A Naturally Occurring Radioactive Material (NORM) Disposal Cost Study

API PUBLICATION 7100
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American Petroleum Institute

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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 picoCuries per gram (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.

CONTENTS

Page

SECTION 1—VOLUME ESTIMATES OF NORM WASTES 1
1.1 Introduction 1
1.1.1 Comments on the NORM Survey Data 1
1.1.2 NORM Database Information 2
1.2 Volumes of NORM Waste—Past, Present, and Forecast 3
1.2.1 General 3
1.2.2 Regions 1, 2, 3, and 5 4
1.2.3 Calculation of the NORM Accumulation Region 4—California 5
1.2.4 Summary of NORM Quantities for Each Region 5
1.3 Reference List 6

SECTION 2—NORM DISPOSAL OPTIONS AVAILABLE 6
2.1 Burial Sites 6
2.2 Surface Treatment 6
2.3 Commercial Disposal Injection 6
2.4 Recycling of Steel 7
2.5 NORM Recycling Into Shielding Bricks 7
2.6 Plug and Abandonment of Wells—Encapsulation and Injection 8

SECTION 3—COST ESTIMATES FOR EACH DISPOSAL OPTION 8
3.1 Disposal Options Review 8
3.1.1 Burial Sites 8
3.1.2 Surface Treatment 8
3.1.3 Commercial Injection Disposal 9
3.1.4 Recycling of Steel 9
3.1.5 NORM Recycling into Shielding Bricks 9
3.1.6 Plug and Abandonment of Wells—Encapsulation and Injection 9
3.2 Cost Estimates 9

SECTION 4—INDUSTRY-WIDE DISPOSAL COST IMPACT 12
4.1 Accumulated NORM 12
4.2 Annual NORM Accumulation 12
4.3 Summary of NORM Transport Disposal Cost Impact by Region 12
4.3.1 Region 1—Gulf Coast 12
4.3.2 Region 2—Mid-Continent 13
4.3.3 Region 3—Rocky Mountain 13
4.3.4 Region 4—California 13
4.3.5 Region 5—Alaska 13
4.4 Conclusion 13

SECTION 5—ASSUMPTIONS FOR DISPOSAL ANALYSIS 13

APPENDIX A—SAMPLE OF NORM DISPOSAL COST SURVEY QUESTIONNAIRE 15
APPENDIX B—SAMPLES OF NORM DISPOSAL JOB/PROGRAM COSTS 21
APPENDIX C—NORM DISPOSAL COST STUDY QUESTIONNAIRE REPLIES 29

APPENDIX D—TRANSPORTATION COST MATRIX BY REGION TO PERMITTED DISPOSAL SITES 33
APPENDIX E—ACTUAL DISPOSAL COSTS (PER DRUM) FOR PLUG AND ABANDONMENT OF WELLS 35
APPENDIX F—NORM DISPOSAL COSTS BY REGION FOR DISPOSAL OPTIONS 37
APPENDIX G—NORM ACCUMULATION BY TYPE OF SOURCE 39

Figures

1—Responding States Grouped Into Regions 1
2—Drums of Stored NORM by Specific Activity and Percentage of Total Stored Per Activity Range 2
3—Drums of Stored NORM by Dose Rate Corrected to 100 Percent Production (From 1993 API Survey) 3

Tables

1—Oil and Gas Questionnaire Replies 1992 2
2—NORM Generated Per Region From 100 Percent of Producers 4
3—Annual NORM Accumulation Rate 1993 4
4—Accumulated NORM in Drums, Tubulars, Vessels, Process Equipment, Ponds, and On Sites 5
5—NORM Specific Activity Distribution by Region 6
6—Per Drum Disposal Costs for NORM 7
7—Accumulated NORM Disposal Costs Derived Using the Minimum and Maximum Average Costs Per Drum 10
8—Annual 1992 NORM Disposal Costs for NORM Over 100 pCi/g (10 Percent of Total—Average Cost by Region) 11
9—Annual NORM Disposal Cost Range Using Minimum and Maximum Average Costs Per Drum 11
10—NORM Transport and Disposal Cost by Region 12

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 Dwights 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 Dwights [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,

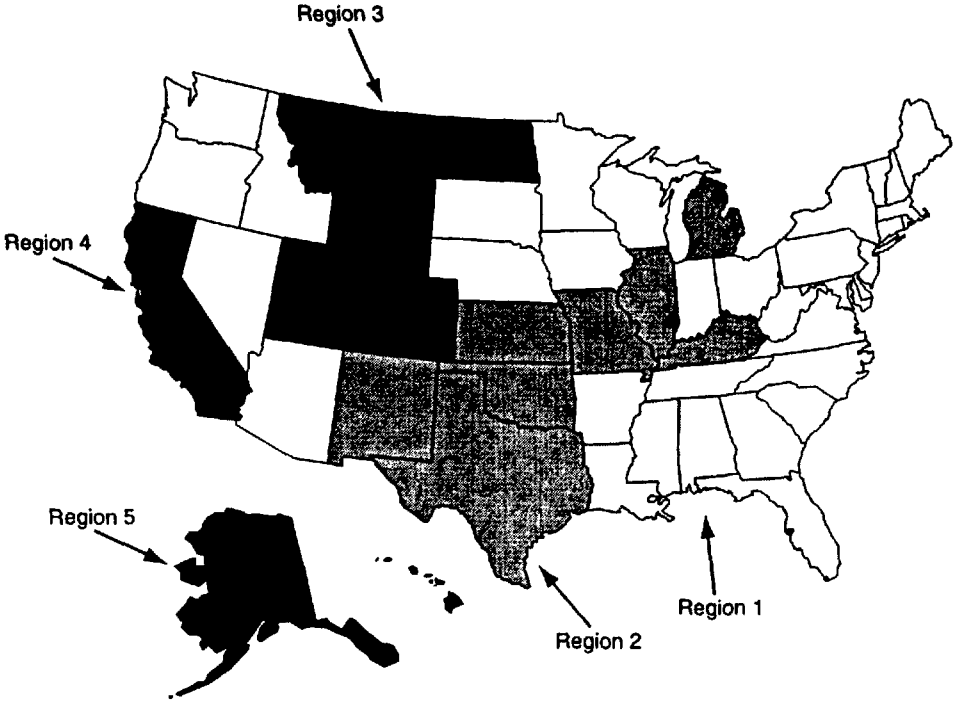

Figure 1—Responding States Grouped Into Regions

Table 1—Oil and Gas Questionnaire Replies 1992

Region	Gulf Coast	Mid-Continent	Rocky Mountains	California	Alaska	Total
Replies 000 BPD	972	323	68	158	1624	3132
(Percentage of region responding)	(44%)	(20%)	(13%)	(17%)	(100%)	(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 picoCuries per gram. However, NORM surveys conducted

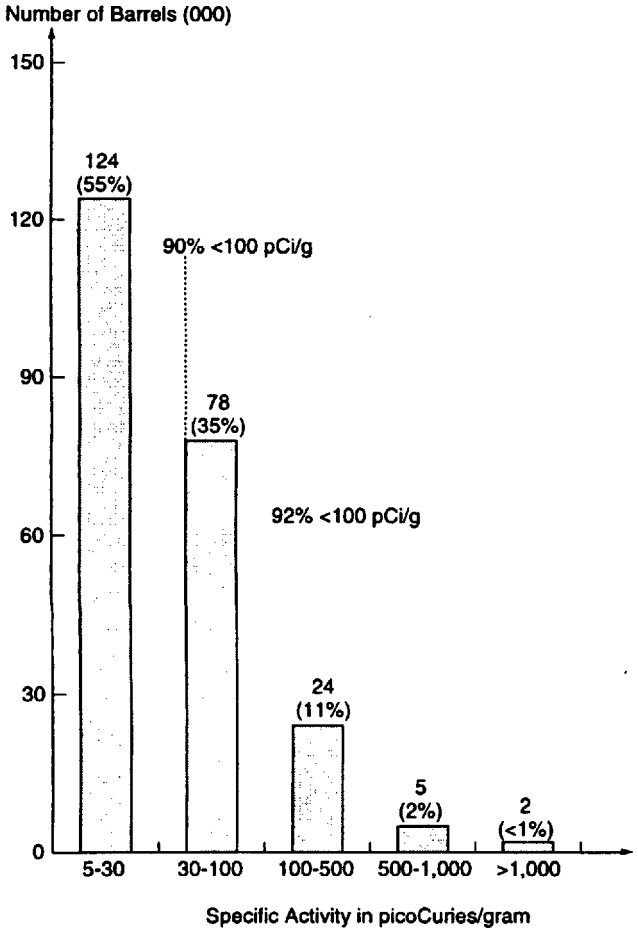

Figure 2—Drums of Stored NORM by Specific Activity and Percentage of Total Stored Per Activity Range

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:

a. Sensitivity of the survey detector.
b. Action level for reporting (currently 50 microR/h).
c. Oil and gas production rates.
d. Ratio of produced water to oil; that is, barrels of water per barrel of oil.
e Use of scale inhibitors to prevent NORM.
f. 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 checked with data from Dwights Energydata, Inc. [4] to enable the information to be prorated to represent 100 percent of the oil, gas, and gas condensate production in each region.

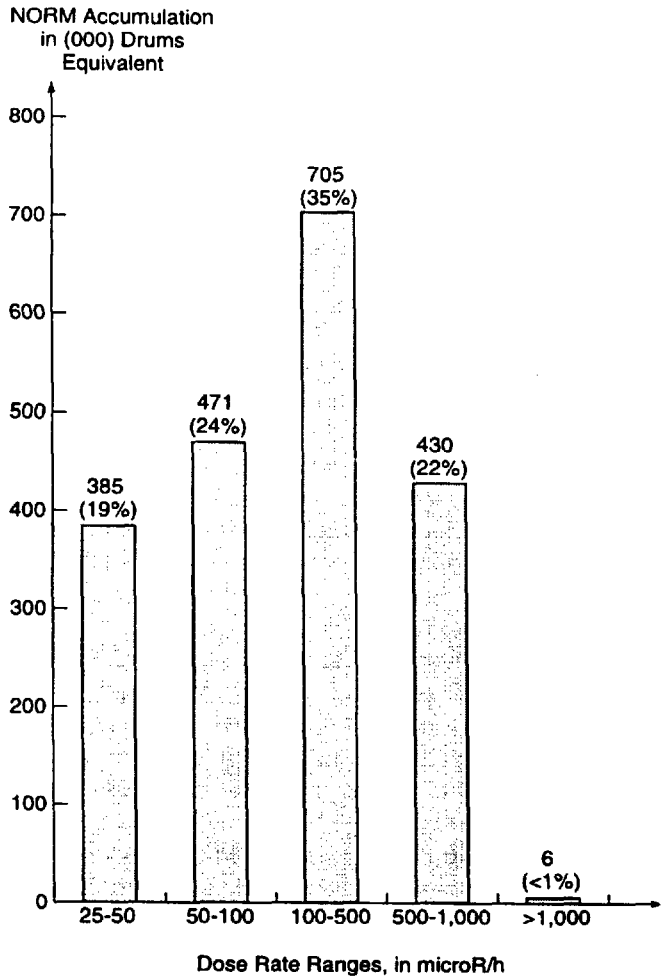

Figure 3—Drums of Stored NORM by Dose Rate Corrected to Percent Production (From 1993 API Survey)

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 oilfield 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.

[a]Calculated value.

[b]Reported 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

Region	< 200 pCi/g (92%)	> 200 < 2,000 pCi/g (7%)	> 2,000 pCi/g (< 1%)	Total
	Number of Drums			
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.

1. W. Russo, "Draft Diffuse NORM Wastes—Waste Characterization and Preliminary Risk Assessment," EPA, May 93.
2. Dwights Energydata Services, Inc.
3. *Oil and Gas Journal*, 1993.
4. *Oil and Gas Journal*, 1993.
5. American Petroleum Institute Publication # 815-13714, *Potential Impact of Environmental Regulations on Oil and Gas Exploration and Production Industries*, March 1995.
6. *A National Survey on Naturally Occurring Radioactive Materials (NORM) in Petroleum Producing and Gas Processing Facilities*. 1989 Otto.
7. Unpublished Report, Louisiana Mid-Continent Oil and Gas Producers Association.
8. A. McArthur, G. Reed, and B. Holland, SPE # 23383, *"Evaluating the Real Risks of Radioactive Scale in Oil and Gas Production,"* ICI Tracerco.
9. American Petroleum Institute Report, *Methods for Measuring Naturally Occurring Radioactive Materials in Petroleum Production Equipment*, December 1989.

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

acceptance criteria to that for burial may be required and should be obtained from the facility operator.

3.1.3 COMMERCIAL INJECTION DISPOSAL

Injection disposal is a recent addition to the range of disposal options for NORM. This service combines the dilution treatment of a NOW material and NORM and provides disposal into a Class II injection well.

NORM up to 2000 pCi/g will be accepted for dilution to 30 pCi/g. The processed fluid will be hydrated and have viscosifiers added to suspend the NORM for injection into the Class II well. The NORM fluids will be injected into deep geological formations below the underground sources of drinking water. Through the dilution step, the NORM is reduced to and is manifested as a NOW material.

Acceptance criteria similar to that for burial may be required. The actual criteria should be obtained from the facility operator.

3.1.4 RECYCLING OF STEEL

Recycling of NORM-containing steel production equipment represents a maximum of 10 percent of the total NORM volume accumulated. Since this option provides for the purchase of NORM-containing steel by the recycler, the small income may cover the transport costs to the extent that shipping provides a zero cost disposal for NORM-containing production equipment.

There is no information available on the protection of the workers or the environment at the recycler's facility. While the recycling of materials is promoted by international agreements, possible future liabilities should be considered. Title transfer occurs on receipt for shipment. Even where no compliance requirements exist, there may still be a significant liability to protect workers and the environment.

Acceptance criteria are believed to include the supply of components as sealed units to contain all NORM. Minimal or no fluid content is acceptable. There are no limits to dose rates, total activity, or quantity of materials.

3.1.5 NORM RECYCLING INTO SHIELDING BRICKS

NORM/NOW waste materials will be recycled into building bricks to be placed on or near the Chernobyl permanent care site as shielding material. The first shipment has been initiated to Russia and no problems have been encountered to date.

Transfer of title to the waste occurs on its acceptance for shipment and in compliance with the shipping manifest.

The acceptance criteria does not limit the specific activity or total activity provided the material meets the EPA/DOT definition of NOW waste. The limit is 10 percent on free liquids. Packaging of NORM in 55 gallon drums to DOT 17E, 17H, or other acceptable container is required. NORM-containing steel is also accepted.

3.1.6 PLUG AND ABANDONMENT OF WELLS—ENCAPSULATION AND INJECTION

3.1.6.1 Encapsulation

Another disposal option is well bore encapsulation in all wells being plugged and abandoned. The NORM is sealed inside tubular goods that are then inserted into the well bore; a cement plug is poured on top of them. The well is then cut off below ground level and abandoned.

There are no limits to total specific activity or quantity. This technique has been proven over many years of use.

The limited volume in each well bore along with the double handling of the tubular goods used for encapsulation makes this option an expensive alternative.

3.1.6.2 Injection

Injection into well bore geological formation may be undertaken either in association with the plug and abandonment of any well or into a Class II well with suitable geology permitted for this activity.

Injection pressures may be less than the pressure needed to fracture the geological formation or over pressure where hydraulic fracture will break open and maintain injection fractures through the geological formations.

Acceptance criteria need to consider the NORM particle size and fluid rheology for compatibility with the geological formation. There are no limits to the total specific activity or quantity of NORM that can be injected when over pressure injection is used.

3.2 Cost Estimates

Table 6 discusses the disposal costs (per drum) of available disposal options for NORM. The disposal cost data was obtained from the published rate sheets for services currently available.

The reported actual costs (per drum) of disposal options for NORM in Table 6 lists the NORM disposal options for which disposal cost information was available in 1993. The commercial options 1 through 6 are summarized by locations; radium acceptance criteria, where required; and a range of disposal costs per drum with minimum, average, and maximum costs.

All disposal options have additional acceptance criteria which in some cases may require the following:

a. Radiochemical analysis ($100 to $500 per sample).
b. Chemical metals analysis ($250 to $500 per sample).
c. Pretreatment washing volume reduction ($10 to $25 per drum).
d. Permitting manifesting.
e. Generator administration costs.
f. Non-NORM waste disposal costs.

The extra cost of these analyses and this processing could increase the total disposal cost per drum to equal or considerably exceed the average cost per drum.

Disposal options 7, 8, and 9 for the plug and abandonment of wells reflect the actual experience of the oil industry while disposing of NORM through the placement of NORM into wells either encapsulated in tubular pipes or injected as a slurry into the well bore (and sometimes the geological formations). These options are more fully discussed in Sections 2 and 6. Inclusion of a disposal option does not imply its acceptability or actual recommendation for use for disposal.

Table 7 shows the minimum and the maximum average cost for transport plus disposal cost per drum for each region. The disposal cost including transportation in cost per drum from Appendix F is followed by the disposal option number from Table 6. For example, $212 (4) means that the minimum average cost of transport plus disposal is $212/drum for disposal option 4 from Region 1.

The number of drums are multiplied by the minimum average cost and the maximum average cost per drum to get the minimum average and the maximum average transport plus disposal costs per region after taking specific activity into account.

Based on the actual reported costs and the accumulated NORM prorated to represent the entire U.S. oil and gas industry and using the assumptions and calculations above, the national cost impact of the implementation and enforcement of NORM regulations as currently in force and proposed on the oil and gas industry for transport and disposal of accumulated NORM is approximately $2.3 billion to $10.9 billion. This cost would be spread over a number of years (for example, 25 years at $92 to $436 million per year).

Table 8 discusses the actual NORM disposal average cost by region. The actual NORM disposal costs reported on the survey as previously discussed are for the higher specific activity NORM that represents 10 percent of total NORM over 100 pCi/g; the 1992 annual total is $7.12 million for all five regions. This total is for transport and disposal only, and it represents an average cost of $540 per drum. This total is the reported minimum annual cost of NORM disposal for 1992.

Table 9 displays the annual NORM accumulation disposal costs range. Using the prorated total annual NORM accumulation figures from Table 3 and the minimum average and maximum average cost figures for transport and disposal from Appendix F, the annual NORM accumulation disposal cost range estimates in Table 9 were calculated. The minimum average cost impact is $27 million, and the maximum average cost impact is $227 million for the transport and disposal of the annual accumulation of NORM.

Table 7—Accumulated NORM Disposal Costs Derived Using the Minimum and Maximum Average Costs Per Drum

	(0-200)		(> 200 < 2000)		(> 2000)		Total Drums	
Specific Activity Region	Avg Min	Avg Max	Avg Min	Avg Max	Avg Min	Avg Max	Min	Max
1								
Cost per Drum (Disposal Option)	212 (4)	1081 (7)	212 (4)	1081 (7)	306 (6)	1081 (7)		
Number of Drums	272,638		20,744		2964		286,346	
Cost in Millions	58	295	4	22	1	3	63	320
2								
Cost per Drum (Disposal Option)	231 (4)	1081 (7)	231 (4)	1081 (7)	320 (6)	1081 (7)		
Number of Drums	8,400,111		639,139		91,305		9,130,555	
Cost in Millions	1940	9080	148	691	29	99	2117	9870
3								
Cost per Drum (Disposal Option)	231 (4)	1081 (7)	231 (4)	1081 (7)	320 (6)	1081 (7)		
Number of Drums	431,358		32,820		4689		468,867	
Cost in Millions	100	466	8	35	2	5	110	506
4								
Cost per Drum (Disposal Option)	231 (4)	1081 (7)	231 (4)	1081 (7)	306 (6)+	1081 (7)		
Number of Drums	146,832		11,172		1596		159,600	
Cost in Millions	34	159	3	12	1	2	38	173
5								
Cost per Drum (Disposal Option)	346 (4)	1081 (7)	246 (4)	1081 (7)	320 (6)	1081 (7)		
Number of Drums	1131		86		12		1229	
Cost in Millions	0.391	1,222	0.211	0.093	0.004	0.013	1	2

Average range of NORM transport and disposal for regions 1-5 (in $Millions) $2329–$10,871.

Table 8—Annual 1992 NORM Disposal Costs for NORM Over 100 pCi/g (10 Percent of Total—Average Cost by Region)

Region	Actual Reported Annual Accumulation Drums (10% of Total)	Actual Reported Average Cost per Drum	Total Cost in Millions
1. Gulf Coast	9444	539	5.1
2. Mid-Continent	1762	545	0.96
3. Rocky Mountain	1216	543	0.66
4. California[a]	–	–	–
5. Alaska	753	552	0.4
Totals	13,064 Drums	–	$7.12 Million

[a]No reported NORM disposal in California.

Table 9—Annual NORM Disposal Cost Range Using Minimum and Maximum Average Costs Per Drum

Specific Activity Region	(0-200) 92% Min	(0-200) 92% Max	(> 200 < 2000) 7% Min	(> 200 < 2000) 7% Max	(> 2000) 1% Min	(> 2000) 1% Max	Total Drums Min	Total Drums Max
1								
Cost per Drum (Disposal Option)	212 (4)	1081 (7)	212 (2)	1081 (7)	306 (6)	1081 (7)		
Number of Drums	86,885		6611		944		94,440	
Cost in Millions	18.42	93.92	1.403	7.15	0.29	1.02	20.1	102
2								
Cost per Drum (Disposal Option)	231 (4)	1081 (7)	74 (4)	3333 (7)	151 (6)	3333 (7)		
Number of Drums	16,210		1233		176		17,620	
Cost in Millions	3.74	17.52	0.09	4.11	0.06	0.20	4	22
3								
Cost per Drum (Disposal Option)	74 (4)	3333 (7)	74 (4)	3333 (7)	151 (8)	3333 (7)		
Number of Drums	11,187		851		122		12,160	
Cost in Millions	.83	37.29	0.06	2.84	0.02	0.41	1	41
4								
Cost per Drum (Disposal Option)	74 (4)	3333 (7)	74 (4)	3333 (7)	151 (8)	3333 (7)		
Number of Drums	10,108		745		106		10,640	
Cost in Millions	0.75	33.69	0.06	2.48	0.02	0.35	1	37
5								
Cost per Drum (Disposal Option)	74 (4)	3333 (7)	89 (4)	3333 (7)	151 (8)	3333 (7)		
Number of Drums	6928		527		75		7530	
Cost in Millions	1.51	23.09	0.05	1.76	0.01	0.25	1	25

Range of NORM transport and disposal for Regions 1-5 (in $Millions) $40–$227.

SECTION 4—INDUSTRY-WIDE DISPOSAL COST IMPACT

4.1 Accumulated NORM

The volume of NORM accumulated on an annual basis together with its transport and disposal costs were derived from questionnaire responses representing 46 percent of the domestic U.S. oil, gas, and gas condensate production.

Some 10 million drums of NORM materials were accumulated as of December 1993 in the oil and gas producing states. The Region 1 Gulf Coast states figure of 296,000 drums would cost an average of $63 million to $320 million to transport and dispose of to one or more of the nine real disposal options available in 1993. These significant costs do not include the costs to survey, sample, remediate, and place the NORM into drums or containers ready for disposal. The cost impact to develop, implement, and manage programs for compliance with NORM regulations will represent an additional significant cost that could double the NORM transport and disposal costs documented in this publication.

Table 7 summarizes the cost impact for transport and disposal of accumulated NORM for the five specific regions. With the addition of the other costs mentioned above, it is probable that the total costs to the oil and gas industry in current dollars to implement NORM programs to meet proposed and actual NORM regulations to remediate tubulars, equipment, and sites, then to transport and dispose of the NORM accumulated to the end of 1993, would be approximately $2.3 to $10.9 billion. The lower figure is probably more realistic due to the potential for volume discounts on transport and disposal, along with the economies of scale represented by the large volume of 10 million drums for which remediation may be required. This cost would be distributed over many years as producing fields are shut down and abandoned.

The large discrepancy among regions in the reported volumes of accumulated NORM versus their production volume can be partially accounted for by one or more of the following factors:

a. The actual amount of NORM accumulated in each region.
b. The age of the oil fields in each region.
c. The duration and volume of the productive operations.
d. The production technology for dealing with produced water and accompanying solids, for example, surface treatment or re-injection.
e. The extent of NORM surveying completed.
f. The need for regulatory compliance and accurate reporting.

4.2 Annual NORM Accumulation

The survey replies provided the 1993 estimates of the annual NORM accumulation rate. The most commonly used NORM survey criteria was the external dose rate of 50 microR/h measured on the outside surface of the component containing the NORM. As previously discussed, this external dose rate indicates NORM specific activity greater than 100 pCi/g. Figure 2 illustrated that 90 percent of the NORM was less than 100 pCi/g; hence, the reported annual accumulation rate, after correction for 100 percent production volumes, is multiplied by 10 to compute the total annual NORM accumulation figure for all specific activities of 142,000 drums per year. Other studies argue [1] that this annual volume estimate of NORM is low by an order of magnitude.

By using the minimum average cost disposal options available to each region, the minimum total annual transportation and disposal cost from Table 9 is $27 million. A worst-case scenario using the maximum average NORM transport and disposal costs results in a maximum total NORM disposal cost of $227 million per year.

When tallying the additional costs of survey, sampling, analysis, remediation, and containerization of the annual NORM accumulation, the minimum average NORM transport and disposal cost of $27 million could double to $54 million.

4.3 Summary of NORM Transport Disposal Cost Impact by Region

Table 10 illustrates the impact of the NORM transport and disposal cost on each of the five regions.

Table 10—NORM Transport and Disposal Cost by Region

Region	Accumulated		Annual	
	Minimum	Maximum	Minimum	Maximum
	Cost in Millions		Cost in Millions	
1	$ 63	$ 320	$20	$102
2	2117	9870	4	22
3	110	506	1	41
4	38	173	1	37
5	1	2	1	25
Total Cost In Millions	$2329	$10,871	$27	$227

4.3.1 REGION 1—GULF COAST

Data from this region at the time of the survey in 1992-93 is more reliable since it was derived from replies from companies representing 44 percent of the annual production of oil and gas condensate in the region. In addition, NORM management and survey programs to meet regulatory requirements in Louisiana, Mississippi, and Texas were being introduced at that time.

Note: The Gulf Coast, Region 1, has the most widespread NORM regulations.

4.3.2 REGION 2—MID-CONTINENT

The data figures from Region 2 depict responses from companies representing 20 percent of the total annual oil and gas condensate production in the region. This data includes two reports of very large NORM accumulations. One report covers accumulations of NORM within produced water pits and ponds in a major production system; the other reports NORM sludge and site accumulations. These two reports have been confirmed as representative of the historical NORM accumulations over many years in this region. Appendix G shows the majority of NORM accumulated comes from sludge located on sites or in produced water ponds or pits.

4.3.3 REGION 3—ROCKY MOUNTAIN

This data represents only 13 percent of the total production of this region and is also heavily biased by one report of NORM accumulations in surface pits. This reply was checked with the responding company and confirmed to be accurate of their NORM accumulation experience.

4.3.4 REGION 4—CALIFORNIA

The California data did not report the detection of any NORM up to the end of 1993. Surveys in 1995 by the California Department of Health Radiological Health Section have detected NORM. The NORM estimates for both accumulated NORM and the annual accumulation were calculated from the results reported for Region 2 and corrected for the differences in total production of oil and gas condensate between Regions 2 and 4. This assumption is thought to be reasonably consistent with early verbal reports of the state NORM survey results.

4.3.5 REGION 5—ALASKA

The data from this region represents 100 percent of the production and is highly reliable. Because the Alaskan oil and gas production has re-injected the produced water since the start of operations, the majority of NORM has been returned to the formation. Scale inhibitor management programs continue to ensure that the volume of accumulated NORM is minimized. This means that other production factors such as increased water production, well corrosion, pressure loss, and so on, control the need to repair production wells rather than deal with NORM scale formation.

4.4 Conclusion

The following conclusions can be made about NORM disposal costs:

a. The actual cost to dispose of NORM from the U.S. oil and gas industry in 1992 was $7.12 million. This data was primarily from the Gulf Coast information (Region 1) in the study.
b. The cost to the entire U.S. oil and gas industry to transport and dispose of the 142,000 drums of NORM produced annually based on current and proposed regulations is approximately $40 to $227 million per year.
c. The cost to remediate the 10,000,000 drums of NORM accumulated over many years of production is approximately $2.3 to $10.9 billion. Note that this cost would be spread over many years and would be related to the life of each producing field and the preparation time for abandonment.
d. No questionnaire replies included NORM from gas production, although it is known to exist and represents a potentially significant cost.
e. NORM is not formed in every oil and gas producing well in the U.S. The large variations in the occurrence and formation of NORM both in any one field and from field to field make it an issue that requires regulation by the individual states.

SECTION 5—ASSUMPTIONS FOR DISPOSAL ANALYSIS

The following information pertains to the questionnaire and its analysis:

a. Each responding company surveyed all business units within their organization.
b. The oil and gas condensate production figures from section 1.6.1 on the questionnaires were cross-checked with the Dwight Energydata Services, Inc.[2] computer database for each region and the Dwight's figures were used in cases of conflict. This method enabled more accurate production figures to be derived for each reply. The *Oil and Gas Journal* [3, 4] daily oil and gas condensate production in 000 bpd from June 30, 1993, and December 31, 1993, were averaged to give the 1993 daily production figure used in this document.
c. Grouping replies into five regions of interest required some revision of the oil and gas condensate production totals to reflect the reported percentages by region for each reply.
d. Replies 102, 120, and 148 (referenced in Appendix C) were not used to calculate disposal cost per drum in Appendix F because of extraordinary uncontrollable costs associated with the disposal well problems.
e. Drums referenced are 55 gallons of 7.35 ft3.
f. NORM volumes per tubular goods were calculated using a scale thickness of 0.25 inches over the inner surface of each tubular good to give equivalent drums.
g. Total accumulations of stored NORM were obtained by adding sections 1.1.1, 1.2.1, 1.3.1, 1.4.1, 1.5, 1.7.1, and

1.8.1 of the questionnaires.

h. "P and A" means "plug and abandon"— this is an oilfield term that means injecting concrete and taking other precautions required by regulations to make a well safe for abandonment.

i. Cost analysis section 3.1 of the questionnaires shown in Appendixes A and B indicate the following:

1. Plug and abandonment of well with NORM injected as a fluid suspension.
2. Plug and abandonment of well with NORM encapsulated in sealed tubular goods and placed into the well.
3. Plug and abandonment of well with NORM injected as a fluid suspension and the well is held available for additional NORM disposal operations.
4. Transport estimates based on 80 drums of NORM per load for full load exclusive use vehicle.

j. Annual reported NORM generation rate is based on 50 microR/h on the external surfaces of steel components. This external dose rate represents a specific activity over 100 pCi/g. Since only 10 percent of NORM reported in the survey replies is over 100 pCi/g, the annual figure must be multiplied by 10 to get the true annual NORM accumulation rate.

APPENDIX A—SAMPLE OF NORM DISPOSAL COST SURVEY QUESTIONNAIRE

Company _____ 2. Contact Name _____

Operating Area _____ Job Title _____

_____ Phone _____

Section 1.0 NORM from Oil and Gas Production

Note: All dose rate readings in microRem/hr (mR/hr), including background)

1.1 Solid NORM Wastes in Storage (Scale and Sludge from Oil and Gas Production)

1.1.1 Solid Wastes (scale, sludges, etc.) 600 drums

Other Solid Wastes (please describe) ____ drums

Radium concentrations (pCi/gram) (if known)		Surface Dose Rates (mR/hr)	
% < 5	%	15	% (25-50)
5 < % < 30	%	8	% (50-100)
30 < % < 200	%	60	% (100-500)
200 < % < 1000	%	8	% (500-1000)
% > 1000	%	9	% (> 1000)

1.1.2 Approximate Geographic Distribution

State	Region (North N. South S. OCS/Offshore O)	Percent
LA	LA–G	10
	LA–OCS/Offshore	90

Comments: _____

1.2 NORM Containing Tubular Goods in Storage (Tubulars, Sucker Rods, Flow Lines)

1.2.1 Total Length in Feet 15,000' 34' x 0.0315 drums/jt = 14 drums

Approximate Percentage Distribution by Size

Less than 2"	____	%
2-3"	100	%
Larger than 3"	____	%

Radium concentrations (pCi/gram) (if known)		Surface Dose Rates (mR/hr)	
% < 5	%	____	% (25-50)
5 < % < 30	%	50	% (50-100)
30 < % < 200	%	50	% (100-500)
200 < % < 1000	%	____	% (500-1000)
% > 1000	%	____	% (> 1000)

1.2.2 Approximate Geographic Distribution

State	Region (See section 1.1.2)	Percent
LA	LA–G	100

Comments: _____

1.3 NORM Containing Stored Vessels, Tanks,Treaters, Etc. (Out-of-Service, In storage)

1.3.1 Approximate Number of Items	Separators	Treaters	Tanks	Other	Estimated Total NORM Volume* (After decontamination)
0 #	0 #	0 #	0 #	0 #	0 drums

Radium Concentrations (pCi/gram) (if known)			Surface Dose Rates (mR/hr)	
% < 5		%		% (25-50)
5 < % < 30		%		% (50-100)
30 < % < 200		%		% (100-500)
200 < % < 1000		%		% (500-1000)
% > 1000		%		% (> 1000)

1.3.2 Approximate Geographic Distribution of the Contaminated Equipment

State	Region (See section 1.1.2)	Percent

Comments: None

1.4 NORM Containing Processing Facilities, Tank Batteries, Well Pads Estimated Volume of Contaminated Soil (In Service and Out of Service on Location)

1.4.1 Estimated Number of Facilities	Estimated Total NORM Volume*
30	3200 drums

Radium Concentrations Estimate (pCi/gram)			Surface Dose Rates (mR/hr)	
% < 5		%	60	% (25-50)
5 < % < 30	80	%	20	% (50-100)
30 < % < 200	20	%	20	% (100-500)
200 < % < 1000		%		% (500-1000)
% > 1000		%		% (> 1000)

1.4.2 Approximate Geographic Distribution of Facilities

State	Region (See section 1.1.2)	Percent
LA	LA–G	80
	LA–OCS/Offshore	20

Comments:

1.5 Estimated total Number of NORM Containing Items Generated in 1992

	Solid Wastes	Tubing	Equipment	Other Accumulations
Estimated Total	740 drums	9,000 feet	4 number	— drums

= 749 drums

Comments:

*Further described in the instruction letter.

1.6 Well Production Data

		1992		1993 (estimate)	
		Oil wells	Gas wells	Oil wells	Gas wells
1.6.1	Total Number of Wells				
	Number of wells in production				
	Total Annual production for: (state units used)				
	Oil ( )				
	Water ( )				
	Gas ( )				
	Condensate ( )				

1.6.2 Approximate Geographic Distribution

State	Region (See section 1.1.2)	Percent
LA	LA–G	25
LA	LA–OSC/Offshore	75

Comments:

1.7 Produced Water Ponds, Pits, Etc, (in Service)

		1992	
1.7.1	Number	3	
	Average Area (ft^2)	25,000	
	Estimated Sludge Depth (ft)	6	
	Average Years in Service	35	
	Average Inflow Bpd	25,000	
	Percent Checked for NORM	100	
	Percent of Pits Checked Found with NORM	67%	> 5 pCi/gm but < 30 pCi/gm
	Estimated NORM Contents	0	
	Estimated Total Drums of NORM Containing Soil & Sludge	0	

1.7.2 Approximate Geographic Distribution

State	Region (See section 1.1.2)	Percent
LA	LA–G	100

Comments: Above numbers do not include out-of-service pits

1.8 P & A (Plug and Abandonment) Program

		1992	1993 (estimate)
1.8.1	Number of Wells P & A's	4	21
	Number of Wells P & A's with NORM Tubulars in Place		6
	Number of Wells P & A's Used for Disposal of NORM Solids		17
	Number of Drums NORM Disposed by P & A		1,400

1.8.2 Approximate Geographic Distribution

State	Region (See section 1.1.2)	Percent
LA	LA–G	40
LA	LA–OCS/Offshore	60

Comments:

Section 2.0 NORM From Gas Plant Operations

2.1 Solid NORM Wastes in Storage (Gas Processing)

2.1.1 Lead–210 Scales and Sludge from Gas Processing _____ drums

Other Solid Wastes (please describe) _____ drums

Lead–210 Concentration (pCi/Gram) (if known)

% < 150 _____ %

% > 150 _____ %

2.1.2 Approximate Geographic Distribution

State	Region (North N. South S. OCS/Offshore O)	Percent
LA	LA–G & LA–OCS/Offshore	

Comments: N/A for this region.

2.2 NORM Containing Stored Vessels, Tanks, Equipment, Etc. (Out-of-Service, In Storage)

2.2.1 Approximate Number of Items

#	Pumps	Filters	Other	Tanks	Approximate Volume of NORM
_____	_____	_____	_____	_____	_____

Lead–210 Concentration (pCi/gram) (if known)

% < 5 _____ %

5 < % < 30 _____ %

Average Interior Surface Dose Rates (mR/hr)

_____ % (25-50)

_____ % (50-100)

_____ % (100-500)

2.2.2 Approximate Geographic Distribution

State	Region (North N. South S. OCS/Offshore O)	Percent

Comments: _____

2.3 NORM Containing Gas Processing Plants (In Service and Out-of-Service on Location)

2.3.1 Approximate Number of Facilities	% Checked for NORM	Average Exterior Surface Dose Rates (mR/hr)
_____	_____ %	_____ % (25-50)
		_____ % (50-100)
		_____ % (100-500)
		_____ % (> 500)

2.3.2 Approximate Goodrich Distribution

State	Region (North N. South S. OCS/Offshore)	Percent

2.4 Estimated NORM (Lead–210) Containing Items Generated in 1992

	Solid Wastes	Piping	Equipment	Other Accumulations
Estimated Total Drums	_____	_____ Feet	_____ Number	_____ Drums

Comments: _____

Section 3.0 NORM Disposal Job Program Costs

3.1 Typical NORM Disposal Job

Job Description: Dispose of NORM Slurry in P & A wells typical job

Duration: 20 Days

NORM Disposal: 550 Drums State: _____ Region: OCS

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	( )	(ū)			
Decon Equipment	(ū)	( )			
Decon Site	( )	(ū)			
NORM Transportation	(ū)	( )			
NORM Storage Company	( )	(ū)			
Disposal Downhole (P & A)	(ū)	( )			
Disposal On Site	( )	(ū)			
Disposal Commercial	( )	(ū)			
Sample Analysis	(ū)	( )			
Other Add Description:					
Rig Up Equipment	(ū)	( )			
	( )	( )			
Total			$		100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 ? 1992 ? 1993 35

Comments: 1991 and 1992 NORM training was conducted "in-house;" not able to trace costs. 1993 training was conducted by consultants.

Note: Please photocopy this sheet and complete one of each typical job.

APPENDIX B—SAMPLES OF NORM DISPOSAL JOB/PROGRAM COSTS

Section 3.0 NORM Disposal Job/Program Costs

3.1 Typical NORM Disposal Job

Job Description: _____

_____

Duration: _____ Days

NORM Disposal: _____ Drums State: _____ Region: _____

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	( )	( )	_____		_____
Decon Equipment	( )	( )	_____		_____
Decon Site	( )	( )	_____		_____
NORM Transportation	( )	( )	_____		_____
NORM Storage Company	( )	( )	_____		_____
Disposal Downhole (P & A)	( )	( )	_____		_____
Disposal On Site	( )	( )	_____		_____
Disposal Commercial	( )	( )	_____		_____
Sample Analysis	( )	( )	_____		_____
Other Add Description:			_____		_____
_____	( )	( )	_____		_____
_____	( )	( )	_____		_____
		Total	$ _____		_____ 100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 _____ 1992 _____ 1993 _____

Comments: _____

_____

_____

Note: Please photocopy this sheet and complete one of each typical job.

Section 3.0 NORM Disposal Job/Program Costs

3.1 Typical NORM Disposal Job

Job Description: Sand sludge generated offshore processed for reuse as landfill cover.

Duration: 1 Days

NORM Disposal: 4 Drums State: LA Region: 1

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	( )	(ü)			
Decon Equipment	( )	(ü)			
Decon Site	( )	(ü)			
NORM Transportation	(ü)	( )	0.1675		50
NORM Storage Company	( )	(ü)			
Disposal Downhole (P & A)	( )	(ü)			
Disposal On Site	( )	(ü)			
Disposal Commercial	( )	(ü)			
Sample Analysis	( )	( )			
Other Add Description:					
Now Land Spreading	(ü)	( )	0.1675		50
	( )	( )			
		Total	$0.335		100 100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 - 1992 - 1993 -

Comments:

Note: Please photocopy this sheet and complete one of each typical job.

Section 3.0 NORM Disposal Job/Program Costs

3.1 Typical NORM Disposal Job

Job Description: Shell production pad (i.e., Soil)

Duration: 41 Days

NORM Disposal: 215 Drums State: LA Region: 5

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	( )	(ü)			
Decon Equipment	(ü)	( )	162,500		25
Decon Site	(ü)	( )	325,000		50
NORM Transportation	( )	(ü)			
NORM Storage Company	( )	(ü)			
Disposal Downhole (P & A)	(ü)	( )	10,000		1.5
Disposal On Site	(ü)	( )			
Disposal Commercial	( )	(ü)			
Sample Analysis	(ü)	( )	52,500		8
Other Add Description:					
Work Done in Remote Location	( )	( )			
Housing, Per Diem	( )	( )			
		Total	$650,000		100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 _____ 1992 _____ 1993 _____

Comments: _____

Note: Please photocopy this sheet and complete one of each typical job.

Section 3.0 NORM Disposal Job/Program Costs

3.1 Typical NORM Disposal Job

Job Description: Dispose of NORM slurry in P & A wells.
Typical job.

Duration: 20 Days

NORM Disposal: 550 Drums State: _____ Region: OCS

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	( )	(ü)			
Decon Equipment	(ü)	( )	60		21.5
Decon Site	( )	(ü)			
NORM Transportation	(ü)	( )	40		14.3
NORM Storage Company	( )	(ü)			
Disposal Downhole (P & A)	(ü)	( )	145		51.8
Disposal On Site	( )	(ü)			
Disposal Commercial	( )	(ü)			
Sample Analysis	(ü)	( )	10		3.6
Other Add Description:					
Rig Up Equipment	(ü)	( )	25		8.9
	( )	( )			
		Total	$280		100.0 100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 ? 1992 ? 1993 35

Comments: 1991 and 1992 NORM training was conducted "in-house." Not able to trace costs. 1993 training was conducted by consultants.

Note: Please photocopy this sheet and complete one of each typical job.

Section 3.0 NORM Disposal Job/Program Costs

3.1 Typical NORM Disposal Job

Job Description: NORM scale/sludge disposal in P & A well.

Duration: 20 Days

NORM Disposal: 400 Drums State: LA Region: S

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	( )	(ü)			
Decon Equipment	(ü)	( )	20		13
Decon Site	( )	( )			
NORM Transportation	(ü)	( )	10		7
NORM Storage Company	( )	(ü)			
Disposal Downhole (P & A)	(ü)	( )	120		80
Disposal On Site	( )	(ü)			
Disposal Commercial	( )	(ü)			
Sample Analysis	( )	(ü)			
Other Add Description:					
	(ü)	( )			
	( )	( )			
Total			$150		100 100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 - 1992 10,000 1993 40.000

Comments:

Note: Please photocopy this sheet and complete one of each typical job.

Section 3.0 NORM Disposal Job/Program Costs

3.1 Typical NORM Disposal Job–1993

Job Description: Decontamination of production equipment, encapsulate in 7 5/8" casing, run into P & A well.

Duration: 6 Days

NORM Disposal: 32.5 Drums State: OCS Region: S

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	( )	(ü)			
Decon Equipment	(ü)	( )	2,800		
Decon Site	( )	(ü)			
NORM Transportation	( )	(ü)			
NORM Storage Company	( )	(ü)			
Disposal Downhole (P & A)	(ü)	( )	15,500		
Disposal On Site	( )	(ü)			
Disposal Commercial	( )	(ü)			
Sample Analysis	( )	(ü)			
Other Add Description:					
Encapsulate	(ü)	( )	7,500		
	( )	( )			
		Total	$25,800		100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 - 1992 - 1993 $5,000

Comments: These are actual cost for disposal job in 1993.

Note: Please photocopy this sheet and complete one of each typical job.

Section 3.0 NORM Disposal Job/Program Costs

3.1 Typical NORM Disposal Job–1992

Job Description: Decontamination of production equipment, slurry and pump down of NORM into P & A well.

Duration: 15 Days

NORM Disposal: 36 Drums State: OCS Region: 1

Breakdown of Services Included	(Y)	(N)	($0000)	and/or	Cost as Percent of Total
Decon Tubulars	(ü)	( )	4,200		3.9
Decon Equipment	(ü)	( )	19,300		18.0
Decon Site	( )	(ü)			
NORM Transportation	(ü)	( )	4,200		3.9
NORM Storage Company	( )	(ü)			
Disposal Downhole (P & A)	(ü)	( )	79,300		74.2
Disposal On Site	( )	(ü)			
Disposal Commercial	( )	(ü)			
Sample Analysis	( )	(ü)			
Other Add Description:					
	( )	( )			
	( )	( )			
Total			$107,000		100%

3.2 NORM Program Regulatory Training Activities

Per Annum 1991 - 1992 $5,000 1993 -

Comments: This is the actual job done in 1992. The slurry and pump was performed on the offshore platform.

Note: Please photocopy this sheet and complete one of each typical job.

APPENDIX C—NORM DISPOSAL COST STUDY QUESTIONNAIRE REPLIES

REGION 1

Section/Sub Reply Reference	1/1.1.1 Drums	1/1.1.1 Avg uR/h Dose Rates	1/1.2.1 Tubular Drums Equiv	1/1.2.1 Avg uR/h Dose Rates	1/1.3.1 Est. Drums	1/1.3.1 Avg uR/h Dose Rates	1/1.4.1 Facilities/ Drums	1/1.4.1 Avg uR/h Dose Rates	1/1.5 1992 Forecast Drums	1/1.6.1 Oil Prod 000 BPD	1/1.6.1 Condensate 000 BPD	1/1.7.1 Pits/Drums
101	10	1000	24	500	30	300	0	0	19	13	4	0/0
102	0	0	0	0	0	0	0	0	0	20	1	0/0
102	0	0	0	0	0	0	0	0	0	0	0	0/0
103	315	100	0	0	100	100	4/1000	100	270	5	8	0/0
105	600	500	0	0	0	0	1/1000	200	300	8	3	0/0
107	No	Data	0	0	0	0	0	0	0	0	0	0/0
110	No	Data	0	0	0	0	0	0	0	0	0	0/0
112	800	500	14	250	0	0	32/3,200	50	750	202	15	3/0
113	38	100	0	0	0	0	2/10	100	50	1	1	0/0
114	No	Data	0	0	0	0	0	0	0	0	0	0/0
115	153	100	119	50	10	50	7/100	50	196	44	0	0/0
116	No	Data	0	0	0	0	0	0	0	0	0	0/0
117	13	250	1	100	2	50	14/88	100	15	2	1	3/0
118	3200	500	51	0	30	0	7/4000	500	404	113	0	0/0
119	7000	500	0	0	0	0	44/5000	500	1000	71	11	0/0
120	0	0	8	0	0	0	0	0	0	3	1	0/0
120	Cost	Data	8	0	0	0	0	0	0	0	0	0/0
120	Cost	Data	37	0	0	0	0	0	0	0	0	0/0
120	Cost	Data	6	0	0	0	0	0	0	0	0	0/0
121	90	100	10	50	90	0	30/0	25	0	3	1	-
124	32	1000	5	100	41	250	18/0	250	31	35	2	0/0
124	Cost	Data	0	0	0	0	0	0	0	0	0	0/0
124	Cost	Data	0	0	0	0	0	0	0	0	0	0/0
129	4	750	0	0	0	0	0	0	0	1	1	0/0
130	No	Data	0	0	0	0	0	0	0	0	0	0/0
136	580	250	188	500	150	250	150/150	250	283	73	6	0/0
140	40	250	0	0	0	0	17/50	100	100	19	6	0/0
140	Cost	Data	0	0	0	0	0/0	0	-	0	0	0/0
141	25	500	0	0	0	0	3/10	250	3	34	12	0/0
142	4	500	0	0	2	100	2/4	100	4	7	2	0/0
146	530	250	234	100	400	100	8000/8000	100	143	43	16	700/12,000
147	3	250	7	100	4	250	6/40	250	36	6	7	0/0
147	Cost	Data		0	0	0	0	0	0	0	0	0/0
148	0	0	0	0	0	0	0	0	0	9	1	0/0
149	43	500	441	500	0	0	0	0	500	147	9	0/0
Totals	**13,280**		**1151**		**859**		**8300/94,630**		**4106**	**655**	**116**	**706/12,000**

REGION 1

Section/Sub	1/1.8.1	2/2.3.1	2/2.4	3/3.1	3/3.1	3/3.1	3/3.2 Training (0008)			A		B
Reply Reference	P & A Wells Well Drums	Checked # Facilities	Est. Drums	Summary Description	Drums	Cost (000$)	91	92	93	Calculated Cost per Drum		Total Accumulated Drums
101	65/40	1	0	0	0	0	5	5	5	0		123
102	0/0	0	0	P & A Injection	2	30	-	-	-	15,000	Blending Problems	0
102	0/0	0	0	Land	2	0	0	0	0	167		0
103	1/2	0	0	P & A (1)	215	102	0	0	0	474		1687
105	3/600	0	0	P & A (1) Injection	900	1600	0	3	3	1700		1901
107	0/0	0	0	No Data	0	0	0	0	0	0		0
110	0/0	0	0	No Data	0	0	0	0	0	0		0
112	17/1400	0	0	P & A (1) Injection	550	280	0	0	35	509		5964
113	0/0	0	0	No Data	0	0	0	0	2	0		98
114	0/0	0	0	No Data	0	0	1	2	2	0		580
115	0/0	0	0	No Data	0	0	0	0	0	0		0
116	0/0	0	0	No Data	0	0	0	0	0	0		0
117	0/0	0	0	P & A Pipe (2) Encapsulate	13	10	0	0	1	792		97
118	0/0	0	0	No Data	0	0	0	0	0	0		7685
119	2/300	0	0	No Data	0	0	0	10	10	0		13,800
120	0/0	0	0	P & A Encapsulate	8	160	0	0	0	20,000	Junk in Hole No Cleaning	8
120	0/0	0	0	P & A Encapsulated	8	10	0	0	0	1250	No Tubular Cleaning	8
120	0/0	0	0	P & A (2) Encapusulate	37	31	0	0	0	838	No Tubular Cleaning	37
120	0/0	0	0	P & A (2) Encapsulate	6	20	0	0	0	3333	No Tubular Cleaning	6
121	2/2	0	0	P & A (1)	90	14	0	2	2	151		192
124	0/0	0	0	Cutting Box	5	2	0	0	0	0		127
124	0/0	0	0	NORM Transfer	23	1	0	0	0	0		0
124	0/0	0	0	SITE Cleanup	0	2	0	0	0	0		0
129	0/0	0	0	Decon Tubulars	5	16	0	0	1	0		4
130	0/0	0	0	No Data	0	0	0	0	0	0		0
136	11/1000	0	0	P & A (1) Injection	400	150	0	10	40	375		1350
140	00	0	0	P & A (1) Injection	100	200	1	2	6	2000		190
140	0/0	0	0	P & A (1) Injection	158	199	0	0	0	1260		0
141	0/0	0	0	No Data	0	0	.5	.1	2	0		38
142	0/0	1	0	Survey	0	1	0	0	0	0		14
146	5/400	27	3	P & A (1) Wellbore	80	32	15	10	5	400		93,710
147	3/62	0	0	P & A (1) Injection	38	84	0	5	0	2300		152
147	0/0	0	0	P & A (2) Encapsulate	26	26	0	0	5	1000		0
148	0/0	0	0	P & A Encapsulate	1	20	0	0	0	20,000	No Cleaning Downhole Item	0
149	0/0	0	0	P & A (1) Injectors	615	220	0	2	0	357		1078
Totals	**109/3,808**	**29**	**3**		**3280**	**3210**	**22**	**52**	**119**	**71,906** **16,908**	**Average 1056.6 $/Drum**	**128,849**

REGION 1

Section/Sub	1/1.1.1	1/1.1.1	1/1.2.1	1/1.2.1	1/1.3.1	1/1.3.1	1/1.4.1	1/1.4.1	1/1.5	1/1.6.1	1/1.6.1	1/1.7.1
Reply Reference	Drums	Avg uR/h Dose Rates	Tubular Drums Equiv	Avg uR/h Dose Rates	Est. Drums	Avg uR/h Dose Rates	Facilities/ Drums	Avg uR/h Dose Rates	1992 Forecast Drums	Oil Prod 000 BPD	Condensate 000 BPD	Pits/Drums
106	15	0	85	0	890	500	71/96,178	100	0	0.00	0.0	0/0
109	0	0	11	100	1	100	43,404	50	0	1.70	2.0	36,526
111	1712	500	50	500	125	500	0/0	0	258	82.60	1.2	0/0
122	0	0	0	0	0	0	0/0	0	0	30.60	1.3	0/0
123	0	0	0	0	0	0	0/0	0	0	30.50	1.3	0/0
125	5	250	13	50	0	0	6/714	250	13	5.50	0.0	28/0
128	0	0	0	0	0	0	0/0	0	0	0.72	0.7	0/0
133	20	2	1	100	10	100	0/0	0	33	16.60	3.2	0/0
137	0	2	0	0	0	0	60/1,800,000	500	0	24.70	1.4	0/0
137	Cost	Data	0	0	0	0	0/0	0	0	0.00	0.0	0/0
139	242	100	25	250	71	250	19/221	250	63	75.00	2.3	11/823
143	0	0	0	0	0	0	1/10	0	0	15.70	0.3	0/0
144	0	0	0	0	0	0	1/10	0	0	15.70	0.3	0/0
145	100	0	0	0	0	0	0/0	0	0	9.60	0.0	0/0
Totals	**2094**		**185**		**1097**		**162/1,897,133**		**367**	**308.82**	**13.85**	

Section/Sub	1/1.8.1	2/2.3.1	2/2.4	3/3.1	3/3.1	3/3.1	3/3.2 Training (000$)			A Calculated Cost		B Total Accumulated
Reply Reference	P & A Wells Well/Drums	Checked # Facilities	Est. Drums	Summary Description	Drums	Cost (000$)	91	92	93	$/Drum		Drums
106	0/0	0	0	0	0	0	0	0	0	0	Abandoned Field	97,108
109	0/0	0	0	0	0	0	0	0	0	0		22
111	3/40	0	0	0	0	0	0	0	0	0		2545
122	0/0	0	0	0	0	0	0	0	0	0		0
123	0/0	0	0	0	0	0	0	0	0	0		0
125	0/0	0	0	Build Storage	0	10	0	0	0	0		745
128	0/0	0	0	0	0	0	0	0	0	0		0
133	0/0	0	0	0	0	0	0	0	0	0		64
137	0/0	0	0	Clean Tank	550	2.5	0	0	0	0	Many Similar Projects	1,800,000
137	00	0	0	Clean Tubing	24	10.0	0	0	0	0		0
139	0/0	0	0	Clean Tanks	10	3.6	10	10	10	0		1445
143	0/0	0	0	0	0	0	0	0	0	0		5
144	0/0	0	0	0	0	0	0	0	0	0		5
145	1/100	0	0	0	0	0	0	0	0	0		200
Totals	**40/823**		**0**		**584**	**26.1**	**10**	**10**	**10**	**0**		**1,902,199**

Section/Sub Reply Reference	1/1.1.1 Drums	1/1.1.1 Avg uR/h Dose Rates	1/1.2.1 Tubular Drums Equiv	1/1.2.1 Avg uR/h Dose Rates	1/1.3.1 Esti Drums	1/1.3.1 Avg uR/h Dose Rates	1/1.4.1 Facilities/ Drums	1/1.4.1 Avg uR/h Dose Rates	1/1.5 1992 Forecast Drums	1/1.6.1 Oil Prod 000 BPD	1/1.6.1 Condensate 000 BPD	1/1.7.1 Pits/Drums
REGION 3												
127	1	250	375	100	1	250	3/1	250	26	36	0.2	120/60,000
131	0	25	0	0	0	0	0/0	0	0	10.7	0.1	0/0
137	130	500	25	400	1000	500	0/0	0	134	16.5	4.4	0/0
Totals	**131**		**400**		**1001**		**3/1**		**160**	**63.1**	**4.7**	
REGION 4												
104	0	0	0	0	0	0	7/0	100	0	47.0	03	0/0
138	0	0	0	0	0	0	0/0	0	0	108.0	0.0	3/0
Totals	**0**		**0**		**0**		**7/0**		**0**	**155.0**	**0.3**	
REGION 5												
108	0	300	45	100	0	0	0/0	0	3.5	813.0	0.0	0/0
108	Cost	Data		0	0	0	0/0	0	0.0	0	0.0	0/0
126	367	50	40	250	1	500	8/0	0	737.0	9.1	0.0	2/0
134	1	120	21	500	1	150	0/0	0	13.0	802.0	0.0	0/0
Total	**368**		**106**		**2**		**3/1**		**753.5**	**1624.1**	**0.0**	

Section/Sub Reply Reference	1/1.8.1 P & A Wells Well/Drums	2/2.3.1 Checked # Facilities	2/2.4 Estimate Drums	3/3.1 Summary Description	3/3.1 Drums	3/3.1 Cost (000$)	3/3.2 Training (000$) 91	92	93	A Calculated Cost $/Drum		B Total Accumulated Drums
REGION 3												
127	0/0	All	0	0	0	0	0	0	0	0	Abandoned Field	60,404
131	0/0	0	0	0	0	0	0	0	0	0		0
137	0/0	0	0	0	0	0	0	0	0	0		1289
Totals	**0/0**		**0**		**0**	**0**	**0**	**0**	**0**	**0**		**61,693**
REGION 4												
104	0/0	0	0	0	0	0	0	0	0	0		0
138	0/0	0	0	0	0	0	0	0	0	0		0
Total	**0/0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**0**
REGION 5												
108	0/0	2	0	Process Injection	350	181	0	0	0	517		48.5
108	0/0	0	0	0	0	0	0	0	0	0		0
126	00	0	0	0	0	0	0	0	0	0		1145.0
134	0/0	2	0	0	0	0	5	15	15	0		36.0
Totals		**0**			**350**	**181**	**5**	**15**	**15**	**0**		**1229.5**

APPENDIX D—TRANSPORTATION COST MATRIX BY REGION TO PERMITTED DISPOSAL SITES

Permitted Disposal Location

1.	Richland	Washington	Burial
2.	Salt Lake	Utah	Burial
3.	Lafayette	Louisiana	Treat Spread
4.	Port Arthur	Texas	Injection
5.	Nearest	Major Port (or Houston)	China Recycle
6.	Nearest	Major Port (or Houston)	Russia Encapsulation
7,8,9.	Local Well	Nearest Suitable Well	Plug & Abandon or Injection

Transport Cost Estimates per Drum

Region/Disposal Site	1[a]	2[b]	3[b]	4[b]	5[b]	6[b]	7, 8, 9[a]
1	0	25	6	6	10	10	0
2	0	20	10	10	10	10	0
3	0	6	25	25	20	20	0
4	0	6	25	25	6	6	0
5	0	30	35	40	20	20	0

[a]Transport included in rates.

[b]Volume on a full load and exclusive use truck.

APPENDIX E—ACTUAL DISPOSAL COSTS (PER DRUM) FOR PLUG AND ABANDONMENT OF WELLS

All Cost Data From Region 1

P & A Injection			
	Drums No.	Cost ($000)	Cost ($000)
	215	102.0	474
	900	1600.0	1700
	550	200.0	509
	90	13.6	151
	400	150.0	375
	100	200.0	2000
	158	199.0	1260
	80	32.0	400
	36	83.5	2300
	615	220.0	357
Total	**3144**	**2880.0**	**916/Drum**
Maximum			2300 Cost Per Drum
Average			916 Cost Per Drum
Minimum			151 Cost Per Drum

P & A Encapsulation			
	Drums No.	Cost ($000)	Cost ($000)
	13	10.3	792
	8	10.0	1250
	37	31.0	830
	6	20.0	3333
	26	26.0	1000
	90	97.3	970
	90	**97.3**	**970**
Maximum			2300 Cost Per Drum
Average			916 Cost Per Drum
Minimum			151 Cost Per Drum

APPENDIX F—NORM DISPOSAL COSTS BY REGION FOR DISPOSAL OPTIONS

Disposal Options		Disposal Cost per Drum	Region 1 Transport Cost per Drum	Region 1 Disposal + Transport	Region 1 Accumulated NORM Drums	Region 1 Disposal Cost Accumulated Per Million	Region 1 Annual 1992 Disposal of 94,440 Drums Per Million	Region 2 Transport Cost per Drum	Region 2 Disposal + Transport	Region 2 Accumulated NORM Drums	Region 2 Disposal Cost Accumulated Per Million	Region 2 Annual 1992 Disposal of 17,622 Drums Per Million	Region 3 Transport Cost per Drum	Region 3 Disposal + Transport	Region 3 Accumulated NORM Drums	Region 3 Disposal Cost Accumulated Per Million	Region 3 Annual 1992 Disposal of 12,160 Drums Per Million
1	Min	395	0	395	296,346	117.1	37	0	395	9,130,555	3606	7	0	395	468,867	185.2	5
	Avg	515	0	515		152.6	49	0	515		4702	9	0	515		241.5	6
	Max	730	0	730		216.3	69	0	730		6665	13	0	730		342.3	9
2	Min	300	25	325		96.3	31	20	320		2922	6	6	306		144	4
	Avg	500	25	525		155.6	50	20	520		4748	9	6	506		237.2	6
	Max	700	25	725		214.9	68	20	720		6574	13	6	706		331	9
3	Min	100	6	106		31.4	10	25	125		1141	2	25	125		58.6	1
	Avg	210	6	216		64	20	25	235		2146	4	25	235		110.2	3
	Max	325	6	331		98.1	31	25	350		3196	6	25	350		164.1	4
4	Min	49	6	55		16.3	5	25	74		676	1	25	74		34.7	1
	Avg	206	6	212		62.8	20	25	231		2109	4	25	231		108.3	0.28
	Max	1000	6	1006		298.1	95	25	1025		9359	18	25	1025		480.6	1.25
5	Break even on contaminated steel. No drums of NORM accepted.																
6	Avg	300	6	306		90.7	29	20	320		2922	6	20	320		150	4
7	Min	792	0	792			75	0	792		7231	14	0	792		371.3	10
	Avg	1081	0	1081			102	0	1081		9870	19	0	1081		506.8	13
	Max	3333	0	3333			315	0	3333		30,432	59	0	3333		1562.7	40
8 & 9	Min	151	0	151			14	0	151		1379	3	0	151		70.8	2
	Avg	919	0	919			86	0	916		8364	16	0	916		429.5	11
	Max	2300	0	2300			217	0	2300		21,000	40	0	2300		1078.4	28

Transport Estimate

Disposal Options			Region 4					Region 5					Totals				
		Disposal Cost per Drum	Transport Cost per Drum	Disposal + Transport	Accumulated NORM Drums	Disposal Cost Accumulated Per Million	Annual 1992 Disposal of 10,640 Drums Per Million	Transport Cost per Drum	Disposal + Transport	Accumulated NORM Drums	Disposal Cost Accumulated Per Million	Annual 1992 Disposal of 7,530 Drums Per Million	Transport Cost per Drum	Disposal + Transport	Accumulated NORM Drums	Disposal Cost Accumulated Per Million	Annual 1992 Disposal of 142,390 Drums Per Million
1	Min	395	0	395	159,600	63	4	0	395	1,299	0.51	0.2				3,971.8	53.3
	Avg	515	0	515		82	5	0	515		0.67	34				5,178.8	103
	Max	730	0	730		117	8	0	730		0.95	5				7,341.6	104
2	Min	300	6	306		49	3	35	335		0.44	3				3,211.2	47
	Avg	500	6	506		81	5	35	535		0.69	4				5,222.5	74
	Max	700	6	706		113	7	35	735		0.95	6				7,233.9	103
3	Min	100	25	125		20	1	40	140		0.18	1				1,251.2	15
	Avg	210	25	235		37	2	40	250		0.32	2				2,357.5	31
	Max	325	25	350		56	4	40	365		0.47	3				3,514.7	48
4	Min	49	25	74		12	1	40	89		0.12	1				739.1	9
	Avg	206	25	231		37	2	40	246		0.32	2				2,317.4	28.28
	Max	1000	25	1025		164	11	40	1040		1.35	8				10,303.1	133.25
5	Break even on contaminated steel. No drums of NORM accepted.																
6	Avg	300	6	306		49	3	20	320		0	1				3,212.1	43
7	Min	792	0	792		126	8	0	792		1	6				7,729.3	113
	Avg	1081	0	1081		173	12	0	1081		1	8				10,551.2	154
	Max	3333	0	3333		532.00	35	0	3333		4	3				32,531.0	452
8 & 9	Min	151	0	151		24	2	0	151		0	1				1,474.0	22
	Avg	916	0	916		146	10	0	916		1	7				8,940.7	130
	Max	2300	0	2300		367	24	0	2300		3	17				22,448.4	326

Transport Estimate

APPENDIX G—NORM ACCUMULATION BY TYPE OF SOURCE

	Drums of NORM				No. of Wells	
Reply No.	(A) Stored Solids	(B) Tubulars	(C) Equipment	(D) Sludge and Sites	Oil	Gas
101	10	31	30	0	514	50
108	0	48	0	0	1087	
109	0	11	1	10	400	300
111	1712	50	125	0	6085	1066
113	38	0	0	10	15	-
115	153	120	10	100	855	514
117	13	1	2	66	290	296
118	3200	451	30	4000	8800	2340
119	7000	0	0	5000	823	334
120	0	41	0	0	42	41
121	90	10	90	0	38	45
124	32	5	41	0	245	155
125	5	13	0	714	1620	0
126	367	40	1	0	32	13
127	0	375	1	1	1095	143
133	20	0	10	0	958	727
137	130	25	1000	1,800,000	10,800	1135
139	242	25	71	221	6844	994
140	40	0	0	50	361	461
141	27	0	0	10	2	52
142	4	0	2	4	75	23
145	100	0	0	0	519	1
146	530	234	400	80,000	2100	900
147	3	7	4	35	70	189
149	43	441	0	0	1070	384
Totals	**2383**	**1928**	**1818**	**1,890,221**	**44,740**	**10,163**
Percentage of Total	**< 1%**	**< 1%**	**< 1%**	**99.7%**		

A + B + C + D = 1,896,350

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