) deoiling, (2) volume reduction, and (3) radionuclide extraction. In the BPF process, the radionuclide extraction process consists of dissolving the NORM solids and segregating the dissolved NORM from insoluble material present in the waste stream. This process is accomplished in a series of treatment steps, including chemical dissolution, carbonate roasting, and solids separation. The liquid effluents containing dissolved radionuclides are disposed of in an injection well along with the produced water already being injected.

Evaluation of the BPF technology is underway; laboratory and bench-scale demonstrations have been conducted, and pilot-scale demonstrations at three field sites are expected to begin in the fall of 1997. At each of the three sites, an existing Class II injection well has been identified for the disposal of the radioactive effluents. During the pilot-scale field demonstrations, BPF expects to dispose of 840 to 2,100 gal/day of radioactive effluent. The activity level of the effluents is expected to range from 40,000 to 80,000 pCi/L of radium. The depths of injection for the identified wells range from 4,000 to 10,500 ft.

Assumptions and Input Parameters

To assist with the technology evaluation, a preliminary radiological dose assessment of the pilot-scale activities was conducted. The exposure pathway in this assessment assumed that casing failure would result in the release of the radioactive effluent at a shallower depth than intended, that the radionuclides would be transported to a drinking water well, and that an individual would ingest the contaminated water. Because the previous generic study indicated that casing failures below the drinking water aquifer resulted in negligible doses, the model runs for the NORM demonstration project considered only direct releases into a drinking water aquifer, even though the Class II wells to be used inject at much greater depths.

As a worst-case scenario for all three sites, it was assumed that casing failure occurred at a depth of 100 ft in a shallow aquifer having a porosity of 0.2. Receptor points were located at a depth of 100 ft at distances of 100, 500, 1,000, and 5,000 ft from the injection well. It was assumed that 2,100 gal of effluent would be lost instantaneously; this volume represents the largest quantity expected to be handled in any given day during the demonstration project. The models were run for effluent activity levels of 40,000 and 80,000 pCi/L of radium.

Results

Table 2 lists the concentrations of radium-226 calculated at the receptor points and the corresponding estimated doses. As they were in the generic study, all of the calculated concentrations were below the current maximum allowable concentration of total radium in drinking water of 5 pCi/L (5), and all of the estimated doses were well below the currently accepted general public dose limit of 100 mrem/yr from all sources (6).

At least two factors characterizing the NORM demonstration project that were not accounted for in the preliminary dose assessment would result in lower estimated doses if they were addressed in the assumptions and input parameters. One factor is that during injection the radioactive effluent will be combined with a significant volume (up to 750,000 gal/day) of produced water that is already being injected into the Class II wells on a regular basis. This will result in significant dilution of the effluent activity levels. The other factor is that the nearest known pumping well to any of the three sites is approximately 0.5 mi away. This well serves a stock tank and is unlikely to produce water consumed by a human. The nearest possible drinking water well appears to be more than 5,000 ft away. Potential doses at distances greater than 5,000 ft will be negligible.

CONCLUSIONS

The results of the radiological dose assessments presented in this paper indicate that the subsurface disposal of NORM wastes via injection into permitted Class II wells presents only a negligible risk to the general public. In simulations of casing failures that release the radionuclides directly into a drinking water aquifer, radioactivity levels and associated radiological doses were predicted to be below levels of regulatory concern, even at nearby receptors. If more realistic assumptions regarding failure scenarios and receptor locations were used, potential doses would be negligible.

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Table 1. Estimated Activities and Potential Doses Associated with Subsurface Injection of 4.2 Million Gallons (100,000 barrels) of NORM in a Generic Setting.

Top Aquifer Failure Depth (ft)	Receptor Location Downgradient from Injection Well (miles)					
	0.0		0.2		0.5	
	Activity Level (pCi/L)	Annual Dose (mrem)	Activity Level (pCi/L)	Annual Dose (mrem)	Activity Level (pCi/L)	Annual Dose (mrem)
300	*	*	1.317	1.00	0.211	0.20
900	0.250	0.20	0.155	0.10	0.053	0.04
1,500	0.015	0.01	0.017	0.01	0.010	0.08

* No value calculated because receptor location is coincident with failure location.

Table 2. Estimated Activities and Potential Doses Associated with Subsurface Injection of 2,100 Gallons (50 barrels) of Radioactive Effluent during the NORM Demonstration Project.

Receptor Location Downgradient from Injection Well (ft)	Effluent Radioactivity Level (pCi/L)			
	40,000		80,000	
	Activity Level (pCi/L)	Annual Dose (mrem)	Activity Level (pCi/L)	Annual Dose (mrem)
100	1.940	1.500	3.870	3.000
500	0.173	0.100	0.346	0.300
1,000	0.061	0.050	0.122	0.090
5,000	0.005	0.004	0.011	0.008

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