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DRAFT

-DIFFUSE NORM WASTES-

WASTE CHARACTERIZATION AND PRELIMINARY RISK ASSESSMENT

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B.5 Oil and Gas Production Sludge and Scale

5.1 INTRODUCTION

Both uranium and thorium and their progeny and potassium-40 are known to be present in varying concentrations in underground geologic formations from which oil and gas are produced (Be60, EPA73, Pi55). The presence of these naturally occurring radionuclides in petroleum reservoirs has been recognized since the early 1930s and has been used as one of the methods for finding hydrocarbons (Ma87). Uranium and thorium compounds are mostly insoluble and, as oil and gas are brought to the surface, remain in the underground reservoir. However, some radium and radium daughter compounds are slightly soluble in water and may become mobilized when water is brought to the surface. When this happens, radium and its daughters may remain dissolved at low levels, or they may precipitate out of solution because of chemical changes and reduced pressure and temperature. Since radium concentrations in the original formation are highly variable, the concentrations that precipitate out in sludges and on internal surfaces of oil and gas production and processing equipment are also variable. NORM radionuclide concentrations in scales and sludges that accumulate in surface equipment may vary from background soil levels to levels as high as several hundred nanocuries per gram, depending upon the presence of radionuclides, the chemistry of the geologic formation from which oil and gas are produced, and on the characteristics of the production process (McA88).

Radioactivity in oil and gas production and processing equipment is of natural origin. Its accumulation and significance were not noted and studied until recently. The problem is now known to be widespread, occurring in oil and gas production facilities throughout the world, and has become a subject of attention in the United States and in other countries. In response to this concern, facilities in the U.S. and Europe have been characterizing the nature and extent of NORM in oil and gas pipe scale, evaluating the potential for exposures to workers and the public, and developing methods for properly managing these low specific activity wastes (EPF87, McA88, Mi87, Mi88).

In 1982, radium and thorium in elevated le· ; were found in mineral scales on British oil and gas production facilities located in the North Sea. Because large quantities of materials were being handled in the confined working area of offshore platforms, operators developed special work procedures for protection against possible exposures to radioactivity. After a review of the situation, the British government and oil industry representatives issued radiation protection guidelines governing worker safety, material handling, and waste disposal (UK85).

In the U.S., the presence of naturally occurring radioactivity in mineral scale deposits came to the attention of industry and government in the spring of 1986 when, during a routine workover of a well in Mississippi, barium sulfate scale deposited in production tubing was found to contain elevated levels of radium and thorium. Assays of this scale showed 6,000 pCi/g of radium-226 and 1,000 pCi/g of thorium-232 coprecipitated in a barium sulfate matrix (Ma87, McA88). Because of the concern that some of the pipes, which had been removed to nearby pipe cleaning facilities, may have contaminated the environment, radiological surveys were conducted by the EPA's Eastern Environmental Radiation Facility. These surveys showed some equipment with elevated external radiation levels and surrounding soil contamination.

Both the oil and gas industry and state regulatory agencies, as well as the EPA, are currently examining the problem and regulating NORM in oil and gas production facilities. The American Petroleum Institute (API) has sponsored studies to characterize accumulations of naturally occurring radioactivity in oil field equipment and to evaluate methods for its disposal (API89, API90). The API has also formed an Ad Hoc Committee on Low Specific Activity (LSA) Scale and has prepared a draft measurement protocol for identifying producing areas where NORM scale is known to exist (API87). The Part N Subcommittee of the Conference of Radiation Control Program Directors has been working since 1983 to develop model state regulations (Part N of Suggested State Regulations for Control of Radiation) for the control of NORM (CRC88). These model regulations are intended to help individual states develop their regulations for consistency among state and federal regulations. Many states with oil and gas production are currently promulgating oil and gas NORM regulations. For example, the State of Louisiana has regulations for NORM in scales and sludges from oil and gas production that differ from the Part N model regulations, where the State of Texas has NORM regulations similar to Part N regulations (DEQ92, TDH92). While these regulations are intended to apply generally to all NORM-containing materials, several parts would apply specifically to oil and gas industry pipe scale.

As part of their studies sponsored to characterize accumulations of NORM in oil field equipment, the API has conducted an industry-wide survey of radiation exposure levels associated with NORM in oil production and gas processing equipment (API89). The purpose of the study was to identify the geographic areas of petroleum producing and gas processing facilities exhibiting the greatest occurrence of NORM, and to identify specific pieces of equipment that have the highest NORM activity levels. However, the data were collected primarily at sites suspected of exhibiting elevated NORM concentrations and may not be typical of all oil and gas production equipment contamination. Over 36,000 individual observations and measurements were made in 20 states and two offshore areas by participating petroleum companies using similar equipment and data collection protocols. Radiation exposure levels were expressed in units of μR/hr, and the results were reported on standardized survey data sheets. Background radiation levels were also measured and reported for each site in order to distinguish background from elevated levels caused by NORM scale and sludge. The results of this study are summarized in Section 5.5.3 of this chapter.

Radium and its decay products are also known to be present in elevated concentrations in produced waters from oil production operations. In general, produced waters are reinjected into deep wells or are discharged into non-potable coastal waters. The impacts of elevated radionuclide concentrations in produced waters are not considered in this risk assessment.

This assessment is limited to NORM in oil production equipment. NORM in gas plant processing equipment is described but is not included in the risk assessment for this sector category because the residual NORM deposition is generally in the form of Pb-210 surface contamination on gas plant equipment. Consequently, it does not have a strong radon or gamma emission component. Furthermore, the critical population groups (CPG) and collective population effects from the oil production equipment should represent an upper bound to any health impacts from the gas plant equipment.

The following sections provide a description of the oil and gas production industry and characterize the properties of oil and gas scale and sludge waste from production equipment. The radiological characteristics and current estimates and projected amounts of scale and sludge produced by this NORM sector are addressed separately. Additionally, the oil and gas specific parameters utilized in the risk assessment are given at the end of this chapter. This information provides the background for postulating the disposal and reuse scenarios in Sections 5.7 and 5.8. The scenarios are then used in the preliminary risk assessment presented in Chapters D.1 through D.3.

5.2 OVERVIEW OF OIL AND GAS PRODUCTION

U.S. crude oil production for the years 1970 through 1989 is shown in Table B.5-1. The highest oil production rate occurred in 1970 at about 9.6 million barrels per day. Crude oil production has since declined to only about 7.6 million barrels per day in 1989 (PET90). The production of domestic crude oil in the U.S. is closely tied to the international price of crude oil, which is determined on a world-wide scale by OPEC countries. Thus, U.S. oil production is subject to fluctuations that depend on world-wide political and economic conditions.

U.S. production of natural gas for the years 1970 through 1989 is also shown in Table B.5-1. Production of natural gas peaked in 1972 and 1973, and has since then been declining. In 1989, marketed production of natural gas was about 78 percent of the volume generated in 1973. This decline in marketed production and consumption is due both to the more efficient use of natural gas for home heating and industrial uses. Table B.5-2 lists the number of operating crude oil production wells in each reporting state and the amount of crude oil produced for 1989 (PET90). Table B.5-3 lists the number of operating natural gas wells in each reporting state and the production of natural gas for 1989.

Table B.5-1. U.S. crude oil and natural gas production. (Source: PET90)

Year	Crude Oil Million bbls/day[a]	Natural Gas Trillion Cubic Feet
1970	9.6	22
1971	9.5	22
1972	9.4	23
1973	9.2	23
1974	8.8	22
1975	8.4	20
1976	8.1	20
1977	8.2	20
1978	8.7	20
1979	8.6	20
1980	8.6	20
1981	8.6	20
1982	8.7	19
1983	8.7	17
1984	8.9	18
1985	9.0	17
1986	8.7	17
1987	8.3	17
1988	8.2	18
1989	7.6	18

a A barrel of oil has a volume of 42 gallons.

Table B.5-2. Crude oil production for 1989 by state. (Source: PET90)

State[a]	Number of Producing Wells	Thousand Barrels	State Rank: Number of Producing Wells	State Rank: Total Production
Alabama	931	19,813	25	16
Alaska	1,337	683,980	24	2
Arizona	25	138	31	29
Arkansas	4,340	11,261	17	17
California	43,745	364,249	4	4
Colorado	6,362	30,655	14	10
Florida	101	7,289	29	19
Illinois	32,441	20,377	5	15
Indiana	7,543	3,310	13	22
Kansas	44,969	55,484	3	8
Kentucky	22,859	5,414	9	21
Louisiana	22,872	404,329	8	3
Michigan	5,557	21,566	15	13
Mississippi	3,589	27,403	20	12
Missouri	807	136	26	30
Montana	4,001	20,956	18	14
Nebraska	1,787	6,232	23	20
Nevada	46	3,218	30	23
New Mexico	17,787	68,713	10	7
New York	4,350	495	16	28
North Dakota	3,442	36,744	21	9
Ohio	30,194	10,219	6	18

Table B.5-2. Continued.

State[a]	Number of Producing Wells	Thousand Barrels	State Rank: Number of Producing Wells	State Rank: Total Production
Oklahoma	96,344	117,493	2	5
Pennsylvania	27,218	2,702	7	24
South Dakota	156	1,613	28	26
Tennessee	713	532	27	27
Texas	186,226	716,061	1	1
Utah	2,234	28,416	22	11
Virginia	--	--	21	31
West Virginia	15,940	2,243	11	25
Wyoming	11,539	107,713	12	6
Federal Waters	3,881	--	19	
Other	20	--		
United States[b]	603,356	2,778,773[c]		

a States not shown did not report data.
b Includes 3,901 wells in Federal waters and at unspecified locations.
c This equates to 7.6×10^6 Barrels/day.

Table B.5-3. Natural gas production for 1989 by state. (Source: PET90)

State[a]	Number of Producing Wells	Million Cubic Feet	State Rank: Number of Producing Wells	State Rank: Total Production
Alabama	1,580	128,317	15	15
Alaska	88	388,247	24	7
Arizona	--[b]	53	--[b]	12
Arkansas	2830	168,300	12	12
California	1181	371,854	18	8
Colorado	4481	203,847	11	9
Florida	0	7,984	26	23
Illinois	296	1,306	22	26
Indiana	1,295	453	16	28
Kansas	13,935	587,099	7	6
Kentucky	11,250	75,810	9	18
Louisiana	13,873	5,131,205	8	2
Maryland	1,265	156,501	17	14
Michigan	739	106,828	19	17
Mississippi	2,575	51,025	13	20
Montana	2,575	51,025	13	20
Nebraska	--[b]	655	--[b]	27
New Mexico	19,191	849,079	6	4
New York	5,184	21,344	10	21
North Dakota	103	53,090	23	19
Ohio	34,232	166,735	3	13
Oklahoma	27,443	2,153,149	5	3

Table B.5-3. Continued.

State[a]	Number of Producing Wells	Million Cubic Feet	State Rank: Number of Producing Wells	State Rank: Total Production
Oregon	6	4,200		
Pennsylvania	29,000	168,930	4	11
South Dakota	54	4468	25	24
Tennessee	598	1,636	20	25
Texas	46,792	6,206,699	1	1
Utah	460	118,671	21	16
Virginia	710	17,687	19	22
West Virginia	34,650	198,200	2	10
Wyoming	2,147	599,747	14	5
United States[c]	261,139	17,943,142		

a States not shown did not report data.
b Not available.
c Includes 3,169 wells in federal waters and at unspecified locations.

As illustrated in Table B.5-2, almost one third of the operating crude oil production wells in the U.S. are located in the state of Texas, which also ranked first in crude oil production in 1989. Five of the contiguous 48 states (Texas, Oklahoma, Kansas, California, and Louisiana) account for two-thirds of the total number of operating crude oil production wells and produced 60 percent of the crude oil in 1989. Alaska, which ranks 23rd in the number of producing wells, ranked second in crude oil production in 1989, producing 25 percent of the total. There are extensive oil producing areas in the coastal regions of Texas, Louisiana, and California, the north slope of Alaska, and some regions of northern Texas, Oklahoma, and Kansas. The states of Illinois, Indiana, Ohio, Pennsylvania, and West Virginia rank high in the number of producing wells, with 19 percent of U.S. wells, but low in total production, with only about one percent of production. The wells in these states are mostly stripper wells used for the removal of residual reserve after the easily-recoverable oil has been extracted. Stripper wells do not necessarily exhibit less NORM activity than other producing wells, and may exhibit greater levels of radioactivity. Stripper wells produce more water and, therefore, may bring more dissolved radium to the surface.

The State of Texas also ranks first in the number of producing natural gas wells and in marketed production of natural gas in 1989, with 35 percent of the total marketed production. Three states, Texas, Louisiana, and Oklahoma, have 34 percent of the producing natural gas wells, and produced three-fourths of the natural gas marketed in the U.S. in 1989.

5.3 WASTE PRODUCTION AND MANAGEMENT OF OIL AND GAS SCALE

5.3.1 Origin and Nature of NORM in Oil and Gas Scale

The initial production of oil and gas from a reservoir does not contain significant entrained water. However, as the natural pressure within the bearing formation falls, formation water present in the reservoir will also be extracted with the oil and gas. This water (called produced water) contains dissolved mineral salts, which may be radioactive. Uranium and thorium compounds are relatively insoluble and remain generally in the formation. However, radium (Ra-226 and

Ra-228 from the uranium and thorium decay chains) is more soluble and may become mobilized by the liquid components in the reservoir. Thus, the amount of NORM material from a producing field generally increases as the amount of water pumped from the formation increases.

Produced water is subjected to changes in temperature and pressure as it is brought to the surface with the oil and gas. Dissolved solids may precipitate out of solution and deposit scale within the oil production system. This solid residue consists principally of barium, calcium, and strontium compounds (sulfates, silicates, and carbonates). Because the chemistry of radium is similar to that of barium, calcium, and strontium (all are Group IIA elements), radium may also precipitate to form complex sulfates and carbonates.

Scale deposits in production equipment are generally in the form of thick and hard scale. The scale in these chemical matrices is relatively insoluble, and may vary in thickness from a few millimeters to more than an inch. Scale deposits in production equipment may at times become so thick to completely block the flow in pipes as large as 4 inches in diameter.

A basic flow diagram for oil and gas production system is shown in Figure B.5-1. The oil and gas production stream passes through a separator where the oil, gas, and water are divided into separate streams based on their different fluid densities. Most of the solids in the original fluid stream are removed in the separator and accumulate there. The production stream may be further treated using a heater/treater to separate oil from produced water and sludge. The produced water flows from the separators into storage tanks and is often injected down disposal or recovery wells. Scales are usually found in piping and tubing, including oil flow lines, water lines, injection and production well tubing, manifold piping and small diameter valves, meters, screens, and filters (RAE93). The API determined that the highest concentrations of NORM occurred in the wellhead piping and in production piping near the wellhead, ranging up to tens of thousands of picocuries per gram (API89). However, largest volumes of scale have been found in the water lines associated with separators, heater treaters, and gas dehydrators (RAE93). Scale deposits of up to 4 inches thick have been observed (RAE93).

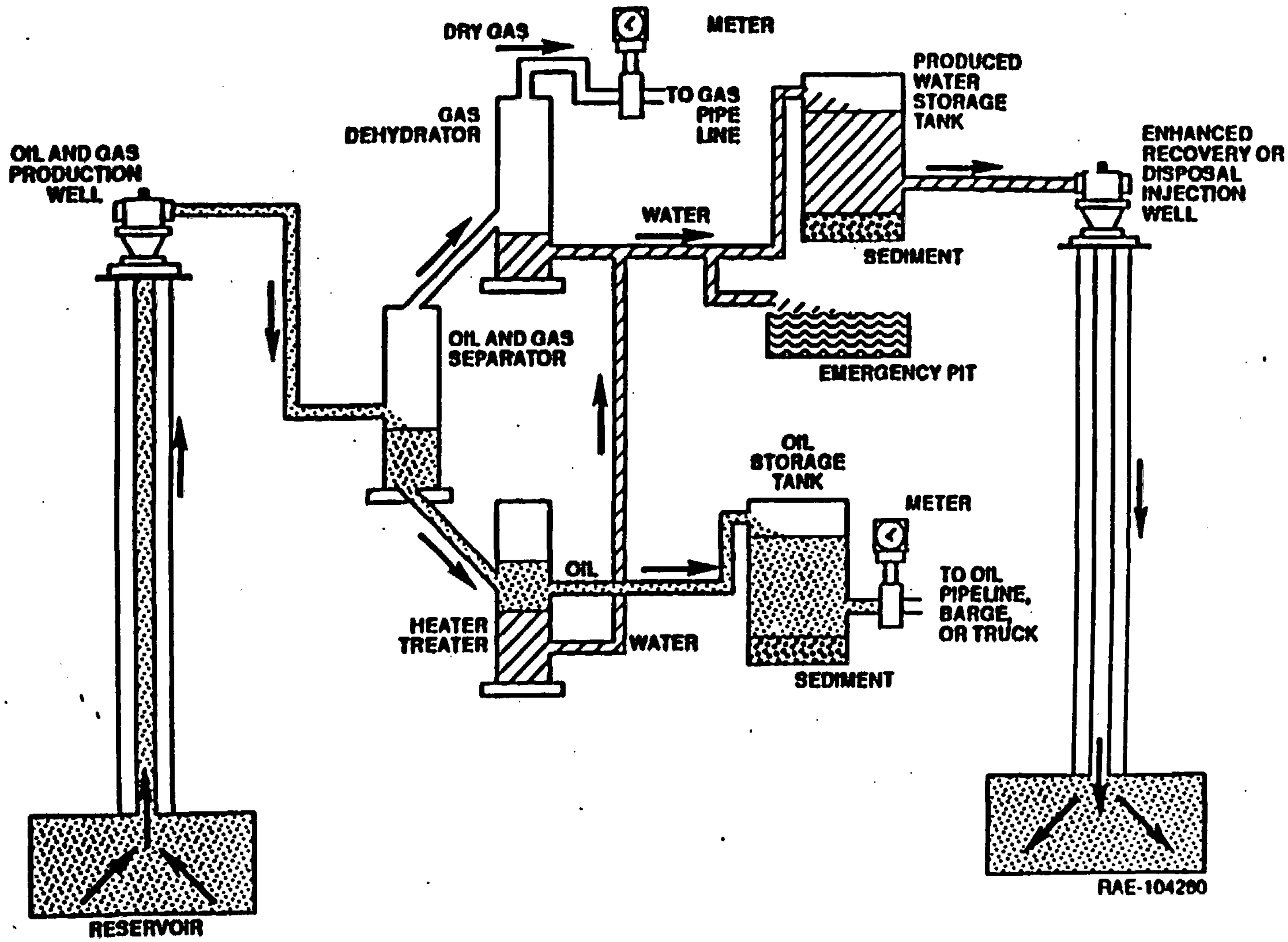

Figure B.5-1. Typical production operation, showing separation of oil, gas and water.

The NORM accumulated as production equipment scales typically contains radium coprecipitated in barium sulfate ($BaSO_4$), calcium sulphate ($CaSo_4$), and calcium carbonate ($CaCO_3$). Ra-226 is generally present in scale in higher concentrations than Ra-228. The nominal activity appears to be about three times greater for Ra-226 than Ra-228 (RAE88). Typically, Ra-226 in scale is in equilibrium with its decay products, but Ra-228 is not (RAE88). Lower concentrations of Ra-228 decay products are due to the occurrence of two nuclides (Ra-228 and Ra-224) separated by Th-228, which has a 1.9-year half-life. Radium becomes depleted in Ra-224 and other radionuclides down the Ra-228 decay chain until more Ra-224 is generated by Ra-228 decay through Th-228.

For convenience, the term radium is used in this section to refer to Ra-226 and Ra-228. Long-term radiological concern in waste disposal is dominated by the decay products of Ra-226 rather than Ra-228 due to the significantly longer half-life of Ra-226 (1,600 years versus 5.8 years for Ra-228). Both nuclides are usually considered together in waste disposal issues, however, since they are not readily distinguished by simple field measurements.

NORM radionuclides may also accumulate in gas plant equipment from Rn-222 (radon) gas decay products, even though the gas is removed from its Ra-226 parent. The highly mobile radon gas originates in underground formations and becomes dissolved in the organic petroleum fractions in the gas plant. In surface equipment, radon is partitioned mainly into the volatile propane and ethane fractions. Gas plant deposits differ from oil production scales, typically consisting of radon decay products plated out on the interior surfaces of pipes, valves, and other gas plant equipment. Since radon decays with a 3.8-day half-life, the only significant radionuclides remaining in gas plant equipment that impact disposal are Po-210 and Pb-210. Po-210 is an alpha emitter with a half-life of 140 days and Pb-210 is a weak beta and gamma emitter with a half-life of 22 years.

5.3.2 Oil and Gas Scale Production Rates

The volume of NORM scale that is produced annually is uncertain, but estimates suggest that up to 30 percent of domestic oil and gas wells may produce some elevated NORM contamination (McA88). It appears that the geological location of the oil reserve, formation conditions, and the type of production operation strongly influence NORM accumulations. A review of surveys conducted in 13 states revealed that the number of facilities reporting elevated NORM in production wells ranged from 90 percent in Mississippi to none or only a few in Colorado, South Dakota, and Wyoming (McA88). However, 20 to 100 percent of the facilities in every state identified the presence of some NORM in heater/treaters. A separate estimate based on Mississippi data indicates that about half of the wells do produce NORM scale and ten percent of these have scale with elevated radium concentrations (B188).

This report assumes an average reference oil and gas production facility consisting of ten production wells (RAE93, RAE88). The NORM waste associated with this facility is estimated from data developed by the API and based on the results of laboratory and field work. The API has developed a database for oil and gas production wells throughout the U.S. and for equipment present at representative facilities. This database includes information on the estimated quantities of scale and sludge in production equipment derived from radiation exposure measurements at facilities throughout the U.S. (API89).

The reference average facility is assumed to have an average operating life of 30 years. Estimated quantities of scale generated over the 30-year lifetime of the representative facility, based on observations and field measurements at many facilities, are shown in Table B.5-4. Table B.5-4 shows that the majority of the scale volume originates from the disposal of piping and valves.

For this assessment, the annual volume of NORM scale from oil and gas production equipment in the U.S. is estimated based on the number of crude oil producing wells shown in Table B.5-2 and the scale volume data characterizing the representative 10-well production facility shown in

Table B.5-4. Summary of NORM scale generated by a 10-well production facility. (Source: RAE93)

Category	Volume of Scale If Removed from Equipment (ft^3)/(m^3)[a]
Scale Bearing Equipment	
Oil Line Piping & Valves	416 / 11.8
Manifold Piping & Headers	2.4 / 0.1
Injection Well Tubing	42 / 1.2
Production Well Tubing	54 / 1.5
Water Lines & Valves	57 / 1.6
Meters, Screen, Filters	<1 / <0.03
SCALE COMPOSITE TOTALS[b]	571 / 16.2
ANNUAL TOTAL[b]	19 / 0.54

a Thirty years worth of waste.

b Obtained by dividing the scale component total by 30 years. Due to roundoff during transcription from the source, the totals may not be exactly the totals for the individual entries shown. They do, however, agree with the totals in the source.

Table B.5-4. The annual volume of NORM scale waste generated by the facility is about 19 ft^3 (0.54 m^3) from Table B.5-4. As stated earlier, up to 30 percent of oil and gas wells may contain elevated NORM contamination. The reference facility is one that does generate NORM waste. Assuming an average scale density of 2.6 g/cm^3 (RAE93), the total annual volume and mass of NORM-contaminated scale from oil production in the U.S. is calculated as:

$$(6\text{x}10^5 \text{ wells in U.S.})\left(\frac{30 \text{ NORM prod. wells}}{100 \text{ wells}}\right) = 1.8\text{x}10^5 \text{ NORM producing wells in U.S.}$$

$$\left(\frac{0.54 \text{ m}^3 \text{ NORM scale}}{10 \text{ NORM producing well} \cdot \text{yr}}\right)(1.8\text{x}10^5 \text{ NORM producing wells}) = 9.7\text{x}10^3 \text{ m}^3\text{/yr NORM scale}$$

$$\left(\frac{9.7\text{x}10^3 \text{ m}^3}{\text{yr}}\right)\left(\frac{2600 \text{ kg}}{\text{m}^3}\right)\left(\frac{\text{MT}}{1000 \text{ kg}}\right) = 2.5\text{x}10^4 \frac{\text{MT}}{\text{yr}} \text{ scale produced in U.S.}$$

As calculated above, it is estimated that about 25 thousand metric tons or 345 thousand ft^3 (9,700 m^3) of NORM scale is generated in the U.S. from oil production each year, based on the number of producing wells in 1989 (Table B.5-2).

A U.K. analysis performed on newer production facilities estimated the amount of scale produced to be 1.8 MT per year for a well producing 3,000 barrels of oil per day (SCA88), or 6.0E-4 MT of scale per barrel of oil produced. Applying this relationship and the 30% NORM production assumption to the U.S. 1989 oil production rate of 7.6 million barrels per day (see Table B.5-2) yields a projected scale generation of about 1,500 MT per year, about 6 percent of the value calculated above. The lower results from the UK correlation is expected, since the newer facilities produce less entrained water in the crude oil (RAE92).

Since there has been roughly 115 billion barrels of oil produced in the U.S. between 1949 and 1989 (DOE92), approximately one million MT of NORM-scale is projected to have been generated over the 40-year period, based on the scale generation rate from the reference 10-well facility and the total barrels of oil produced in 1989. This factor, however, is considered to be very conservative since the scale generation rate for a well increases with age (RAE92).

5.3.3 Oil and Gas Scale Handling and Disposal

In the past, when scale fouling in oil and gas piping became a problem, the pipes were sent off-site to companies that would either clean out the scale or recycle the pipes as scrap. Pipes are cleaned by sandblasting, by hydroblasting with extremely high pressure water or by reaming the scale out using a rotating bit on a long shaft. Scale residue generally was left on the ground at pipe cleaning yards or washed into ponds or drainage basins.* In the past, some piping containing scale has been given to schools for use in playground equipment and as material for vocational welding classes.**

Because of concern that contaminated pipes that were sent to nearby pipe cleaning facilities may have contaminated the environment, EPA's Eastern Environmental Radiation Facility has conducted environmental radiological surveys of pipe cleaning facilities in Mississippi. Pipe, pipe cleaning equipment, contaminated ponds, and cleaning wastes were sampled. These surveys showed that some equipment and disposal locations exhibited external radiation levels above 2 mR/hr and radium-226 soil contamination above 1,000 pCi/g. Some contamination had also been washed into a nearby pond and drainage ditch at one site, as well as into an agricultural field with subsequent uptake of radium by vegetation (Po87).

Most companies in the petroleum industry are now aware that pipe scale may be radioactive. Pipes are usually surveyed for the presence of radioactivity. Piping and equipment containing

* Personal communication, E. Bailey, Texas Department of Health, Austin, TX, March 10, 1988.

** Personal communication, E.S. Fuentes, State Department of Health, Jackson, MI, February 19, 1988.

elevated NORM is generally being held in storage pending the promulgation of disposal regulations (CRC88, TDH92, DEQ92). Scale that is being removed from piping and equipment is placed in drums and stored for later disposal.

Ground disposal of radioactive scale (as practiced in the past) may lead to ground and surface water contamination, even though the scale is very insoluble. In addition, direct radiation exposures may result from individuals working or residing near the disposal site. Homes built over areas where scale has been disposed could experience elevated indoor radiation exposure levels and radon concentrations. There is little likelihood that radioactive scale would be incorporated in building materials because of its physical properties.

5.4 WASTE PRODUCTION AND MANAGEMENT OF OIL AND GAS SLUDGE

5.4.1 Origin and Nature of NORM in Oil and Gas Sludge

The origin of NORM-contaminated sludge is similar to that of scale discussed in Section 5.3.1. As the produced water is subjected to changes in temperature and pressure, dissolved solids may precipitate out of solution and deposit sludge within the oil production system. Sludge deposits in production equipment are generally in the form of oily, loose material. Sludge often contains silica compounds, but may also contain significant amounts of barium. Dried sludge that is low in oil content is similar to soil in appearance and consistency. Other sludges, however, remain very oily.

As illustrated in the oil and gas production system flow diagram, Figure B.5-1, the oil production stream passes through a separator where the oil, gas, and water are divided into separate streams based on their different fluid densities. Some of the solids in the original fluid stream are removed in the separator and accumulate there in the form of sludge. As the production stream is further treated using heater/treaters to separate oil from water, sludge is also separated and allowed to accumulate. The API determined, however, that the largest volumes of sludge settles out of the production stream and remains in the oil stock and water storage tanks (API89, RAE93).

The NORM accumulated as production equipment sludges typically is dominated by silicates or carbonates, but also incorporates trace amounts of radium by coprecipitation. As with NORM-contaminated scale, Ra-226 is generally present in sludge in higher concentrations than Ra-228. The nominal activity appears to be about three times greater for Ra-226 than Ra-228 (RAE88). Typically, Ra-226 in sludge is in equilibrium with its decay products, but Ra-228 is not (RAE88). Lower concentrations of Ra-228 decay products are due to the occurrence of two nuclides (Ra-228 and Ra-224) separated by Th-228, which has a 1.9-year half-life. Radium becomes depleted in Ra-224 and other radionuclides down the Ra-228 decay chain until more Ra-224 is generated by Ra-228 decay through Th-228.

5.4.2 Oil and Gas Sludge Production Rates

The volume of NORM-contaminated sludge that is produced annually is uncertain, but estimates suggest that up to 30 percent of domestic oil and gas wells may produce some elevated NORM contamination (McA88). As with scale, it appears that the geological location of the oil reserve, formation conditions, and the type of production operation strongly influence NORM-contaminated sludge accumulations.

Referring to the reference 10-well facility described in 5.3.2, estimated quantities of sludge generated over the 30-year lifetime, based on observations and field measurements at many facilities, are shown in Table B.5-5. Table B.5-5 shows that the majority of the sludge volume originates from the oil stock and water storage tanks.

For this assessment, the annual volume of NORM sludge from oil and gas production equipment in the U.S. is estimated based on the number of crude oil producing wells shown in Table B.5-2 and the waste volume data characterizing the representative facility shown in Table B.5-5. Gas production wells are not considered because the generation process differs from oil wells

Table B.5-5. Summary of NORM sludge generated by a 10-well production facility. (Source: RAE93)

Category	Sludge Volume (ft^3)/(m^3)[a]
Sludge Bearing Equipment	
Separators, Feed Water Knock Outs, Wash Tanks	822 / 23
Oil Stock Tanks	4,418 / 125
Heater/Treaters	126 / 3.6
Sump Pits	80 / 2.2
Water Storage Tanks	2,828 / 80
SLUDGE COMPOSITE TOTALS[b]	**8,272 / 234**
ANNUAL TOTAL:[b]	**276 ft^3 (7.8 m^3)**

a Thirty years worth of waste.

b Obtained by dividing the sludge component total by 30 years. Due to roundoff during transcription from the source, the totals may not be exactly the totals for the individual entries shown. They do, however, agree with the totals in the source.

(generation consists of a radioactive film of primarily Po-210 and Pb-210). These two radionuclides do not present the same degree of external radiation exposure and environmental contamination as radium and its decay products. The annual volume of NORM sludge waste generated by the 10-well facility is about 276 ft^3 (7.8 m^3) from Table B.5-5. Assuming an average sludge density of 1.6 g/cm^3 (RAE93), the annual volume and mass of NORM-contaminated sludge from oil production in the U.S. is calculated to be:

$$(6x10^5 \text{ wells in U.S.}) \left(\frac{30 \text{ NORM prod. wells}}{100 \text{ wells}}\right) = 1.8x10^5 \text{ NORM prod. wells in U.S.}$$

$$\left(\frac{7.8 \text{ m}^3 \text{ sludge}}{10 \text{ well} \cdot \text{yr}}\right)(1.8x10^5 \text{ NORM prod. wells}) = 1.4x10^5 \text{ m}^3\text{/yr NORM sludge in U.S.}$$

$$\left(\frac{1.4x10^5 \text{ m}^3}{\text{yr}}\right)\left(\frac{1600 \text{ kg}}{\text{m}^3}\right)\left(\frac{\text{MT}}{1000 \text{ kg}}\right) = 2.25x10^5 \text{ MT/yr NORM sludge in U.S.}$$

As calculated above, it is estimated that about 230 thousand metric tons or 5 million ft^3 (141 thousand m^3) of NORM sludge is generate in the U.S. from oil production each year, based on the estimate that up to 30 percent of the producing wells may generate NORM-contaminated sludge.

Since there has been roughly 115 billion barrels of oil produced in the U.S. between 1949 and 1989 (DOE92), approximately 10 million MT of sludge is projected to have been generated over the 40-year period, based on the sludge generation rate from the reference 10-well facility and the total barrels of oil produced in 1989. This factor, however, is considered to be very conservative since the sludge generation rate for a well increases with age (RAE92).

5.4.3 Oil and Gas Sludge Handling and Disposal

In the past, when sludge fouling in water and oil storage tanks became a problem, the tanks were drained and the sludge disposed of in waste pits. Both burn and brine waste pits have traditionally been the primary disposal method for oil production sludges and some produced water residues (RAE93). Burn pits are generally earthen pits intended for use as places to temporarily store and periodically burn non-hazardous oil field waste (excluding produced water) collected from tanks and other equipment. Brine pits are generally produced water pits that are lined, or earthen pits used for storing produced water and other nonhazardous oilfield wastes, hydrocarbon storage brine, or mining waster (RAE93).

Most companies in the petroleum industry are now aware that tank sludge may be radioactive, so sludges are usually surveyed for the presence of radioactivity. Sludges containing elevated NORM are generally dewatered and held in storage pending the promulgation of disposal regulations (CRC88, TDH92, DEQ92). Sludge that is being removed from tanks and equipment is placed in drums and store for later disposal.

Surface disposal of radioactive sludge (as practiced in the past) might lead to ground and surface water contamination. In addition, direct radiation exposures may result from individuals working or residing near the disposal site. There is little likelihood that radioactive sludge would be incorporated in building materials because of its physical properties.

5.5 RADIOLOGICAL PROPERTIES OF NORM CONTAMINATED SCALE

5.5.1 Radionuclide Concentrations in Scale

Naturally occurring radioactive material (NORM) is present in varying concentrations in the geologic formations from which oil and gas are extracted. Elevated NORM concentrations in oil and gas production equipment result when Ra-226 and Ra-228 and their decay products co-precipitate with mineral scales, such as $BaSO_4$, forming deposits on inside surfaces of field production equipment. Radionuclide concentrations in scale can vary from essentially soil background levels (about 1 pCi/g) to hundreds of thousands of picocuries per gram. Factors that can affect the magnitudes of NORM concentrations include the location of the production facility, the type of equipment, how long the production well has been in operation, and changes in temperature and pressure during petroleum extraction.

As discussed in Section 5.5.3, an API industry-wide survey of radiation exposure levels in oil and gas production equipment (API89) showed a wide variation in NORM radioactivity levels depending on the geographic origin of the equipment. The geographic areas with the highest equipment readings were northern Texas and the gulf coast crescent from southern Louisiana and Mississippi to the Florida panhandle. Very low levels of NORM radioactivity were noted in California, Utah, Wyoming, Colorado, and northern Kansas production fields.

The highest concentrations of radium contaminated scale appear to occur in the wellhead piping and in production piping near the wellhead (API89). The concentration of radium deposited in separators is about a factor of ten less than that found in wellhead systems. There is a further reduction of up to an order of magnitude in the radium concentration in heater/treaters. Concentrations of radium in scale deposited in production tubing near wellheads can range up to tens of thousands of picocuries per gram (API89). The concentrations in more granular deposits found in separators range from one to about one thousand picocuries per gram (API89).

The quantity and concentration of NORM waste in oil and gas production equipment also changes with time as the relative quantities of gas, oil, and water in the producing geologic formation change. The trend is for the relative quantity of NORM to increase as the well ages and as gas and oil resources are depleted.

In addition to the previously cited API study (API89), several other studies, both in the U.S. and in other countries, have been made to evaluate NORM concentrations in oil and gas scale. A British study of Ra-226 concentrations in oil and gas scale in production facilities in the North Sea revealed concentrations in scale ranging from 10 to over 100,000 pCi/g (McA88). The highest radium concentrations were reported in downhole tubing and valves and ranged from 1,000 to 410,000 pCi/g. The measurements targeted scale with suspected elevated Ra-226 activity so these results represent the high end of the range of Ra-226 concentrations in scale.

One survey of U.S. facilities included the analysis (for Ra-226) of 125 scale samples collected from areas of elevated external gamma radiation readings. The Ra-226 concentration in these samples ranged from 50 pCi/g to as high as 30,000 pCi/g, with an average of 5,480 pCi/g (Mi88). Since the study concentrated on scale with suspected high levels of radium, these concentrations are probably also well above the average.

A survey of 25 facilities, performed by the E&P Forum, revealed Ra-226 concentrations ranging from less than 27 pCi/g to over 27,000 pCi/g (EPF87). One major oil company has speculated that levels of 800 to 900 pCi/g may be common in the U.S., with some regional trending.

The average radium concentration in scale from oil and gas production equipment has been estimated based on detailed statistical curve fitting of API data from Louisiana to be 480 pCi/g (API89, RAE93). This database is used here because both the raw data and the analyses that led to the NORM concentration estimate are considered the most complete. Using the 3:1 ratio of Ra-226 to Ra-228 described earlier, this concentration reduces to 360 pCi/g of Ra-226 and 120 pCi/g of Ra-228. It is assumed that the progeny of both radium isotopes are in secular equilibrium. In summary, the radionuclides and their respective concentrations used in the assessment for oil and gas scale are as follows:

Radionuclide	Concentration (pCi/g)
Ra-226	360
Pb-210	360
Po-210	360
Ra-228	120
Th-228	120

5.5.2 Radon Fluxes in Scale

Several factors make it difficult to characterize radon flux from NORM scale deposits. Disposal or storage methods, particle grain size, and the thickness of the scale deposits may influence the radon flux rates. Similarly, the presence of oil or other petroleum products associated with the scale may reduce radon flux rates. Finally, since much of this waste is held within equipment (internally deposited), it may be difficult or even impractical to characterize net radon flux rates from the equipment. For the purpose of this report, radon flux is characterized by a radon emanation coefficient of 0.05 for scale (RAE89).

5.5.3 External Radiation Exposures Rates from Scale

The results of a statistical evaluation of the external radiation exposure level data from the API's industry-wide survey (API89) are summarized in Table B.5-6. NORM radioactivity levels showed wide variability between geographic regions and equipment types. Approximately 64 percent of the gas producing equipment and 57 percent of the oil production equipment surveyed showed radioactivity levels at or near background. Table B.5-6 shows the results in terms of difference over background by facility and type of equipment. The abbreviations used to specify equipment type are shown in Table B.5-7. NORM radioactivity levels tend to be highest in the water handling equipment. Median exposure levels for this equipment were measured in the 30 μR/hr to 40 μR/hr range (about 5 times background). Gas processing equipment with the

Table B.5-6. Summary Tabulation of radiation exposure levels associated with NORM in oil production and gas processing equipment. (Source: API89)

			Difference Above Background (μR/hr)				
Equipment	Number of Observations	Number of Observations Above Background	Minimum	25th Percentile	Median	75th Percentile	Maximum
Oil Production Facilities							
WOTHER	24	5	1.2	1.6	2.0	3.8	5.5
WPROD	2,324	777	0.1	1.0	2.3	7.9	1,500
METER	306	72	1.0	1.0	3.0	5.8	92
PUMP	1,393	424	0.1	1.0	3.0	14	990
OTHER	2,397	1,007	0.1	1.0	4.0	15	3,800
STANK	7,005	2,696	0.1	2.0	4.0	14	2,500
MANIFOLD	2,537	895	0.1	1.0	6.0	55	3,000
SUMP	454	253	0.1	3.0	7.0	26	790
SEP	7,887	3,816	0.1	2.0	8.0	40	4,500
H/T	2,962	1,495	0.1	2.0	8.0	47	3,500
WTANK	3,431	2,140	0.1	3.0	8.0	35	3,800
VRU	115	25	0.2	2.0	17	207	1,300
WINJ	102	50	1.0	4.0	20	53	890
WLINE	341	176	0.2	6.0	34	100	2,800
FLINE	1,748	419	0.1	7.0	42	112	3,000
Gas Producing Facilities							
COMPRESSOR	648	119	0.3	1.0	2.0	3.0	490
DEHYDRATOR	244	72	0.3	1.35	3.0	6.7	530
SWEETENER	234	30	0.2	1.0	3.4	19	220
INLET SCRUB	593	156	0.1	1.0	5.0	19	700
METER	101	32	0.3	1.15	5.5	51	700
CRYO UNIT	50	20	1.0	2.0	6.0	22	3,000
OTANK	423	140	0.2	2.0	6.0	30	380
OTHER	430	165	0.3	2.9	7.0	23	990

Table B.5-6. Continued.

Equipment	Number of Observations	Number of Observations Above Background	Difference Above Background (μR/hr) Minimum	25th Percentile	Median	75th Percentile	Maximum
FRAC TOWER	272	123	0.2	1.5	9.5	33	400
REFRIGER	143	56	0.1	2.0	16.0	69	590
BOTTOMS PUMP	40	30	0.5	3.0	17.0	45	220
PTANK	124	90	0.5	7.3	25.0	66	680
OPUMP	232	114	0.4	6.8	28.0	96	1,400
PPUMP	71	53	0.1	9.5	31.0	98	1,100
PROD LINE	146	82	0.1	14.0	35.0	110	1,080
PUMP	3	2	3.0	3.0	38.0	73	73
REFLUX PUMP	110	95	0.2	16.0	76.0	290	3,000
Background				5.0	7.0	9.0	

Table B.5-7. Abbreviations used to designate equipment types in oil production and gas processing facilities.

Abbreviation	Description
Oil Production Equipment	
WOTHER	Other wellheads except injection and production wellheads
WPROD	Production wellhead
METER	All metering equipment to include meters, meter runs, strainers, etc.
PUMP	All pumps
OTHER	All other measurements on service equipment
STANK	Stock tanks
MANIFOLD	Manifold/header piping, valves, chokes, etc.
SUMP	Sumps to include pits, pigtraps, ponds, etc.
SEP	Separators of all types
H/T	Heater treater
WTANK	Water tanks
VRU	Vapor recovery units
WINJ	Injection wellhead
WLINE	Water lines to include all valves and elbows
FLINE	Flow lines to include all valves and elbows

Table B.5-7. Continued.

Abbreviation	Description
Gas Processing Equipment	
COMPRESSOR	Compressors and associated equipment
DEHYDRATOR	Dehydration equipment to include Glycol, EG, TEC systems, etc.
SWEETENER	All gas sweetening equipment
INLET SCRUB	Inlet scrubbers, separators, etc.
METER	All metering equipment to include meters, meter runs, strainers, etc.
CRYO UNIT	All cryogenic process equipment
OTANK	All other tanks
OTHER	All other gas processing equipment
FRAC TOWER	All process towers and columns
REFRIGER	All propane refrigeration system equipment
BOTTOMS PUMP	Pumps transferring liquids from the bottoms of towers
PTANK	Propane tank
OPUMP	All other pumps
PPUMP	Propane pump
PROD LINE	All product lines
PUMP	All pumps
REFLUX PUMP	All reflux pumps

highest levels includes the reflux pumps, propane pumps and tanks, other pumps, and product lines. Median radiation exposure levels for this equipment were noted to be in the 30 μR/hr to 70 μR/hr range. For both oil production and gas processing equipment, a few measurements were observed to be in excess of 1 mR/hr.

The radiation exposure measurements given in Table B.5-6 represent the most comprehensive and consistent set of data available to date. However, much of the data were collected at sites suspected of exhibiting increased radioactivity levels and were not collected in a statistically designed sampling plan. The number of observations from oil and gas equipment for a given geographic area may not be proportional to the actual amount of operational equipment in that area. Hence, the data may not be typical of randomly chosen sites and may tend to overstate the magnitude of the NORM problem across all oil and gas production facilities.

5.6 RADIOLOGICAL PROPERTIES OF NORM CONTAMINATED SLUDGE

5.6.1 Radionuclide Concentrations in Sludge

Naturally occurring radioactive material (NORM) is present in varying concentrations in the geologic formations form which oil and gas are extracted. Elevated NORM concentrations in oil and gas production equipment result when Ra-226 and Ra-228 and their decay products co-precipitate with mineral sludges, forming deposits in storage tanks and other collection equipment. Radionuclide concentrations in sludge can vary from essentially background levels (about 1 pCi/g) to several hundred picocuries per gram (API90). Factors that can affect the magnitudes of NORM concentrations include the location of the production facility, the type of equipment, how long the production well has been in operation, and changes in temperature and pressure during petroleum extraction.

The highest concentrations of NORM-contaminated sludge appear to occur in the separator and collection areas near the separator (separator drain, etc.) (RAE88). The concentrations of radium deposited in heater/treaters and in sludge holding tanks is about a factor of 10 less than that found in the separator. NORM concentrations in sludge deposits in heater/treaters and tanks are generally around 75 pCi/g (RAE93). Chevron speculates that levels of 20 to 25 pCi/g may be more common. However, tank bottoms may have concentration as high as 100 pCi/g (B188).

The average radium concentration in sludges from oil and gas production equipment has been estimated based on detailed statistical curve fitting of API data from Louisiana to be 75 pCi/g (RAE93). This database is used here because both the raw data and the analyses that led to the NORM concentration estimate are considered the most complete. Using the 3:1 ratio of Ra-226 to Ra-228 described earlier, this concentration reduces to 19 pCi/g of Ra-226 and 56 pCi/g of Ra-228. As with the NORM contaminated scale, it is assumed that the progeny of both radium isotopes are in secular equilibrium. In summary, the radionuclides and their respective concentrations used in the assessment for oil and gas sludge are as follows:

Radionuclide	Concentration (pCi/g)
Ra-226	56
Pb-210	56
Po-210	56
Ra-228	19
Th-228	19

5.6.2 Radon Fluxes in Sludge

Several factors make it difficult to characterize radon flux from NORM sludge. The presence of oil or other petroleum products associated with the sludge may reduce radon flux rates. As noted earlier, the presence and concentration of Ra-226 will govern radon flux and diffusion properties from sludge. For the purpose of this report, radon flux from sludge is characterized by a radon emanation coefficient of 0.22 (RAE89).

5.6.3 External Radiation Exposures Rates from Sludge

The results of the statistical evaluation of the radiation exposure level data from the API's industry-wide survey (API89) that was presented in Table B.5-6 and discussed in Section 5.5.3 did not distinguish between external readings caused by contaminated sludge or scale. However, it is assumed that facilities with elevated external exposure levels have contaminated levels of NORM sludge and scale in production equipment. Therefore, external radiation exposure rates discussed in Section 5.5.3 will not be repeated here.

5.7 DISPOSAL SCENARIOS FOR RISK ASSESSMENT

5.7.1 Scenario Description

The preliminary risk assessment presented in Chapters D.1 through D.3 evaluates potential radiological doses and risks resulting from the disposal of NORM-contaminated oil and gas scale and sludge based on the disposal site characteristics. Radiological doses and risks are assessed for workers, onsite individuals, the critical population group (CPG), and the generic population.

Doses and risks assessed for the workers include exposures due to direct gamma radiation and dust inhalation, and to the office worker due to indoor radon inhalation. The disposal site worker is an individual who works directly on top of the uncovered waste. The office worker is an individual who works inside an office building inadvertently constructed on top of the waste pile sometime after the disposal site is closed or abandoned.

Doses and risks assessed for the onsite individual include exposures from direct gamma radiation, dust inhalation, and indoor radon inhalation. Ingestion of food grown onsite is not considered because oil and gas waste piles generally do not have the textural and nutritional properties and the water-retention capabilities to support vegetation.

Doses and risks evaluated for the member of the CPG residing 100 meters from the disposal site include exposures from direct gamma radiation, inhalation of contaminated dust, inhalation of downwind radon, ingestion of contaminated well water, ingestion of food contaminated by well water, and ingestion of food contaminated by dust deposition.

Doses and risks analyzed for the general population within a 50 mile radius of the disposal site include exposures arising form the downwind transport of resuspended particulates and radon, and exposures arising from ingestion of river water contaminated via the groundwater pathway and via surface runoff. Downwind exposures include inhalation of the resuspended particulates, ingestion of the food contaminated by deposition of the resuspended particulates, and inhalation of radon.

The above exposure scenarios and assumptions are described in more detail in Chapter D.1 "Risk Assessment Methodology." Chapter D.2 "Risk Assessment Parameters" presents the generic parameters that are necessary to the preliminary risk assessment. The radiological doses and risks for the above scenarios are presented in Chapter D.3 "Risk Assessment Results."

5.7.2 Representative Disposal Facility and Location Characteristics

The generic oil and gas NORM waste disposal site is assumed to be located in the State of Texas. Texas is known to have the highest number of oil and gas production wells (see Table B.5-2). The annual NORM-contaminated scale and sludge generated in Texas of 6.6×10^4 MT/yr can be estimated based on the U.S. annual combined scale and sludge generation rate of 2.55×10^5 MT/yr (2.5×10^4 MT/yr scale + 2.3×10^5 MT/yr sludge) and the ratio of the oil generation rates for the U.S. and Texas ($716{,}061 \times 10^3$ barrels of oil for Texas/$2{,}778{,}773 \times 10^3$ barrels of oil for the U.S. = 0.258).

Although much of the oil and gas production equipment containing NORM is presently stored in controlled areas, some companies are now cleaning the equipment and proposing to dispose of the NORM at disposal sites (RAE92). Therefore, the risk assessment for this sector is based on disposal of NORM-contaminated oil and gas scale and sludge waste at a disposal site. Assuming that the reference facility, located within Texas, is designed to store half of 40 years of waste from the entire state, it would therefore contain 1.32 million MT of such wastes, or 780,000 m^3 based on a composite density of 1.66 g/cm^3 (RAE93). The facility is assumed to have a waste disposal area of about 160,000 square meters (400 m square), with a waste depth of 4.9 m. It is also assumed that the site is located near a surface stream and that the region is underlain by a large aquifer. For comparison purposes, an on-site disposal facility is also modeled for the reference 10-well facility. The on-site facility is assumed to store 30 years of waste from the individual facility and have a waste disposal area of about 102 square meters and a waste depth of 2.45 m. As shown in Tables B.5-4 and B.5-5, the total sludge plus scale volume for the on-site facility is 250 m^3. The population density near and around the sites are assumed to be 65 persons per square mile, the average for the State of Texas (DOC91).

Radionuclide concentrations for the disposal sites are weighted averages of the concentrations presented in Sections 5.5.1 and 5.6.1. The weighting was performed on a mass basis (to account for density differences).*

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$$\frac{\left(\frac{480\text{pCi Radium}}{\text{g scale}}\right)\left(\frac{2.6\text{ g}}{\text{cm}^3}\right)\left(\frac{1\times10^6\text{ cm}^3}{\text{m}^3}\right)\left(\frac{16.18\text{ m}^3\text{ scale}}{30\text{ year}}\right)+\left(\frac{75\text{ pCi radium}}{\text{g sludge}}\right)\left(\frac{1.6\text{ g}}{\text{cm}^3}\right)\left(\frac{1\times10^6\text{ cm}^3}{\text{m}^3}\right)\left(\frac{234.3\text{ m}^3\text{ sludge}}{30\text{ yr}}\right)}{\left(\frac{16.18\text{ m}^3\text{ scale}}{30\text{ yr}}\right)\left(\frac{2.6\text{ g}}{\text{cm}^3}\right)\left(\frac{1\times10^6\text{ cm}^3}{\text{m}^3}\right)+\left(\frac{234.3\text{ m}^3\text{ sludge}}{30\text{ yr}}\right)\left(\frac{1.6\text{ g}}{\text{cm}^3}\right)\left(\frac{1\times10^6\text{ cm}^3}{\text{m}^3}\right)} = 120\ \frac{\text{pCi radium}}{\text{g waste}}$$

Therefore, the average concentration of the radium in the oil and gas wastes at the offsite and onsite disposal facilities is 120 pCi/g. Using the 3:1 ratio of Ra-226 and Ra-228 described earlier, this concentration reduces to 90 pCi/g of Ra-226 and 30 pCi/g of Ra-228. It is assumed that the progeny of both radium isotopes are in secular equilibrium. In summary, the radionuclides and their respective concentrations used in the assessment for oil and gas sludge are as follows:

Radionuclide	Concentration (pCi/g)
Ra-226	90
Pb-210	90
Po-210	90
Ra-228	30
Th-228	30

Volume-averaged densities, porosities, and radon emanation coefficients for the facility are calculated in the following manner:

$$P_{avg} = \frac{(P_{scale})\,(16.18\ m^3) + (P_{sludge})\,(234.3\ m^3)}{(16.18\ m^3) + (234.3\ m^3)} \qquad \text{(B.5-1)}$$

where

P_{avg} = scale/sludge volume averaged parameter

P_{scale} = scale parameter

P_{sludge} = sludge parameter.

Table B.5-8 summarizes the above NORM pile characteristics and presents additional values necessary for assessment of the radiological impact. The sources of the parameters or report section of the derivation are also identified in Table B.5-8.

Table B.5-8. · · assessment parameters for the representative disposal of oil and gas waste.

Parameter	Value	Units	Source
Location	Texas		Section 5.7.2
Population Density	65	person/mi^2	DOC91
NORM Pile Dimensions (Regional Facility):			
Mass	1.3×10^6	MT	Section 5.7.2
Volume	7.8×10^5	m^3	Section 5.7.2
Top Surface Area	1.6×10^5	m^2	Section 5.7.2
Length	400	m	Section 5.7.2
Width	400	m	Section 5.7.2
NORM thickness	4.9	m	Section 5.7.2
Cover Thickness	0	m	Section 5.7.2
NORM Pile Dimensions (On-Site Facility):			
Mass	416	MT	Section 5.7.2
Volume	250	m^3	Section 5.7.2
Top Surface Area	102	m^2	Section 5.7.2
Length	10	m	Section 5.7.2
Width	10	m	Section 5.7.2
NORM thickness	2.45	m	Section 5.7.2
Cover Thickness	0	m	Section 5.7.2
Density	1.7	g/cm^3	(RAE93)
Radon Emanation Coefficient	0.15		(RAE89)
Respirable Fraction of Resuspended NORM	0.05		Assumed
Nuclide Concentrations:			
Ra-226	90	pCi/g	Section 5.7.2
Pb-210	90	pCi/g	Section 5.7.2
Po-210	90	pCi/g	Section 5.7.2
Ra-228	30	pCi/g	Section 5.7.2

Table B.5-8. Continued.

Parameter	Value	Units	Source
Th-228	30	pCi/g	Section 5.7.2
Distribution Coefficients:			
Ra-226	2.5	m^3/kg	Ma89
Pb-210	0.10	m^3/kg	Ma89
Po-210	0.10	m^3/kg	Ma89
Ra-228	2.5	m^3/kg	Ma89
Th-228	2.5	m^3/kg	Ma89
Annual Rainfall	0.51	m/yr	Ma89
Saturated Hydraulic Conductivity	300	m/yr	Ma89
Distance of Groundwater Flow to River	10,000	m	Assumed

5.8 RECYCLING SCENARIOS OF SCALE-COATED STEEL FOR RISK ASSESSMENT

5.8.1 Representative Reuse and Location Characteristics

Most of the NORM scale generated by the oil industry is contained in production equipment. Equipment contaminated with NORM may be either cleaned and reused, disposed, or sold for recycle. Before the accumulation of NORM in oil production equipment was fully recognized, contaminated equipment, such as tubing, was occasionally released to the public for alternative uses (RAE92). The uses included: load-supporting beams in house construction, plumbing for culinary water, fencing material, for playground equipment in school yards, awning supports, and practice welding material in classrooms (RAE93).

Since its discovery, greater precautions have been taken to evaluate and remove NORM contamination from used oil production equipment before its release for reuse (RAE93). Loads of scrap metal being transported are often surveyed for hidden radioactive sources and for NORM (RAE93). Piping and equipment are generally cleaned before release or before being sent to a smelter. Additionally, pollution control devices, such as filters and bubblers, are emplaced in the smelter stacks to reduce airborne emissions (RAE93).

One method of recycling used steel is to reprocess the material via smelting. Melt-refining of NORM-contaminated materials separates the NORM (contained in the scale deposits) from the steel. Currently, three steel mills are performing tests involving controlled melting of NORM-contaminated equipment. These are: Shaparell Steel of Texas, Segean Structured Metals of Texas, and Sheffield Steel of Oklahoma.*

The scale is expected to volatilize and be released in the gaseous effluent from the furnace (RAE92). The final product steel is essentially free of NORM contaminants. If the steel mill has pollution control equipment, most of the NORM will be trapped in the baghouses and

* Personal communication, Turner, David J. Joseph & Co., June 26, 1992.

scrubbers (RAE92). The representative melt refinery used here is an electric arc furnace. The furnaces operate between 2,800 and 3,000°F.* A batch cycle lasts between 30 and 50 minutes.** A typical smelting operation includes particulate emission control capable of capturing 99 percent of the particulates.**

Since the projected disposal sites and two of the three steel mills performing NORM smelting tests are in the State of Texas, it is assumed that the NORM-contaminated equipment is also recycled there. It is estimated that about 6,100 metric tons of scale and 59,000 metric tons of sludge are generated by oil production in Texas annually based on U.S. scale and sludge generation rates and the ratio of oil production of Texas to that of the U.S. It is assumed that the reference mill processes NORM equipment containing 40 percent of the annual scale produced in Texas (2,425 MT). Since waste sludge is less dense and easier to remove from equipment than scale, it is assumed that sludge bearing equipment is cleaned before shipment to the melt refinery.

As discussed in Section 5.5.1, the scale is assumed to have a NORM radium (Ra-226 and Ra-228 in a 3:1 ratio) concentration of 480 pCi/g (RAE93). Therefore, it is estimated that 1.2×10^{12} pCi of radium are smelted each year at the modeled facility. Since the NORM contamination is volatilized and released in the effluent gases, and 99 percent of these particulate aerosols are captured, only 1 percent or 1.2×10^{10} pCi of radium smelted annually is released to the atmosphere. This is equal to an average radium release rate of 400 pCi/sec.

Although not needed in the risk analysis, the representative steel mill has a stack-gas effluent rate of 29,000 ft^3/min at 200 degrees F*, stack diameter of 100 inches, and a stack height of 30 feet.**

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* Personal communications, Steve Rowlan, Nucor Steel, May 26, 1992, May 27, 1992, and May 28, 1992.

** Personal communication, Steve Rowlan, NUCOR Steel, September 18, 1992.

Scaling ... average radium release rate given above for the 3:1 Ra-226 to Ra-228 ratio and assuming secular equilibrium of the progeny, the release rates of radionuclides of interest in inhalation in the effluent are then

Radionuclide	Effluent Concentration (pCi/sec)
Po-210	$3.0x10^2$
Pb-210	$3.0x10^2$
Ra-226	$3.0x10^2$
Th-228	$1.0x10^2$
Ra-228	$1.0x10^2$

5.8.2 Reprocessing Scenario

The preliminary risk assessment presented in Chapters D.1 through D.3 evaluates potential radiological risks resulting from the reprocessing of NORM-scale contaminated oil and gas equipment based on the above recycle characteristics. Radiological risks are assessed for the critical population group (CPG) and the generic population. Scenarios evaluated for the member of the CPG residing 181 meters from the smelter include exposures from inhalation of contaminated dust. This is the distance at which ground-level concentrations are at a maximum. Scenarios analyzed for the general population within a 50 mile radius of the smelter include exposures arising from the downwind transport and inhalation of resuspended particulates.

Table B.5-9 summarizes the recycling scenario characteristics and presents values necessary for the assessment of radiological impact. The sources of the parameters or report section of the derivation are also identified.

The above exposure scenarios and assumptions are described in more detail in Chapter D.1 "Risk Assessment Methodology." Chapter D.2 "Risk Assessment Parameters" presents the generic

Table B.5-9. Risk assessment parameters for the representative cycle of oil and gas waste.

Parameter	Value	Units	Source
Location	Texas		Section 5.8.1
Population Density	65	person/mi^2	DOC91
NORM Smelted:			
Mass	2,400	MT	Section 5.8.1
Volume	933	m^3	Section 5.8.1
Density	2.6	g/cm^3	RAE92
Nuclide Release Rates:			
Ra-226	3.0×10^2	pCi/sec	Section 5.8.1
Pb-210	3.0×10^2	pCi/sec	Section 5.8.1
Po-210	3.0×10^2	pCi/sec	Section 5.8.1
Ra-228	1.0×10^2	pCi/sec	Section 5.8.1
Th-228	1.0×10^2	pCi/sec	Section 5.8.1

parameters that are necessary to the preliminary risk assessment. The radiological doses and risks from the above scenarios are presented in Chapter D.3 "Risk Assessment Results."

5.9 SECTOR SUMMARY

This chapter provides a description of U.S. production of oil and gas and of NORM wastes from oil and gas production activities. The estimate of 260 thousand MT of NORM waste each year, as well as NORM radionuclide concentrations in the waste, are based on oil production. It is assumed that only about 30 percent of oil wells produce significant amounts of NORM wastes.

The estimated radionuclide concentration in oil production NORM wastes is 120 pCi/g of radium, with 75 percent of that activity in Ra-226 and the remainder in Ra-228. Their decay products are assumed to be in secular equilibrium. For the reuse scenario involving oil production equipment sent as scrap to a steel mill, sludge is assumed to be removed and only the scale goes with the scrap. The scale is assumed to have a radium (Ra-226 plus Ra-228 in the mix described above) concentration of 480 pCi/g.

For the disposal of sludge and scale wastes, a generic disposal facility for the State of Texas is postulated. The disposal unit is assumed to be 400 meters by 400 meters with a waste depth of 5 m. It holds a total of 780,000 cubic meters of waste (20 years of the waste generated for Texas). It is assumed that the disposal facility is located near a stream and underlain by a large aquifer. For comparison purposes, an onsite disposal facility capable of handling 30 years of waste from the reference 10-well facility is also defined.

The reuse scenario (also projected to be in Texas) involves production equipment being smelted to a steel mill. The NORM radium radionuclides are emitted into the air at a rate of 400 pCi/s at an average exhaust rate of 29,000 ft^3/min. The exposed population for both the disposal and reuse scenarios is the average population density of Texas, 65 persons per square mile (DOC91).

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