Options and Cost for Disposal of NORM Waste

John A. Veil
Argonne National Laboratory
Washington, DC

to be presented at:
5th International Petroleum Environmental Conference
Albuquerque, NM
October 20-23, 1998

DISCLAIMER

DISCLAIMER

Options and Cost for Disposal of NORM Waste

John A. Veil
Manager, Water Policy Program
Argonne National Laboratory
Washington, DC, USA

ABSTRACT

Oil field waste containing naturally occurring radioactive material (NORM) is presently disposed of both on the lease site and at off-site commercial disposal facilities. The majority of NORM waste is disposed of through underground injection, most of which presently takes place at a commercial injection facility located in eastern Texas. Several companies offer the service of coming to an operator's site, grinding the NORM waste into a fine particle size, slurrying the waste, and injecting it into the operator's own disposal well. One company is developing a process whereby the radionuclides are dissolved out of the NORM wastes, leaving a nonhazardous oil field waste and a contaminated liquid stream that is injected into the operator's own injection well. Smaller quantities of NORM are disposed of through burial in landfills, encapsulation inside the casing of wells that are being plugged and abandoned, or land spreading. It is difficult to quantify the total cost for disposing of NORM waste. The cost components that must be considered, in addition to the cost of the operation, include analytical costs, transportation costs, container decontamination costs, permitting costs, and long-term liability costs. Current NORM waste disposal costs range from $15/bbl to $420/bbl.

INTRODUCTION

Since 1992, the U.S. Department of Energy (DOE) has funded Argonne National Laboratory (Argonne) to conduct a series of studies evaluating issues related to management and disposal of oil field wastes contaminated with naturally occurring radioactive material (NORM). This paper is based on information developed for a DOE study on NORM disposal in salt caverns (1).

NORM OCCURRENCE AND CHEMISTRY

Oil and gas production and processing operations sometimes accumulate NORM at elevated concentrations in by-product waste streams. The sources of most of the radioactivity are isotopes of uranium-238 (U-238) and thorium-232 (Th-232) naturally present in subsurface formations from which oil and gas are produced. The primary radionuclides of concern in NORM wastes are Ra-226 of the U-238 decay series, and Ra-228 of the Th-232 decay series. Other radionuclides of concern include those that form from the decay of Ra-226 and Ra-228.

The production waste streams most likely to be contaminated by elevated radium concentrations include produced water, scale, and sludge (2). Spills or intentional releases of these waste streams to the ground can result in NORM-contaminated soils that must also be disposed of. Radium, which is slightly soluble, can be mobilized in the liquid phases of a formation and transported to the surface in the produced water stream. Dissolved radium either remains in solution in the produced water or precipitates out in scales or sludges. Conditions that appear to affect radium solubility and precipitation include water chemistry (primarily salinity), temperature, and pressure.

NORM contamination of scale and sludge can occur when dissolved radium coprecipitates with other alkaline earth elements, such as barium, strontium, or calcium. In the case of scale, the radium coprecipitates, primarily with barium, to form hard, insoluble sulfate deposits. Scale typically forms on the inside of piping, filters, injection wellhead equipment, and other water handling equipment, but also can form as a coating on produced sand grains. Radium can be present in several forms in sludge. It can coprecipitate with silicates and carbonates that form in the sludge, or it can be present in pieces of barium sulfate scale that become incorporated into the sludge. NORM-contaminated sludges can accumulate inside piping, separators, heater/treaters, storage tanks, and any other equipment where produced water is handled. The U.S. Environmental Protection Agency (EPA) estimates that approximately 25,000 tons of NORM-contaminated scale and 225,000 tons of NORM-contaminated sludge are generated annually by the petroleum industry (3).

In addition to their radioactive characteristics, NORM wastes also have physical and chemical characteristics typical of nonhazardous oil field waste (NOW). The authors of reference 4 assumed that a typical NOW stream going to a disposal cavern consists of accumulated heavy hydrocarbons, paraffins, inorganic solids, and heavy emulsions.

REGULATORY CONSIDERATIONS

Hazardous Waste Status of NORM Waste and Other Oil Field Wastes

The most important distinction between oil field wastes and many other types of industrial wastes is that the former are exempted from the hazardous waste requirements of the Resource Conservation and Recovery Act (RCRA). Most types of oil field wastes are commonly considered to be nonhazardous oil field wastes (NOW). On July 6, 1988, the EPA issued a regulatory determination that exempted any wastes arising from the exploration, development, and production of crude oil, natural gas, and geothermal energy from regulation as hazardous wastes under RCRA Subtitle C (53 FR 25477). On March 22, 1993, the EPA clarified the 1988 determination and exempted many other wastes that were uniquely associated with exploration and production operations from RCRA Subtitle C requirements (58 FR 15284). Given the federal exemption from RCRA for oil field wastes, the waste management requirements faced by most operators will be state requirements.

The difference between NOW and NORM waste is the presence in the latter of radionuclides above a state-specified action level. The presence of those radionuclides does not change the waste's exempt status under RCRA as long as the waste itself, exclusive of the radiological components, is an exempt waste. Therefore, most oil field NORM waste is not regulated as hazardous waste.

The term "nonhazardous oil field waste" should not be interpreted to mean that no hazardous substances are found in oil field wastes. At least one oil- and gas-producing state, does not follow the blanket RCRA exemption for exploration and production wastes and associated wastes. In California, each batch of waste is tested for specified parameters to determine whether the waste is hazardous. Those wastes found to be hazardous must be managed at a hazardous waste management facility, which typically is much more expensive than management at a NOW disposal facility.

Summary of NORM Regulations

No existing federal regulations specifically address handling and disposal of NORM wastes. In the absence of federal regulations, individual states have taken responsibility for developing their own regulatory programs. These programs have been evolving rapidly over the last few years. Many states have promulgated NORM regulations, and many others are reviewing the magnitude of NORM issues within their borders and the need for specific regulations.

Existing state regulatory programs establish requirements for (a) a NORM exemption standard or action level; (b) licensing of parties possessing, handling, or disposing of NORM waste; (c) release of NORM-contaminated equipment and land; (d) worker protection; and (e) NORM waste disposal. The action level defining when waste must be managed as NORM varies from state to state. In general, state action levels range from 5 to 30 picocuries per gram (pCi/g) of total radium (i.e., radium-226 [Ra-226] plus radium-228 [Ra-228]). Several states have established two action levels, depending upon the radon emanation rate[1] of the waste. In these states, the action level is 5 pCi/g total radium if the radon emanation rate exceeds 20 pCi per square meter per second (pCi/m^2/s) and 30 pCi/g total radium if the radon emanation rate is below that level. A picocurie (pCi) is equal to 10^{-12} curies.[2]

Most state regulations currently approve the following disposal methods for waste exceeding the NORM action levels: (a) burial at either a licensed NORM waste or low-level radioactive waste disposal facility, (b) downhole disposal via encapsulation inside the casing of a plugged and abandoned well, and (c) underground injection into subsurface formations via a permitted Class II well. A few states also allow NORM waste to be disposed of via land spreading, provided that specific criteria are met. The State of Michigan also allows NORM waste containing up to 50 pCi/g radium to be disposed of in landfills that are permitted to accept only nonhazardous wastes (5). Downhole encapsulation and underground injection of NORM waste typically are approved on a case-by-case basis only and, in the case of underground injection, may require a modification to the existing Class II permit.

---

[1] The radon emanation rate is the fraction of radon atoms that escape the grain material containing the parent nuclide into the gaseous, porous space between the grains.

[2] A conventional unit, the curie (Ci) is defined as the quantity of a given radionuclide in which 3.7×10^{10} atoms undergo nuclear transformations each second. One Ci is roughly equal to the decay rate of one gram of Ra-226.

NORM MANAGEMENT PRACTICES

The presence of NORM in oil and gas wastes has been recognized since the 1930s. NORM was not recognized as a waste management issue, however, until the mid-1980s, when the industry and regulators realized that NORM occurrence was more widespread than originally thought and that radioactivity levels could be high. The petroleum industry adopted methods for managing and disposing of NORM-contaminated wastes that are more restrictive than past practices and are likely to provide greater isolation of the radioactivity. Simultaneously, state agencies have promulgated NORM regulations that establish new, more restrictive standards for the management and disposal of NORM wastes. These actions have served to limit the number of disposal options available for NORM wastes, thereby increasing waste management costs.

The largest volume oil and gas waste stream that contains NORM is produced water. Except at offshore platforms, which discharge produced water to the ocean, nearly all produced water is injected into the subsurface through injection wells. At this time, the radium content of produced water going to injection wells is not regulated. Consequently, radium that stays in solution in the produced water stream does not present a significant waste management problem from a regulatory perspective and is not considered further in this paper.

Some operators dispose of NORM wastes at their own sites, although most use off-site commercial disposal facilities. Pipes and casing with NORM contamination may be recycled as scrap steel if NORM levels are below background concentrations. In the past, NORM was commercially managed by surface treatment – NORM was blended with nonradioactive materials to reduce the NORM activity below action levels and then was spread on the land. Today, the primary method used for disposal of NORM wastes is underground injection. Smaller quantities of NORM waste are disposed of at licensed radioactive waste landfills, encapsulated in the casing of a well being abandoned, or managed on lease sites through land spreading.

Only four off-site commercial NORM disposal companies have been identified in the United States; two of these inject the NORM waste underground and the other two bury NORM waste in landfills. Identification of disposal companies by name in the following sections does not constitute an endorsement of those companies or provide any indication of their performance capabilities. The companies are included solely to provide an indication of the types of commercial disposal options available to operators in the mid-1998 time frame.

Underground Injection

NORM-contaminated scales, sludges, and other solid wastes have also been disposed of through underground injection wells. The authors of reference 6 report on a NORM waste injection project in the North Slope Alaska oil field developed by two major producing companies. Approximately 100 tons of NORM solids were cleaned from 3,000 oil production pipes and casing. The resulting solids were processed to a particle size of less than 80 micrometers (μm), slurried with 10,000 bbl of water, and then injected into a Class II injection well.

Two of the four U.S. commercial off-site NORM disposal companies utilize underground injection. Newpark Environmental Services, Inc., operates a NORM disposal facility near Winnie in eastern Texas that receives the majority of all NORM wastes disposed of commercially in the United States. In July 1997, Lotus, LLC opened a NORM disposal facility in western Texas near Andrews. Both facilities crush, mill, and slurry the incoming NORM waste before injecting it.

DOE has funded BPF, Inc., to develop a mobile NORM treatment system. The BPF process dissolves the radioactive component of NORM into an aqueous solution that can then be disposed of through underground injection. The residual solids no longer contain radioactivity above levels of regulatory concern and can be disposed of as NOW (7). As of summer 1998, the BPF process is at the pilot-scale stage of development.

Other disposal contractors (e.g., Apollo Services and National Injection Services) will come to an operator's site and process NORM wastes so that they can be injected through the operator's own injection well. The process consists of grinding and milling the waste to a small particle size, slurrying the waste to facilitate pumping, and injecting to formations at fracture pressure (8). Apollo Services and National Injection Services are primarily disposing of drilling wastes at offshore platforms, but can also accommodate NORM wastes.

Landfill Disposal

The other off-site commercial NORM waste disposal option in the United States is burial in landfills. US Ecology operates a low-level radioactive waste landfill on DOE's Hanford site in southeastern Washington State. The landfill is primarily designed to handle radioactive wastes other than oil field wastes, but oil field NORM waste is accepted. Because of its location remote from most oil-producing areas and the higher costs associated with general low-level radioactive waste management requirements, US Ecology receives relatively little NORM waste. For example, in 1997, US Ecology received less than 500 ft^3 of NORM wastes.

Envirocare of Utah, Inc., also operates a landfill for mixed wastes and low-specific activity radioactive wastes in Clive, Utah, that has accepted NORM waste for disposal.

Encapsulation and Downhole Disposal

Under the encapsulation and downhole disposal option, an operator encapsulates NORM waste either inside a section of pipe that is then sealed on both ends and lowered into a wellbore or directly in the wellbore. A plug is placed on top of the waste-containing zone. The authors of reference 9 report on two encapsulation projects conducted in the offshore Gulf of Mexico. In the first project, NORM waste was placed into eight joints of casing as the pipe was being lowered into the hole. In the second project, 31 drums of NORM waste were placed into 21 joints of casing on shore and sealed on both ends. The sealed joints were transported offshore and lowered into the well bore. In both projects, cement plugs were placed on top of the waste-containing joints.

Encapsulation works well for NORM waste disposal, but each well can handle only a relatively small volume of waste. Because of this restriction, the process is not widely used.

Land Spreading

The principle behind land spreading is to mix NORM wastes having an activity concentration higher than the action level with clean soil so that the resulting blend has an activity concentration lower than the action level. Sanifill/Campbell Wells operated a commercial land spreading site until recently, when it no longer was economical to operate. Some producers utilize land spreading on their lease site to blend patches of high-activity NORM soils with low-activity NORM soils. However, the present use of land spreading for disposal of NORM waste is limited.

COST OF NORM WASTE DISPOSAL

Elements of Cost

The total cost of NORM waste disposal comprises several components. In addition to the cost of the actual disposal operation, operators must consider costs associated with transportation, physical inspection, radionuclide and chemical analysis, and container decontamination. Given the limited number of off-site commercial disposal sites available, transportation costs from remote locations can represent a significant component of total cost. Operators must consider all cost components before selecting a disposal option. To the extent possible, it will be indicated whether the cost figures presented in this chapter reflect just the cost of disposal or include other costs as well.

In addition to direct costs, there are other important potential costs, such as long-term liability under the Superfund law. Remediation costs, if the disposal activity results in environmental contamination, can be substantial. The EPA estimates the average cost for cleaning up a Superfund site is approximately $30 million in 1994 dollars (60 FR 20330, April 25, 1995). Long-term liability costs are not quantified here because they represent a future potential cost, not an actual current cost. Liability insurance rates paid by operators include the insurer's perception of long-term liability from all phases of the operator's business, including waste disposal. The incremental insurance costs associated with NORM waste disposal were not identified in this study.

Historical NORM Waste Disposal Costs

The American Petroleum Institute (API) surveyed the U.S. oil and gas industry in 1992 to learn how NORM waste was disposed of, how much it cost for disposal, and what volume of NORM required disposal (10). The results of that survey indicated that disposal costs varied greatly, depending on the specific activity of the NORM, the number of drums being disposed of, and the disposal option selected. Disposal costs from the API survey are summarized in Table 1. The costs ranged from $49 to $3,333 per 55-gal drum, with an average of $544 per drum (equivalent to $415 per 42-gal bbl). For some of the disposal options, various additional costs are identified, including radiological analysis ($100 - $500 per sample), chemical analysis ($250 - $500 per sample), transportation ($6 - $40 per drum), "pretreatment washing volume reduction" ($10 - $25 per drum), permitting and manifesting, administrative costs, and non-NORM waste disposal costs.

Current NORM Waste Disposal Costs

The costs presented in the previous section are those that operators faced in 1992. Some of the disposal options in use in 1992 are no longer available, particularly the commercial surface treatment facility in Louisiana. That facility was closed because the operation was no longer profitable. In general, however, NORM waste disposal costs have decreased between 1992 and 1998. The following sections provide current information on the cost of off-site commercial disposal companies and other companies that provide disposal services at an operator's site using an existing injection well. These costs are summarized in Table 2. Cost information was collected directly from disposal companies and from oil and gas operators.

Costs for Off-site Commercial Disposal of NORM Waste - The costs presented below are those reported to the author in early 1998. They are included in this report for comparative purposes at one point in time. There is no guarantee that these costs reflect the actual costs that would be charged to customers or that these companies still charge the same fees. Most commercial disposal companies will negotiate more favorable rates than those described below for customers with large volumes of waste.

Newpark Environmental Services, Inc., charges $196.50 per 55-gal drum or $150/bbl for disposal of NORM wastes through injection. This cost includes inspection and verification of contents as well as the necessary analytical costs. The cost of decontamination is $25 for a drum and $150 for a bulk container (11). Transportation costs are not included in these figures.

Lotus LLC began accepting NORM waste in 1997. Lotus charges $132 per 55-gal drum or $100/bbl for disposal by injection. Gamma spectroscopy analysis costs an additional $100 per sample. Transportation cost is not included but is estimated to be about $3 per loaded mile for a full 72-bbl roll-off box (12).

US Ecology operates a low-level radioactive waste disposal landfill that receives various types of radioactive waste, including NORM waste. Because the facility primarily receives radioactive wastes other than oil field wastes, the requirements are more stringent than those for typical NORM disposal facilities and costs are higher. Base disposal costs range from $500 to $550 per 55-gal drum or from $66.67 to $73.33 per cubic foot, depending on the volume. The State of Washington does not recognize the RCRA exemption from hazardous waste status for exploration and production wastes. Therefore, each waste stream must be analyzed for hazardous waste characteristics and radionuclides. Transportation cost is not included but is estimated to be about $2.10 per mile based on a full truck load. All waste generators shipping waste to US Ecology must obtain a site use permit from the Washington Department of Ecology. Obtaining that permit will add to the total cost. All shipments are subject to a minimum disposal charge of $2,500 (13).

Envirocare of Utah, Inc. operates a landfill for mixed wastes and low-specific activity radioactive wastes that has, on occasion, accepted NORM waste for disposal. Envirocare declined to provide a standard price for disposal but indicated that it set prices on a case-by-case basis. According to the company contact, Envirocare is competitive when bidding on large disposal jobs but is not competitive on small jobs because its overhead costs, set for all low-level radioactive waste disposal activities, is quite high and is constant regardless of the job size.

For large jobs, the overhead is spread over many drums of waste and is therefore low on a cost per drum basis (14).

Costs for On-site Commercial Disposal of NORM Waste - The three companies discussed in this section process and dispose of NORM waste on-site. All three companies use the operator's injection well to dispose of the NORM wastes.

BPF, Inc., is developing a system that dissolves the radioactive component of NORM into an aqueous solution that can then be disposed of through underground injection. The residual solids no longer contain radioactivity above levels of regulatory concern and can be disposed of as NOW. The process is currently at the pilot stage of development. BPF estimates that costs of the full-scale system, when commercially available, will be approximately $140/bbl ± 20%. These costs would include an initial survey, obtaining the necessary permits, labor, off-site disposal costs for the resulting NOW solids, chemicals, and a final survey. The cost of an injection well would be extra if the operator does not already have a functioning injection well (15).

At least two companies, Apollo Services and National Injection Services, provide NOW and NORM disposal at an operator's site. Wastes are ground up, slurried, and injected into the operator's own injection well. The process of injecting ground and slurried NORM waste could potentially plug the receiving formation. Operators should consider the potential cost of an injection well workover when estimating total disposal costs for these companies.

As of early 1998, Apollo was primarily disposing of NORM at offshore platforms. Apollo estimates that NORM waste disposal costs range from $100/bbl to $300/bbl, depending on the volume of NORM to be disposed of (16).

National Injection Services disposes of NOW and NORM through on-site injection. National's cost ranges from $15/bbl to $150/bbl, depending on the nature of the materials to be disposed of (17).

Actual Disposal Practices and Costs

To provide another perspective on NORM waste disposal, several major U.S. oil and gas producers were asked how they dispose of their NORM wastes. Contact persons at these companies agreed to provide information under the condition that their companies not be identified by name. Therefore, companies are identified as Company A, Company B, etc.

Company A disposes of about 600 bbl/year of NORM waste from offshore and the eastern United States at a commercial injection well facility. The cost for disposal and decontamination of containers is $150/bbl, and the cost for lab analyses, transportation, and handling added another $30/bbl.

Company B used to operate its own offshore injection well for disposing of offshore NORM waste but now sends all of its NORM wastes to a commercial injection well facility. Disposal costs range from $125/bbl to $200/bbl. The typical cost rate for a 15-barrel cuttings box is $150/bbl. Company B does some analytical work at $100/test before shipping the waste. Transportation costs are estimated to be $25/bbl.

Company C sends much of its NORM waste to a commercial injection well facility. In the past, Company C operated annular injection wells offshore for NORM disposal. Disposal costs at these wells ranged from $500/bbl for "trouble-free" projects to more than $2,000/bbl for "trouble-plagued" projects. As less expensive commercial alternatives became available, Company C opted for off-site commercial disposal. Company C needs to dispose of a large volume of NORM-contaminated soils from remediation projects and recently opted to develop its own onshore injection well to handle these wastes. Cost figures are not yet available, but the contact person noted that capital and operating costs are high. In order to make the process cost effective on a $/bbl basis, the project needs to handle a large volume of wastes.

Company D also sends most of its NORM waste to a commercial injection well facility. During lease abandonment, Company D sometimes blends patches of NORM-contaminated soils with clean soils to reduce the aggregate NORM activity below levels of regulatory concern. In other cases, large volumes of NORM-contaminated soils are excavated and sent off-site for disposal. Company D did not provide specific cost figures but indicated that it had received a significant discount from the disposal company's standard rates for one particularly large project.

Two companies operating in Alaska utilize different NORM disposal methods. Company E ships all its Alaskan NORM waste to a commercial injection facility in Texas, whereas Company F grinds and slurries NORM waste and injects it into its own injection well. No cost information was available for these projects.

One disposal option that was not mentioned by any of the companies is encapsulation in pipes and casing and downhole disposal during plugging and abandonment. This practice is probably occurring, but the costs tend to be higher than other options (see Table 1). If a company has NORM waste at the same location where it is plugging and abandoning multiple wells, this option may be cost effective.

Consideration of Liability Costs

Long-term liability costs are an important consideration for major operators. Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), companies that dispose of wastes into sites that later become Superfund sites have joint and several liability. This means that a company that contributes only a small portion of a disposal site's waste volume can potentially be held liable for a large portion of the remediation costs if some or all of the other waste contributors are out of business or are otherwise unable to pay. Given that background, prudent companies that have historically disposed of waste at a particular disposal site will think twice before extending their potential liability to new disposal sites, even if the new disposal sites are less costly.

ACKNOWLEDGMENTS

The work described in this paper was sponsored by the U.S. Department of Energy, National Petroleum Technology Office (NPTO), under Contract W-31-109-ENG-38. The author acknowledges John Ford of the NPTO for supporting and encouraging this work. The author of this paper is the program manager for Argonne's salt cavern work, but the study on

which this paper is based was co-authored by Karen P. Smith, David Tomasko, Deborah Elcock, Deborah L. Blunt, and Gustavious P. Williams.

REFERENCES

1. Veil, J.A., K.P. Smith, D. Tomasko, D. Elcock, D.L. Blunt, and G.P. Williams, 1998, "Disposal of NORM-Contaminated Oil Field Wastes in Salt Caverns," prepared for U.S. Department of Energy, Office of Fossil Energy, Argonne National Laboratory, Argonne, IL, August.

2. Smith, K.P., D.L. Blunt, G.P. Williams, and C.L. Tebes, 1996, "Radiological Dose Assessment Related to Management of Naturally Occurring Radioactive Materials Generated by the Petroleum Industry," ANL/EAD-2, Argonne National Laboratory, Argonne, IL, September.

3. EPA, 1993, "Draft Diffuse NORM-Waste Characterization and Preliminary Risk Assessment," U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, DC.

4. Tomasko, D., D. Elcock, J. Veil, and D. Caudle, 1997, "Risk Analyses for Disposing Nonhazardous Oil Field Wastes in Salt Caverns," prepared for U.S. Department of Energy, Office of Fossil Energy, Argonne National Laboratory, Argonne, IL, December.

5. MDEQ, 1996, "Cleanup and Disposal Guidelines for Sites Contaminated with Radium-226," Drinking Water and Radiological Protection Division, Michigan Department of Environmental Quality, Lansing, MI.

6. McArthur, A., M. Major, and D.J. Lowe, 1995, "NORM Disposal in Class II Wells," SPE paper 29713, presented at the Society of Petroleum Engineers/Environmental Protection Agency Exploration & Production Environmental Conference, Houston, TX, March 27-29.

7. Capone, D.W., S. Chatterjee, T. Cleland, D. Fortunato, G. Roehrig, H.B. Walker, and T.O. Bush, 1997, "Results of Bench Scale Testing of a Mobile On-Site NORM Treatment System in Texas and New Mexico," in proceedings of U.S. Department of Energy's Natural Gas Conference, Houston, TX, March 24-27.

8. Sipple-Srinivasan, M., M.S. Bruno, R.A. Bilak, and P.G. Danyluk, 1997, "Field Experiences with Oilfield Waste Disposal through Slurry Fracture Injection," SPE paper 38254, presented at 67th Annual Western Regional Meeting of the Society of Petroleum Engineers, Long Beach, CA, June 23-27.

9. Scaife, W.W., S.G. Mueller, and D.R. Young, 1994, "Downhole Disposal of NORM Wastes in An Offshore Setting: Lessons Learned," in Proceedings of the International Petroleum Environmental Conference, Houston, TX, March 2-4.

10. API, 1996, "A Naturally Occurring Radioactive Material (NORM) Disposal Cost Study," API Publication 7100, 1st edition, American Petroleum Institute, Washington, DC, November.

11. Sammons, J., 1998, personal communication between Sammons, Newpark Environmental Services, Houston, TX, and J. Veil, Argonne National Laboratory, Washington, DC, January 23.

12. Kelly, J., 1998, letter from Kelly, Lotus LLC, Andrews, TX, to J. Veil, Argonne National Laboratory, Washington, DC, January 9, and personal communication between Kelly and Veil, June 3.

13. White, C., 1998, letter from White, US Ecology, Richland, WA, to J. Veil, Argonne National Laboratory, Washington, DC (received in January).

14. Rafati, A., 1998, personal communication between Rafati, Envirocare of Utah, Inc., Salt Lake City, UT, and J. Veil, Argonne National Laboratory, Washington, DC, February 11.

15. Bush, T.O., 1998, fax from Bush, BPF, Inc., Duncanville, TX, to K. Smith, Argonne National Laboratory, Denver, CO, January 15.

16. Reddoch, J., 1998, personal communication between Reddoch, Apollo Services, Lafayette, LA, and J. Veil, Argonne National Laboratory, Washington, DC, January 21.

17. Page, W., and N. Guidry, 1998, personal communication between Page and Guidry, National Injection Services, Inc., Lafayette, LA, and J. Veil, Argonne National Laboratory, Washington, DC, February 11.

Table 1 - 1992 NORM Disposal Costs (from Reference 10)

Disposal Method	Disposal Cost ($) per 55-gal Drum			Additional Costs
	Low	Average	High	
Landfill - Washington	395	515	730	None
Landfill - Utah	300	500	700	Radiological analysis, physical properties check, transportation, waste profile, decontamination of vehicle
Surface treatment – Louisiana	100	210	325	Radiological and chemical analysis, physical properties check, transportation, waste profile, packing
Injection - Texas	49	206	1,000	Radiological and chemical analysis, physical properties check, transportation, waste profile, packing
Recycling steel – China	No cost - steel purchase price pays for transportation costs			
Encapsulation in pipes and disposal in abandoned wells	792	1,081	3,333	None
Injection into private wells	151	916	2,300	None

Table 2 - 1998 Commercial Disposal Costs for NORM (from Reference 1)

Disposal Company	Disposal Method	On-site/ Off-site	Costs ($/bbl)[a]
Newpark Environmental Services, Inc.	Injection	Off-site	150
Lotus LLC	Injection	Off-site	100
US Ecology	Landfill	Off-site	380 - 420
Envirocare of Utah, Inc.	Landfill	Off-site	Variable - no costs provided
BPF, Inc.	Treatment/ Injection	On-site	140[b]
Apollo Services	Injection	On-site	100 - 300
National Injection Services	Injection	On-site	15 - 150

[a] One bbl = 42 gal. To convert these costs to $/55-gal drum, multiply by 1.31.
[b] BPF is not in commercial operation as of summer 1998. The costs presented here are projected costs for commercial-scale operation.