RISK ESTIMATES FOR DISPOSAL OF NORM OIL PRODUCTION WASTES IN LOUISIANA

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ABSTRACT

NORM waste generated in the State of Louisiana by the oil production industry was characterized and risks were estimated for disposing the wastes in plugged and abandoned wells and in near-surface facilities. The radiological characterization of the NORM waste was performed using the survey measurement data reported by the American Petroleum Institute and normalizing the data to establish mean NORM concentrations for the various types of waste being generated. Individual and population doses and lifetime risks were calculated for disposal of the NORM waste in plugged and abandoned wells. Risks were also estimated for inadvertent human intrusion into a disposal well containing NORM waste and a variety of near-surface disposal methods.

Lifetime risks associated with the downhole disposal of NORM-contaminated equipment, loose scales, and sludges were estimated to range from $3x10^{-8}$ to $2x10^{-4}$. Lifetime individual risks to one or a few individuals of up to $2.8x10^{-2}$ were estimated for an extremely unlikely scenario of human intrusion into a disposal well containing NORM waste and illegal disposal of drilling mud contaminated with the waste. Lifetime individual risks to potential future reclaimers on land used for near-surface disposal ranged up to 0.09 and to on-site residents $2x10^{-3}$. The indoor radon exposure pathway dominated the latter.

INTRODUCTION

Since the discovery in the early 1930s of naturally occurring radioactive materials (NORM) in fluids brought to the surface during oil exploration and production, a number of studies have been completed to characterize oil field wastes (1). The Environmental Protection Agency (EPA) has a continuing interest in addressing potential radiation exposures and risks from the management and disposal of NORM. A cooperative effort has been initiated between the EPA and the State of Louisiana to identify NORM wastes from the oil industry and analyze risks from their disposal. The overall objective of this effort is to evaluate the risks associated with specific options for disposal of NORM wastes generated by the oil industry in Louisiana. The evaluation focusses on NORM wastes generated during production activities, not during exploration.

Uranium and thorium, because of their relative insolubility, are not usually carried with the fluids to the surface. However, radium and lead (Ra-226, Ra-228, and Pb-210 resulting from the decay of uranium and thorium) are significantly more soluble and, under some conditions, are mobilized by the liquids (primarily water) in the producing formation.

As the natural formation water experiences changes in pressure and temperature, scale and sludge are deposited in downhole tubing and surface equipment. The scale and sludge are made up principally of barium, calcium, and strontium compounds (sulfates, silicates, and carbonates). The solubilized radium in the formation water also precipitates to form complex sulfates and carbonates, since it is chemically similar to barium, calcium, and strontium.

Deposits in production equipment are generally in the form of hard scale, loose undissolved material, or oil sludge. The scale deposited on the walls of tubing and production equipment is typically very hard and relatively insoluble. It may vary in thickness from a few hundredths of an inch to several inches. The sludge that may be deposited in production vessels often contains silica compounds, but may also be composed of significant amounts of barium compounds. The dewatered sludge, having low oil content, is similar in consistency and appearance to soil. However, some sludge does retain oil and therefore exhibits an oily appearance.

In October 1988, the Louisiana Department of Environmental Quality released an interim policy on the handling, storing, and disposing of scale and contaminated soil. The policy, which prohibits transfer of NORM-contaminated items to other individuals, also provides worker protection guidelines and NORM storage options. This guidance preceded release of an Emergency Rule on February 20, 1989, which amended the Louisiana radiation regulations by adding a chapter entitled, "Regulation and Licensing of Naturally Occurring Radioactive Materials (NORM)." Following several months of review and hearings, a permanent rule was adopted, and Louisiana became the first state to promulgate a NORM regulation. In June of 1992, Louisiana's revised regulations became effective. If a NORM site is under a general license, the radium concentration must be less than 5 pCi/g before being released from licensure. The radium cleanup criterion for a non-licensed area is 30 pCi/g.

The purpose of the present study is to:

- Characterize the NORM waste and equipment that may be suitable for disposal in oil wells that will eventually be plugged and abandoned;
- Estimate the radiation doses and risks associated with down-hole disposal of these wastes;
- Identify and evaluate past and present near surface disposal options;
- Estimate the doses and risks associated with sites that were contaminated with oilfield NORM wastes but that meet a 5 pCi/g-15 pCi/g soil release criterion for release for unrestricted use.

BASIS OF ANALYSIS

A reference oil and gas production facility consisting of ten production wells was assumed for this analysis. This typical facility was assumed to have a life of 30 years. It was further assumed that tubing and some of the pipe in the wells will be replaced about every seven years, giving a total of three replacements of the original tubing during the 30-year facility life. Sludge was assumed to be emptied from tanks and heater treaters about every three years. Estimated quantities of equipment containing scale and sludge for disposal, resulting from a 30-year operation are identified in Table I.

The average radium concentrations given in Table I were calculated from external gamma data using the following equation (2):

$$C = \frac{K\,E\,\left(1+\frac{St_n}{8}+2t_w\right)}{t_n \rho_n \left[1-\left(\frac{3}{d}\right)^2\right]} \qquad \text{(Eq. 1)}$$

where

C	=	concentration (pCi/g)
E	=	exposure rate (μR/hr)
S	=	correlation parameter, 2.6 for scale 1.0 for sludge
t_n	=	thickness of NORM sludge or scale (cm)
t_w	=	thickness of equipment wall (cm)
ρ_n	=	density of NORM, 2.6 for scale 1.6 for sludge (g/cm^3)
d	=	effective diameter of the equipment (cm)
K	=	$K = \frac{6.2\ \text{pc/cm}^2}{\mu\ \text{R/hr}}$.

The external gamma data were from surveys made at the oil and gas production facilities in the state (3).

RISKS FROM DOWNHOLE DISPOSAL OF NORM WASTES

There are currently about 37,000 active or shut in oil wells in Louisiana (4). Only from 10 to 30 percent of all oil wells in the U.S. produce significant NORM waste (5). Assuming 30 percent of the 37,000 wells in Louisiana will produce NORM waste there will be about 1,100 10-well clusters of the kind characterized in Table I in Louisiana. Thus, about 9,000 m^3 of sludges and 600 m^3 of scales are estimated to be generated annually in the state.

Fourteen scenarios for downhole disposal of NORM-contaminated equipment, fluids, scale, and sludge were developed. The fourteen scenarios, given in Table II, involve disposal of different combinations of the types of NORM.

The risks associated with the disposal of the NORM-contaminated equipment and materials in a plugged and abandoned well were determined utilizing the PRESTO-EPA-DEEP (6) and PATHRAE-EPA (7) computer codes designed for evaluating such disposal scenarios. The PATHRAE-EPA, RAETRAD (8), and COMPLY (9) codes were used to analyze doses and risks from near-surface disposal of NORM wastes.

The estimated maximum lifetime risks and collective population health effects from the use of a single plugged and abandoned well for disposal of the wastes described in the second, third and fourth columns are given in the last two columns of Table II. The reclaimer well pathway dominated the estimated risks for downhole disposal. When considering the transport of the NORM nuclides to the upper aquifer, the

TABLE I
Summary of NORM Waste Suitable for Downhole Disposal

Category	Total Disposal Volume as is (m^3)^a	Volume of Scale/Sludge Only (m^3)^a	Sludge Volume (m^3)^a	Average Radium Concentration (pCi/g)	Total Radium for Disposal (mCi)
Scale Bearing Equipment					
Oil Line Piping & Valves	148.4	11.8		700	21.42
Manifold Piping & Headers	0.74	0.07		590	0.11
Injection Well Tubing	9.32	1.2		170	0.53
Production Well Tubing	11.36	1.5		230	0.92
Water Lines & Valves	1.81	1.6		220	0.92
Meters, Screen, Filters	<0.03	<0.03		260	<0.02
SCALE COMPOSITE TOTALS	171.64	16.18		480	20
Sludge Bearing Equipment					
Separators, Feed Water Knock Outs, Wash Tanks			23.3	150	5.6
Oil Stock Tanks			125	73	14.6
Heater/Treaters			3.6	110	0.63
Sump Pits			2.2	26	0.04
Water Storage Tanks			80	66	8.45
SLUDGE COMPOSITE TOTALS		234.3	75		28
Produced Water		1.3×10^6		0.9	1,200

a) Thirty years worth of waste from a 10 well facility.

TABLE II
Summary of Downhole Disposal Scenarios, Estimated Risks, and Estimated Health Effects

Scenario	Emplaced Waste	Total Volume Disposed (m^3)	Total NORM Radioactivity (mCi)	Estimated Maximum Individual Lifetime Risk	Regional Health Effects Over 10,000 yr
1	One string of 4" dia. oil line piping	19	2.9	$2x10^{-7a}$	$1x10^{-4}$
2	One string of 2" dia. production well tubing	5	0.38	$1x10^{-7}$	$7x10^{-5}$
3	One string of 3" dia. injection well tubing	11	0.62	$7x10^{-8}$	$5x10^{-5}$
4	One string of 3" dia. water line	11	3.4	$6x10^{-7}$	$4x10^{-4}$
5	2" dia. production well tubing plus scale slurried with produced water	59	35	$1x10^{-8}$	$1x10^{-5}$
6	Dry granular scale slurried with produced water	59	37	$2x10^{-8}$	$1x10^{-5}$
7	One string of 2" dia. production well tubing plus dry granular scale	32	35	$3x10^{-6}$	$2x10^{-3}$
8	Dry granular scale only (480 pCi/g)[a]	30	37	$5x10^{-6}$	$3x10^{-3}$
9	Dry granular scale only (5,070 pCi/g)[b]	30	390	$5x10^{-5}$	$3x10^{-2}$
10	Dry granular scale only, but the casing or plug are assumed to have failed[b]	30	37	$4x10^{-6}$	$3x10^{-3}$
11	One string of 3" dia. injection well tubing plus produced water	59	0.66	$8x10^{-8}$	$6x10^{-5}$
12	Produced water only	59	0.056	$9x10^{-9}$	$6x10^{-6}$
13	One string of 2" dia. production well tubing plus sludge	59	6.9	$5x10^{-7}$	$4x10^{-4}$
14	Sludge only	59	7.1	$7x10^{-7}$	$5x10^{-4}$

a. The reclaimer well is assumed to be 1 meter from the disposal well except for scenarios 5 and 6, which used a well at 100 meters.

b. Scenarios 9 and 10 are assumed to be worst case scenarios providing maximum NORM concentration and breached containment, respectively.

time when nuclides become available for transport is also a factor. For all scenarios except Scenario 10 the assumption was made that the casing and plugs in the disposal well are intact, the casing is free of any serious corrosion damage at the time of waste placement and the NORM radionuclides won't be available for transport until the casing fails, at about 50 years following emplacement.

Lifetime risks to future individuals ranged from a low of about $9x10^{-4}$ for scenario 12 to $5x10^{-4}$ for the worst-case scenario. Except for the worst-case scenario and scenarios 7, 8, and 10, the largest estimated lifetime risks to future reclaimers are less than $6x10^{-5}$.

Collective regional health effects, accumulated over 10,000 years, are estimated to be for less than 0.1 for all scenarios.

RISKS FROM NEAR-SURFACE DISPOSAL ALTERNATIVES

Five near-surface disposal alternatives were examined. The alternatives, listed in Table III, range from landspreading to a licensed NORM disposal facility. The NORM disposed volumes and average radium activities are given in that table. For comparison, doses and risks were also calculated for NORM contaminated soils that have been cleaned up to 5 pCi/g of radium above background (assumed to be 1 pCi/g) in the top 15 cm and 15 pCi/g of radium above background in deeper 15-cm layers. This is the Release for Unrestricted Use Alternative listed in Table III.

Landspreading

Disposal by landspreading involves few requirements. It consists simply of spreading sludges and scales over the soil surface to allow the hydrocarbon component to degrade. The size and location of the site is left to the site owner. It was assumed for this analysis that subsequent uses of the land are not restricted, permitting home construction, food production, or any other land uses.

The thickness of the waste in landspreading ranges from a quarter of an inch to about 8 inches. In the analysis of risks and doses from landspreading without dilution contained here, it was assumed that, due to repeated application, the top eight inches (20 cm) of land surface was composed of undiluted NORM waste. An average NORM concentration of 120 pCi/g was used.

Landspreading With Dilution

Landspreading with dilution results from mixing the applied NORM wastes thoroughly within the top eight-inch (20 cm) layer of soil and waste. The radium concentration of the 8-inch layer of diluted NORM was assumed to be 15 pCi/g based on 120 pCi/g for one inch of undiluted NORM.

TABLE III
Near-Surface Disposal Alternatives, Risks, and Estimated Health Effects to the Off-site Resident

Alternative	Average Ra Activity (pCi/g)	Estimated Lifetime Individual Risk	Regional Health Effects Over 10,000 Yr (per site)
Landspreading	120	$2x10^{-3}$	0.4
Landspreading With Dilution	15	$6x10^{-4}$	1.1
Incineration and Pit Closure	240	$9x10^{-4}$	0.01
Oil Industry Landfill	20	$4x10^{-4}$	0.03
Licensed NORM Disposal	120	$6x10^{-4}$	0.01
Release for Unrestricted Use	5/15	$1x10^{-3}$	0.2

Incineration and Pit Closure

Although pits were commonly used for waste management in the oil industry in the past, the State of Louisiana is now mandating closure of all pits and ponds formerly used for waste disposal. For pits without high concentrations of NORM, incineration is often the method of choice for reducing the volume of the waste prior to closure.

Incineration and pit closure involves removing the waste from the waste pit and loading it into a sequence of two incinerators. The primary incinerator operates at 1350 degrees F minimum, and the secondary incinerator at 1750 degrees F minimum. At these temperatures the radium is not volatilized. After incineration, the ash was assumed to be returned to the former waste pit, and covered with three feet of clean soil. Almost all of the NORM is contained in the ash. Because incineration reduces the volume of the waste by about 50 percent, the radionuclide concentrations are doubled. Therefore, the concentration of radium in the ash is 240 pCi/g. The buried ash was assumed to be 10 feet deep and capped with a 3 foot soil cover.

Disposal at an Oil Industry Landfill

This scenario involves burial of the NORM waste with other oil field wastes at a dedicated oil industry landfill. Since NORM wastes are about 25 percent of total oil industry wastes and intermediate clean soil covers are usually applied daily, it was assumed that dilution by a factor of six occurs. Further, since the disposed waste is covered daily with clean fill, an additional dilution factor of 1.5 was applied. This leads to a final, in place NORM concentration of 20 pCi/g. The waste deposits were assumed to be 10 feet thick and covered by 3 feet of clean soil.

Disposal at a Regulated NORM Disposal Facility

The NORM waste disposal site was assumed to satisfy EPA regulations for disposal of uranium and thorium mill tailings and related byproduct materials (10). It is designed to be effective for 1,000 years where reasonably achievable, or for at least 200 years, and to limit surface radon flux to 20 pCi/m^2 sec. The impoundment usually is designed with an earthen cover for radon control and has suitable liners and siting to protect local groundwater from contaminant leaching and migrations. After closure, it is also assumed that the site is deeded to the state for permanent monitoring and restricted future use. Thus, no intrusive activities or construction of occupiable structures on the site are permitted. The NORM radionuclide concentration in the waste was assumed to be 120 pCi/g.

Release of Former NORM-Contaminated Sites for Unrestricted Use

A common criterion for sites that are to be released for unrestricted use is a maximum radium-226 concentration of 5 pCi/g above background in the top 15 cm of soil and a maximum radium concentration of 15 pCi/g above background averaged over each 15 cm layer below the top 15 cm. This is referred to as the "5/15 requirement" scenario. For the analysis, it was assumed that the background concentration of Ra-226 in the soil is 1 pCi/g. Therefore, the top 15 cm of soil was modeled as having a concentration of Ra-226 of 6 pCi/g and the soil below as having a concentration of 16 pCi/g. For the analysis, the soil at 16 pCi/g was assumed to extend to 10 feet.

As expected, the estimated lifetime risks to individuals in the critical off-site population group are higher than those for downhole disposal. They range from $4x10^{-4}$, for an oil industry landfill, to $2x10^{-3}$ for landspreading. The individual risk for the release for unrestricted land use is $1x10^{-3}$. Estimated collective population health effects over 10,000 years range from a low of 0.03 for the oil industry landfill to 1.1 for landspreading with dilution. The collective population health effects for unrestricted land use are estimated to be about 0.2.

CONCLUSIONS

The conclusions obtained from this evaluation are:

- Downhole disposal of NORM wastes offers a significant reduction in radiation doses and risks to the public compared to near-surface disposal.
- The reinjection of NORM contaminated produced water and finely divided scale into a depleted oil formation would not result in any significant doses or risks to the public.

ACKNOWLEDGEMENTS

This work was sponsored by the U.S. Environmental Protection Agency, Office of Radiation Programs through a contract with S. Cohen and Associates, Inc. Neither the United States Government nor the Environmental Protection Agency makes any warranties concerning this work or the use of the results.

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