

A Naturally Occurring Radioactive Material (NORM) Disposal Cost Study

API PUBLICATION 7100
FIRST EDITION, NOVEMBER 1996

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Exploration and Production Department

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FOREWORD

This publication is based on oil and gas company questionnaires representing naturally occurring radioactive materials (NORM) accumulated to the end of 1992 and annually produced during 1993, along with some replies from 1994 also added. The production of oil and gas in the United States has resulted in the formation of scales and sludges containing NORM. This study is based on the actual costs of NORM disposal obtained through questionnaire replies from oil and gas producers. The NORM questionnaire replies were received from companies representing 46 percent of the domestic U.S. oil, gas, and gas condensate production. The survey results were prorated to represent 100 percent of the U.S. oil and gas industry. Most of the oil and gas producing states of the U.S. are represented in the survey replies.

This document details the reported quantities of NORM that have accumulated over the years and the annual rate of NORM production for 1993 from the domestic U.S. oil and gas condensate production. No data was received for NORM in the gas industry. This publication documents the 1992 costs of the available NORM disposal options at that time and calculates the cost impact of disposing of the accumulated NORM and the annual cost of compliance with existing and proposed NORM regulations.

Over a number of years, it is estimated that on a volume basis some 10 million drums (55 gallons each) of NORM have accumulated in widely scattered pieces of production and process equipment, produced water ponds, and treatment pits. Of this accumulation, some percentage has been processed and disposed of by routine industry disposal practices. For instance, NORM-containing scrap steel such as old production tubulars were routinely recycled by the steel scrap industry, until that industry installed radiation detectors that screened steel scrap for radiation sources. The detectors became widely used in the late 1980's. Consequently, NORM-containing scrap steel recycled before the use of radiation detectors is no longer part of the waste stream. Similarly, some percentage of NORM-containing E&P waste may have undergone treatment such as land farming in which the concentration of NORM in the waste material is no longer distinguishable from background levels. Nevertheless, the 10 million drum accumulation figure is conservative and provides some margin for possible underreporting.

Survey monitoring programs to detect and quantify NORM are in operation in virtually all domestic U.S. oil and gas producing areas. These programs are designed to provide NORM data to satisfy regulatory reporting requirements. The questionnaire replies include two reports of very large NORM accumulations. These two reports, along with a concentration of reported NORM data from the Gulf Coast of Louisiana and Texas, were included in the database used to extrapolate the reported NORM quantities to represent the entire U.S. oil and gas condensate production industry. However, recent reports of NORM in the feed stocks to the downstream refining and processing industry that are not included in this report may indicate an underreporting of the annual NORM accumulation rate of 140,000 drums per year. Other studies [1, 2] have indicated that this annual figure could be four times higher than reported in the questionnaire replies, even after prorating to represent the entire industry.

There are a growing number of NORM disposal options defined by the specific activity of the NORM that they will accept, all of which are licensed or permitted by federal and state agencies. The NORM acceptance criteria are different for each disposal site, as are the disposal costs. The range of available NORM disposal options at the end of 1993 include the following:

- Burial sites.
- Surface treatment.
- Commercial injection disposal.
- Recycling of steel.

- NORM recycling into shielding bricks.
- Plug and abandonment of wells, encapsulation and injection.

Disposal costs per drum of NORM vary depending on the specific activity of the scale, the number of drums, and the disposal option selected. Costs range from approximately \$74 minimum to \$3333 per drum. Actual average costs to date reported in the NORM questionnaire from the U.S. domestic oil and gas industry are \$544 per drum with a maximum of \$20,000 per drum reported by more than one company.

Using the average disposal cost per drum of \$544, the annual cost impact of disposing of the 142,000 drums of accumulated NORM would be \$77 million per year. The potential cleanup over 25 years of the accumulated NORM volume of 10,000,000 drums at 400,000 drums per year adds an additional cost of \$218 million per year. The total annual NORM disposal cost could be \$295 million per year for the next 25 years. These figures do not include the costs to identify, sample, analyze, clean, and contain the NORM ready for disposal.

NORM disposal costs may be reduced significantly if one or more of the following options are used:

- Volume discounts offered by the disposal companies.
- Cheaper disposal options becoming an operational reality.
- Disposal volume reduction due to regulatory compliance matched to real risk.
- Exempt concentration level above 30 pCi/g.

Other disposal options may have been introduced since the date of this survey in 1992-93. They are not evaluated in this publication.

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Suggested revisions are invited and should be submitted to the director of the Exploration and Production Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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A Naturally Occurring Radioactive Material (NORM) Disposal Cost Study

SECTION 1—VOLUME ESTIMATES OF NORM WASTES

1.1 Introduction

NORM accumulation data was received from the oil and gas producing states of the U.S. shaded in Figure 1. Most of the questionnaire replies were grouped by individual oil company regions; most regions included more than one state. Because of the different grouping of states included by each company, the information was analyzed using the five regions shown. Figure 1 illustrates the states from which the data was compiled and how the data are grouped into the five regions used in the data analysis.

The NORM survey questionnaire was sent out to API member companies. The appendixes and tables in this document were derived from the 50 questionnaire replies received, representing approximately 46 percent of the domestic U.S. oil, gas, and gas condensate production capacity. The questionnaire replies are summarized in Table 1 by total oil and gas condensate production as a percentage of each region's total. Annual oil and gas condensate production figures from the *Oil and Gas Journal* [3] are shown for comparison. No replies were received relating to NORM in natural gas.

The data for oil and condensate production was obtained in section 1.6.1 of the questionnaire and is shown in Appendix C. This data was cross-checked with reported oil and

gas condensate figures from the Dwigths Energydata, Inc. [2] information database to ensure an accurate division of production by state and region for the responding companies. This was done to prorate the figures for the total accumulated NORM to December 1992, and the 1993 annual NORM accumulation to represent the total oil and gas condensate production in each region. The Dwigths [4] information also allowed the replies to be more accurately divided by state and grouped by region.

No two questionnaire replies had the same regional grouping of states; hence, the replies were adjusted to the regional groupings shown in Figure 1. The two survey replies with NORM drum disposal costs of \$20,000 per drum were omitted due to the unusual operational problems causing these high costs which are not anticipated to recur. The first high-cost NORM disposal job reported was due to loss of the well use because junk steel was lost in the well bore. The second high-cost NORM disposal job was also due to an unusable well bore because a piece of equipment lodged in the well.

1.1.1 COMMENTS ON THE NORM SURVEY DATA

The NORM surveys did not use a single, consistent survey procedure or dose rate decision criteria. For example,

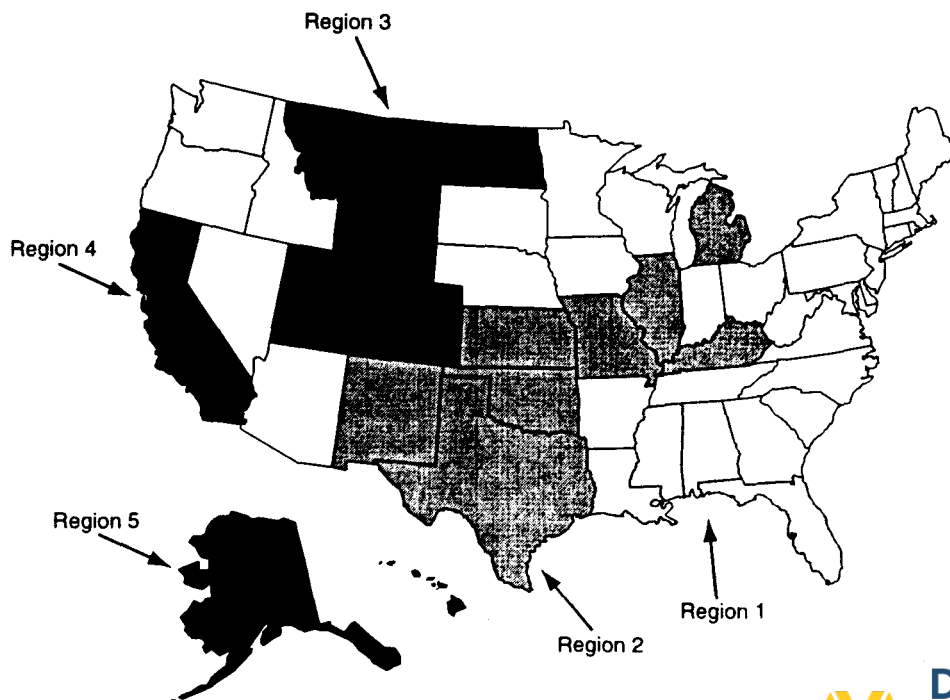


Figure 1—Responding States Grouped Into Regions

Table 1—Oil and Gas Questionnaire Replies 1992

Region	Gulf Coast	Mid-Continent	Rocky Mountains	California	Alaska	Total
Replies 000 BPD (Percentage of region responding)	972 (44%)	323 (20%)	68 (13%)	158 (17%)	1624 (100%)	3132 (46%)
000 BPD (100 Percent) Ref [5]	2233	1583	512	936	1624	6888

the distance of the detector from the item being surveyed (when known) varied from 1 centimeter to 18 inches. The dose rate decision criteria of either 25 or 50 micro Roentgen per hour (microR/h) was universally applied to NORM in equipment, in drums, on the ground, and in produced water pits. The reported data did not include the number of items surveyed and found to be free of NORM; the items would be more numerous than items found containing NORM.

Figure 2, prepared from the previously unpublished Louisiana Mid-Continent Oil and Gas Association (LMOGA) NORM survey data, shows that 90 percent of the NORM held in storage in 1992 using a 25 microR/h decision criteria had a specific activity less than 100 picoCuries per gram. However, NORM surveys conducted

by surveying the outside surfaces of the oil, gas, and gas condensate equipment and tubulars and using an action level of 50 microR/h may have difficulty [5], depending on the quantity of NORM material accumulated inside the equipment and the thickness of the steel, and in detecting NORM on the inside of the item being surveyed where the specific activity is less than 100 pCi/g. Hence, it is possible that only NORM with a specific activity greater than 100 pCi/g (that is 9 percent of all NORM) was being reliably detected with an external dose rate over 50 micro R/h, and reported in the survey replies. Figure 2 also illustrates that less than 1 percent of NORM has a specific activity greater than 1000 pCi/g. Other field survey factors that affect the production, detection, and reporting of NORM are the following:

- Sensitivity of the survey detector.
- Action level for reporting (currently 50 microR/h).
- Oil and gas production rates.
- Ratio of produced water to oil; that is, barrels of water per barrel of oil.
- Use of scale inhibitors to prevent NORM.
- Percent of produced water re-injected versus surface treatment processing.

1.1.2 NORM Database Information

The NORM information used throughout this publication was obtained via a survey questionnaire. Appendixes A through G provide examples of the questionnaire, the information received, and various summaries of the information. A description of the contents of each appendix follows.

Appendix A illustrates a typical questionnaire reply received with the universal and notable absence of NORM data associated with gas production. Only one reply contained NORM-specific activity information. Figure 3 summarizes the dose rate data for the accumulated NORM.

Appendix B includes a range of NORM disposal job/program costs to illustrate the data received in the questionnaire replies and incorporated into the database in Appendix C.

Appendix C contains a listing of the Questionnaire Survey Replies Database. The survey questionnaire replies for the oil and gas condensate production were combined with data from Dwigths Energy, Inc. [4] to enable the information to be prorated to represent 100 percent of the oil, gas, and gas condensate production in each region.

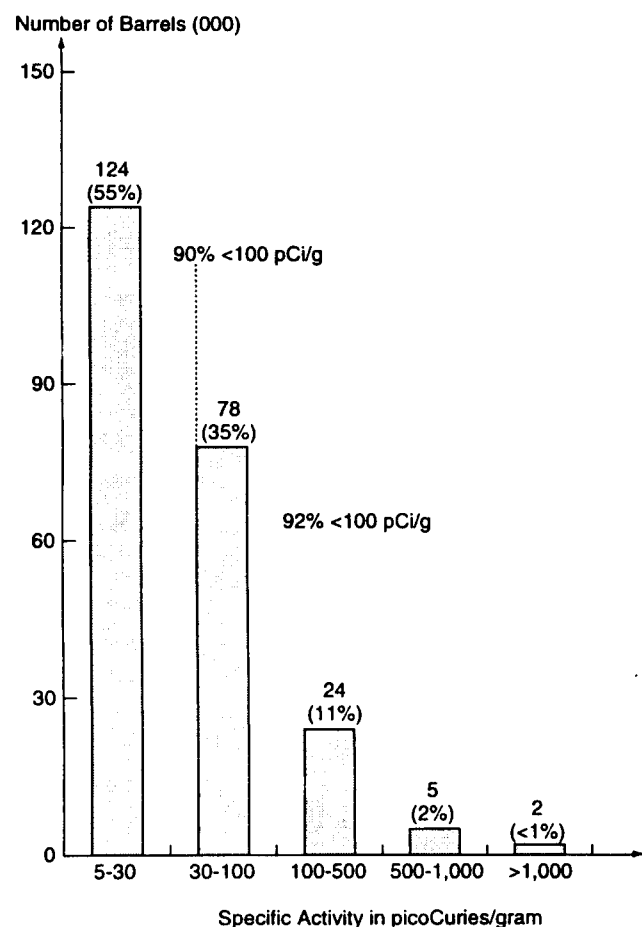


Figure 2—Drums of Stored NORM by Specific Activity and Percentage of Total Stored Per Activity Range

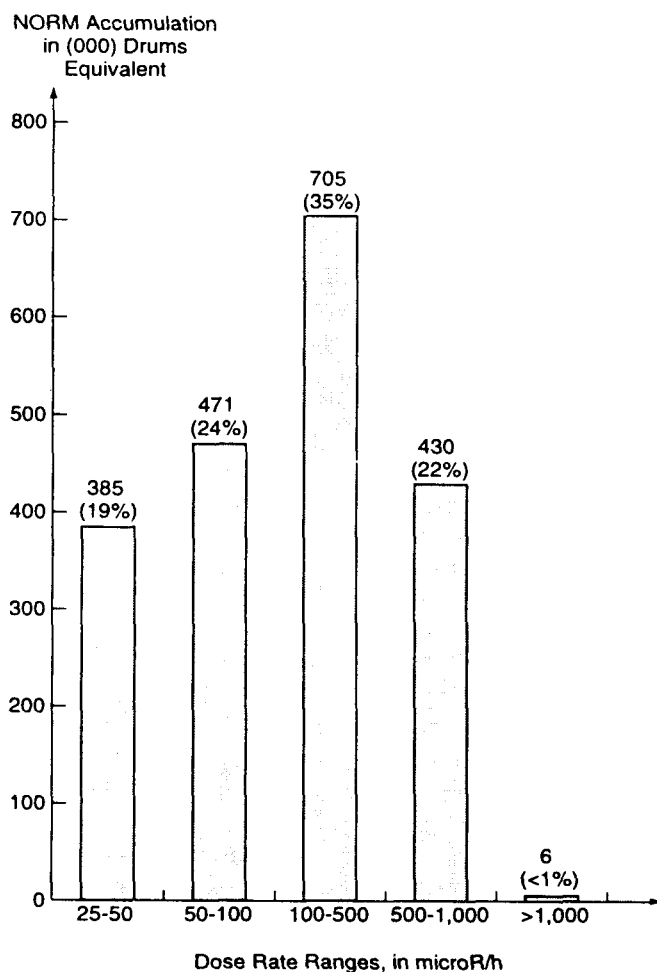


Figure 3—Drums of Stored NORM by Dose Rate Corrected to Percent Production
(From 1993 API Survey)

Appendix D contains a transportation cost matrix by region to permitted disposal sites (1993). Estimates were derived from transport company rate sheets and modified through discussions with oil and gas producing companies. Rates are for exclusive use full-load vehicles.

Appendix E illustrates actual disposal costs per drum for plug and abandonment summarized from Appendix C. Maximum, average and minimum costs per drum for NORM disposal injection or encapsulation placement were obtained; virtually all the data came from Region 1, the Gulf coast.

Appendix F lists NORM disposal costs by region for disposal options. This matrix summarizes the maximum, average, and minimum disposal cost per drum from each region to each disposal site; it also adds in the transport costs to give the total disposal costs per drum for the annual NORM accumulation and the accumulated NORM material for each region to each disposal site. The accumulated NORM drums per region is multiplied by these costs to give the range of

accumulated NORM disposal costs per region. See Section 3.2 (Table 7).

The annual NORM accumulation rates from Table 3 for all five regions are also multiplied by the minimum average and maximum average transport and disposal costs per drum (from Appendix F) to give the annual NORM transport and disposal cost range summarized in Table 9.

Each of the five regions is summarized separately, and all five are totaled to give the range of transport plus disposal costs for all accumulated NORM and the annual cost of disposal for the annual volume of NORM accumulated; see Section 4.3.

Appendix G details NORM accumulation by type of source. Summarized data from the replies are grouped for comparison by the source generating the NORM. The two enormous accumulation reports (# 137 and # 146) were checked with the responding companies and their accuracy confirmed; these reports are representative of the historical NORM accumulations.

Appendix G shows that stored solids were not identified in the survey concerning their original source of accumulation. NORM-containing stored tubulars and equipment, along with stored solids, each represent less than 1 percent of the total NORM known to have been accumulated as of December 1993. The single largest source of accumulated oil-field NORM reported in the questionnaire replies is contained in produced water pits or ponds.

1.2 Volumes of NORM Waste—Past, Present, and Forecast

1.2.1 GENERAL

The actual survey replies represent 46 percent of the domestic oil, gas, and gas condensate production. The ratio of the total oil and gas condensate production from the *Oil and Gas Journal* [3] to the reported production data was used to multiply the reported number of drums (of NORM for each region) to represent 100 percent of the domestic oil and gas condensate production as shown in Table 2.

The U.S. oil and gas producing states from which replies were received and shown in Figure 1 have been grouped into five regions to facilitate the calculation of the NORM disposal costs. Most responding companies had operating areas with different state groupings, some of which were not identified by individual states. In those cases, the survey data was prorated for the total production between the individual states and regions.

Region 1, the Gulf Coast survey, reported oil, gas, and gas condensate production was 971.62 thousand barrels per day (MBPD) (43.5 percent of the actual 2333 MBPD [3] (100 percent) produced in Region 1). Hence the prorating factor is $(100/43.5) = 2.3$. The prorating factors for Regions 2, 3, 4, and 5 were calculated in the same manner.

Table 2—NORM Generated Per Region From 100 Percent of Producers

	Regions				
	1	2	3	4	5
Derivation of Production Multiplier to 100 Percent mbpd					
Production replies	971.62	322.67	67.85	145.3	1,624.0
Oil and gas journal ave	2,230.0	1,559.0	517.0	936.0	1,624.0
Percent of regional total	43.5	20.7	13.1	15.5	100.0%
Multiplier	$100/43.5 = 2.3$	$100/20.7 = 4.8$	$100/13.1 = 7.6$	$100/15.5 = 6.45$	1.0

1.2.2 REGIONS 1, 2, 3, AND 5

Table 3 calculates the annual NORM accumulation rate from the reported annual rates contained in the survey replies.

The annual reported quantities of NORM generated for Regions 1, 2, 3, and 5 are based on a fraction of each region's oil and gas production which is first multiplied by a factor derived in Table 2 which then equates the annual NORM generation rate to 100 percent of the production for each region.

The NORM survey dose rate decision criteria of 50 microR/h is measured on the outside of the steel components surveyed. No one measurement protocol was used to take the readings. Some of the survey issues affecting the accuracy of these readings are the various thicknesses of the equipment steel, the distance of the detector from the component and its orientation to the equipment being surveyed, the quantity of NORM present within a component, and the possibility of non-radioactive shielding barium scales. Because of these sources of error and external decision criteria, it is difficult to detect NORM with a specific activity less than 100 pCi/g.

The accumulation of NORM in oil and gas equipment (see Figure 2) has a relationship between the quantity produced and the specific activity such that, based on the LMOGA data, 90 percent of the NORM accumulated is less than 100 pCi/g. This material is not easily detected by external surveys unless they are carefully conducted by trained and experienced NORM technicians [5]. From a review of

the difficulties and the factors that affect the accuracy of these readings even in a laboratory controlled situation [5], the reported quantities of NORM based on these readings may be underestimated by a factor of 2 to 10. Hence, both the annual and the accumulated quantities of NORM are multiplied by a factor of between 2 and 10 to represent the full range of NORM specific activities. This document uses the factor 10 to calculate the total annual NORM accumulation and the quantities of NORM accumulated over many years of production.

Table 3 shows the annual NORM accumulation rates reported by Regions 1, 2, 3, and 5. The reported figures are multiplied by the factor from Table 2 to represent 100 percent of the production and then by 10 to take into account the difficulties in detecting the lower specific activities of NORM.

The data in Figure 3 comes directly from the questionnaire replies and shows the reported quantities (in 000's of drums) of stored NORM grouped by the dose rate ranges 25–50; 50–100; 100–500; 500–1000; and greater than 1000 microR/h. From the previous discussion, the readings over 50 microR/h represent NORM over 100 pCi/g; and Figure 2 shows that this is 10 percent of the total NORM accumulated. The total quantity of NORM based on these data, if fully identified, can be illustrated in this equation:

Total NORM accumulated

= 10 x (471,000 + 705,000 + 430,000 + 6,000) drums

= 16,120,000 drums

Table 3—Annual NORM Accumulation Rate 1993

Region	NORM Reported > 100 pCi/g	Prorated to 100 Percent Accumulation	Total Per Annum Prorated Drums	Multiplier for All NORM	Total NORM Accumulation Per Annum Drums
Gulf Coast	4,106	2.3	9,444	10	94,440
Mid-Continent	367	4.8	1,762	10	17,620
Rocky Mountain	106	7.6	1,216	10	12,160
California	0	0.0	1,064 ^a	10	10,640 ^a
Alaska	753	1.0	753	10	7,530
			14,239 ^b		142,390

Note: Using the multiplier 10 as previously discussed gives a total annual NORM accumulation of 142,000 drums.

^aCalculated value.

^bReported number represents NORM greater than 100 pCi/g; from Figure 2 that is 10 percent of the total annual accumulation

1.2.3 CALCULATION OF THE NORM ACCUMULATION IN REGION 4—CALIFORNIA

From the survey results, no NORM was reported for Region 4. However, a 1995 NORM survey of oil and gas production equipment in California by the California Department of Health Services Radiological Health Branch (RHB) found that NORM was present in some of the oil and gas equipment that had been removed from service. Their survey locations were selected to maximize the chance of finding the existence of NORM; hence, their preliminary detection frequency (23 percent) is not thought to be representative of the real occurrence rate previously reported as 3.42 percent [6]. From recent NORM survey work in California by a number of oil and gas companies, it has been learned that the occurrence of NORM appears to be lower in California than the Gulf Coast states. Because of the data in these reports and in discussion with the RHB, an estimate has been made of NORM occurrence for the California region by comparing it to the next closest region, region 2 (Mid-Continent), in both oil and gas production and NORM incidence reported [6] and calculated for the states grouped in each region.

Region 2—Mid-Continent

Reported oil and gas condensate production	
From questionnaire	= 323,000 bpd
Reported annual NORM accumulation	= 367 drums per annum
Total annual oil and gas production [3]	= 1,583,000 bpd
	————— x 367
Total annual NORM generated	= 323,000
Total	= 1799 Drums

Region 4—California

Reported oil and gas condensate production	
From questionnaire	= 145,000 bpd
Reported annual NORM accumulation	= 0 drums per annum
Total annual oil and gas production [3]	= 936,000 bpd
Total annual NORM generated	————— x 1799
Total	= 1064 Drums

1.2.4 SUMMARY OF NORM QUALITIES FOR EACH REGION

Table 4 summarizes accumulated NORM in drums, tubulars, vessels, process equipment, ponds, and on sites. The questionnaire replies and the multipliers developed in Table 2 were used to prorate the reply data to represent 100 percent of each region except Region 4, which was calculated as above. Table 4 summarizes the total accumulated NORM from all sources calculated from the replies and representing the total industry.

Region 4 is a calculated value for a 15-year accumulation based on the annual value calculated in Table 3.

The minimum annual NORM generation rate of 142,390 drums was derived from the reported data. The reported NORM accumulations prorated to represent all the domestic oil and gas condensate production totals 10,056,597 drums from the domestic U.S. oil and gas production.

Table 5 presents NORM quantities by specific activity for each region. It uses the graph in Figure 2 with the total accumulated NORM in Table 4 to calculate the actual number of drums in each specific activity range.

Figure 2 shows that 92 percent of all NORM is less than 200 pCi/g, and 7 percent is greater than 200 but less than 2000 pCi/g. Applying these percentages to the accumulated NORM per region from Table 4 gives the number of drums in each band of specific activity. These numbers will be used to calculate the minimum average and maximum average cost of disposal per drum, including transportation.

The bands of specific activity were chosen because of the limits set on some of the disposal facilities. The nine disposal options are listed in Table 6. Disposal options 2 and 4 could (at the survey date of 1993) accept NORM with a radium concentration up to 2,000 pCi/g. Disposal option 3 could accept NORM with a radium content up to 200 pCi/g.

The bands chosen for costing are:

0 to < 200 pCi/g
over 200 < 2,000 pCi/g
>2,000 pCi/g

Table 4—Accumulated NORM in Drums, Tubulars, Vessels, Process Equipment, Ponds, and On Sites*

Region	1	2	3	4	5	Total
Replies, drums (Appendix C)	128,846	1,902,199	61,693	10,640	1,229	159,388
Multiplier to represent 100 percent production (Table 2)	2.3	4.8	7.6		1.0	
100 percent of region	296,346	9,130,055	468,867	159,600	1,229	10,056,597

*Prorated to 100 percent of each region.

Note: Calculated value based on the average NORM drums accumulated per million bpd per region



Table 5—NORM Specific Activity Distribution by Region

	< 200 pCi/g (92%)	> 200 < 2,000 pCi/g (7%)	> 2,000 pCi/g (< 1%)	
Region	Number of Drums			Total
1. Gulf Coast	128,846	26,671	2,964	296,346
2. Mid-Continent	8,217,499	821,750	91,306	9,130,555
3. Rocky Mountain	421,980	42,198	4,689	468,867
4. California	372,978	37,298	4,144	414,420
5. Alaska	1,106	111	12	1,229

1.3 Reference List

Publications cited in other sections of this document are listed here.

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SECTION 2—NORM DISPOSAL OPTIONS AVAILABLE

To be included as an available option, each alternative had to be reported in the questionnaire replies, together with actual cost data, or had to have a market price schedule, an existing organization that could accept NORM in drums for legal permanent disposal in a manner approved by regulation and where appropriate, a permit for each facility.

Additional options for NORM drum disposal have been reported, but without firm cost data and shipping directions they could not be included in this disposal cost study. Table 6 summarizes the available disposal options for NORM. NORM disposal options typically require permitting to meet regulatory approval.

2.1 Burial Sites

All placement and burial sites will have 10,000-year perpetual care funds along with a detailed record of all parties supplying NORM materials for burial. Should future regulatory changes dictate reopening of the site and remediation of the NORM with costs in excess of the perpetual care fund, then site users could face a share of the cost should the government of the day be unprepared or incapable of meeting the cost. Hence, use of a placement and burial site may have some future unquantifiable financial risk. Individual sites have detailed acceptance criteria. Only specific activity limitations were considered in this study.

2.2 Surface Treatment

A dilution and mixing of low level NORM less than 200 pCi/g with land spreading is available to reduce the NORM concentration below the level of regulatory concern of 5 pCi/g. This service would require large areas of land, quantities of material free from NORM, and other organic material to treat the quantities of accumulated NORM. To reduce 1,000,000 drums of NORM with an average specific activity of 50 pCi/g to less than 5 pCi/g would require more than 10,000,000 barrels of material with no NORM component.

2.3 Commercial Disposal Injection

The processing dilution and deep well injection of NORM offers a reusable well and facility that could provide a cost-effective NORM disposal option. At this time, an acceptance limit of 2000 pCi/g maximum is in effect. The injected NORM would be permanently placed and, provided geological factors were taken into account and the facilities operated in accordance with the regulations, this option could provide a local disposal service throughout the oil and gas producing states at a reasonable cost. One commercial injection facility is already in operation, with others likely to be permitted based on geographical density of demand.

Table 6—Per Drum Disposal Costs for NORM

Options	Type	Radium Acceptance	Disposal Cost Range Per Drum (55 Gallons)		
			Low	Average	High
1	Burial	No limit on specific activity. No limit on total activity.	\$395 Includes: Disposal Transportation User fees Perpetual care fees	\$515	\$730
2	Burial	2000 pCi/g or less. No limit on total activity.	\$300 Additional costs: Radiochemical analysis Physical properties check Transportation Waste profile Transport vehicle decon.	\$500	\$700
3	Surface treatment NOW (Nonhazardous Oilfield Waste)	200 pCi/g or less. No limit on total activity.	\$100 Additional costs: Transport Physical properties check Chemical analysis EPA/DOT NOW analysis Packing Radiochemical analysis	\$210	\$325
4	Injection Class II well after dilution	2000 pCi/g or less No limit on total activity.	\$49 Additional costs: Transport Physical check Chemical analysis Radiochemical analysis Packing	\$206	\$1000
5	Recycling of steel	No limits.	No cost. Steel purchase value pays for transport to port F.O.B.		
7	Encapsulation in tubulars in plug and abandoned wells	No limits.	\$792 All inclusive costs from actual reports for oil and gas costs.	\$1081	\$3333
8,9	Injection Class II wells, well bores, and geological formations	No limits.	\$151 All inclusive costs from actual reports for oil and gas costs.	\$916	\$2300

Note: Minimum figure forecast to reduce with more competitive services and reusable injection well.

2.4 Recycling of Steel

The purchase of NORM-containing steel for processing and recycling in China represents the most cost effective method to dispose of scrap steel containing NORM. While the recycling of high grade NORM-containing scrap steel is an excellent objective, it represents a potential future liability to users of the service unless strict procedures are used and enforced to protect personnel and the environment.

The U.S. steel recycling industry uses highly detailed procedures and sensitive inspection equipment to prevent the accidental smelting of radioactive-contaminated steel. Current research work into smelting NORM-containing

steel will help with the development of procedures to enable the safe recycling of NORM-containing steel in the U.S.

2.5 NORM Recycling Into Shielding Bricks

A recent industry-wide solicitation was received for the shipment of NORM waste to Russia. The proposed service would provide for the reprocessing of NORM into a brick-like form. The bricks would then be placed into the entombed reactor at Chernobyl where they would become part of the proposed managed perpetual care fund for 200,000 years. While this technically feasible disposal option awaits detailed costs and claims regulatory approval, it is suggested that an independent risk assessment should be undertaken to determine if other financial, political, and operational factors would attach to the use of this service.

2.6 Plug and Abandonment of Wells—Encapsulation and Injection

Oilfield operations have developed a number of new techniques based on the disposal of NORM into well bores and geological formations (now being plugged and abandoned with cement). The NORM disposal may be encapsulated in steel tubulars that are placed into the well bore or mixed as a NORM fluid slurry that is then injected into the well bore or into the geological formation. The injection pressure may be sufficiently high to fracture the formation rock and allow very large quantities of NORM to be injected. All plug and abandonment operations with or without NORM disposal

are covered by detailed regulatory approval procedures. All states require reporting of the NORM disposal operations.

There are no geographical limitations to oilfield operations disposal, provided the appropriate geological formations are available and the regulations are in effect to permit plug and abandonment disposal. All states with oil and gas condensate production already have these regulations in place.

One commercial project was reported covering the process and injection disposal of NORM into a Class II well which continues in use for other non-NORM Class II materials.

SECTION 3—COST ESTIMATES FOR EACH DISPOSAL OPTION

The basic costs for each of the nine disposal options were obtained from the questionnaire replies, the published price schedules of the commercial facilities, or telephone inquiries if no published price list was available for a permitted service. All cost data are indicative only, since volume discounts are an acknowledged feature of the waste disposal industry when competing services are available.

Since the questionnaire data is compiled into five regions and the disposal options are also geographically distributed throughout the lower 48 states, a transport cost matrix was developed to estimate the cost of transporting a full load of 80 drums of NORM from each region to each fixed disposal site. Transport estimates (Appendix D) are based on full load, exclusive use, or single load estimates and do not reflect bulk discounts or alternative transport options such as bulk rail shipment.

3.1 Disposal Options Review

3.1.1 BURIAL SITES

Permitted low-level radioactive burial sites may be private or publicly owned and operated. For oilfield NORM, the site must have a permanent care fund to provide for inspection, care, and maintenance of the site for 10,000 years. This is approximately seven times the 1620 year half-life of radium 226, which is the longest half-life isotope found in NORM produced with oil and gas.

The NORM sent to burial sites is carefully characterized for isotope content, chemical composition free of moisture content, and physical characteristics. All companies using the site will receive a certificate of disposal acknowledging the placement of their waste into the facility.

Site acceptance criteria may include limits on the following:

- a. Isotope type and concentration (for example, one site up to 2000 pCi/g radium 226; one site with no limit on concentration of radium 228).

- b. Chemical composition.
- c. Physical form.
- d. Free liquid content.
- e. Annual quantities from a single generator.
- f. Total quantities per year.
- g. Classes of hazardous materials.
- h. State NORM site use permit.
- i. Package in approved container or bulk shipment.

Federally permitted facilities allow for the transfer of title (ownership) of NORM material when it meets the acceptance criteria and is accepted for burial. Title ownership transfers to the federal government and all future site management costs are expected to be met from the perpetual care fund established during the site operation.

3.1.2 SURFACE TREATMENT

The state of Louisiana permits treatment dilution for NORM materials. Input materials are limited to 200 pCi/g of total radium. Nonhazardous oilfield waste (NOW) mixed with NORM waste is treated by mixing both with clean material until the specific activity is less than 5 pCi/g total radium. The diluted material is then released as an unregulated material that may be reused or disposed of in a permitted landfill, depending on other non-NORM criteria.

Since 90 percent of the NORM is less than 100 pCi/g, this disposal option could accept the bulk of all NORM produced. Treated NORM that is less than 5 pCi/g radium is below regulatory concern; it is no longer considered to be a radioactive material. The volume of clean materials needed to dilute the 10 million drums of NORM to less than 100 pCi/g would be very large.

The treatment site has drainage for leachate collection and deep well disposal into permitted Class II wells. The permitting of the disposal wells provides for a performance bond to cover the cost of injection well closure and abandonment. This process has been completed in many other Class II wells over the years and is well proven. Similar