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Environmental Protection
Agency

Office of Solid Waste
and Emergency Response
Washington, DC 20460

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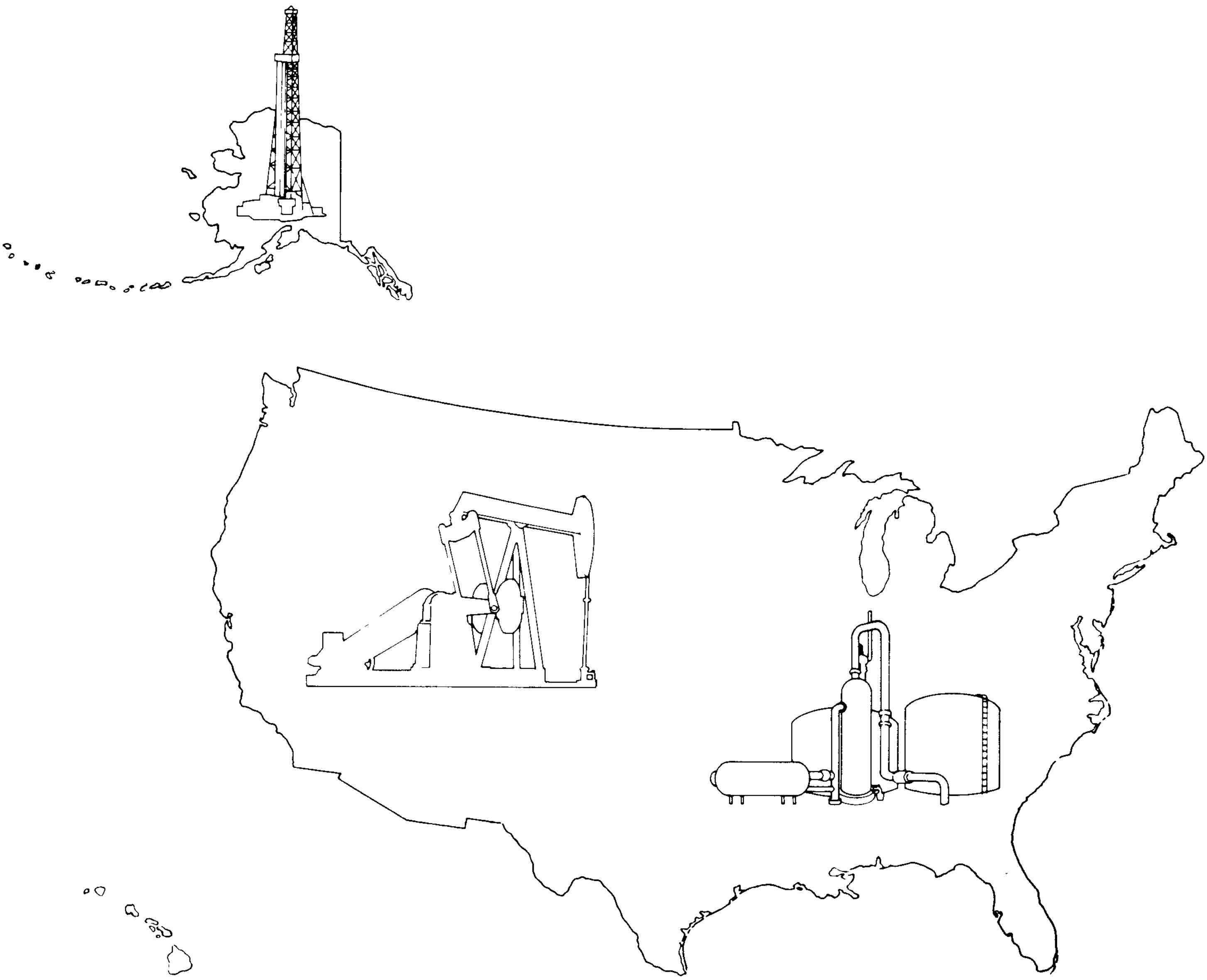
Report to Congress

Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy

Executive Summaries



Report to Congress

Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy

EXECUTIVE SUMMARIES

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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This Report to Congress is dedicated to the memory of Susan L. de Nagy, United States Environmental Protection Agency, and John F. Catlin, United States Department of the Interior.

EXECUTIVE SUMMARY

MANAGEMENT OF WASTES FROM THE OIL AND GAS INDUSTRY

Under Section 3001(b)(2)(A) of the 1980 Amendments to the Resource Conservation and Recovery Act (RCRA), Congress temporarily exempted several types of solid wastes from regulation as hazardous wastes, pending further study by the Environmental Protection Agency (EPA). Among the categories of wastes exempted were "drilling fluids, produced waters, and other wastes associated with the exploration, development, or production of crude oil or natural gas." Section 8002(m) of the 1980 Amendments requires the Administrator to study these wastes and submit a report to Congress evaluating the status of their management. This report must include appropriate findings and recommendations for Federal and non-Federal actions concerning the effects of such wastes on human health and the environment.

RCRA defines a specific sequence of events that would precede the promulgation of any new Federal regulations (including use of Subtitle C):

1. Study of issues and submission of Report to Congress with appropriate recommendations;
2. Formal public comment period on Report to Congress;
3. A formal regulatory determination by EPA; and
4. If regulations are to be developed:
   a. Proposal of regulations;
   b. Formal public comment period on proposed regulations; and
   c. Revision of proposal.

Should regulations be developed, the statute provides that they shall take effect only when authorized by act of Congress.

The current report is the first step in this sequence. Recognizing that this class of wastes is temporarily exempt because of the complexity of its impacts and the problems of its management, EPA has sought to be as comprehensive as possible in its discussion of issues for Congress. Further steps noted above will progressively refine the issues of concern. Congress retains ultimate control over the scope and direction of any additional Federal actions that might be taken to improve the management of these wastes.

SPECIAL WASTES

Oil and gas wastes fall within a general category of wastes that RCRA regards as "special" because of their unusually high volume, which could make the application of some RCRA regulatory requirements technically infeasible or impractical, and because of their relatively low level of apparent environmental hazard (based on data available in 1980). The issues raised by all special wastes are complex, requiring the balancing of environmental, logistical, and economic considerations.

Congress' intent in temporarily exempting these wastes from regulation under RCRA Subtitle C was to provide an opportunity for developing an appropriate strategy for their management, should new or additional measures prove to be needed.

PURPOSE OF THIS STUDY

This study is intended to respond as fully as possible to each of the study factors described by Congress in the various paragraphs of Section 8002(m). The Agency has designed this report to respond specifically to each study factor within separate chapters or sections of chapters. Although every study factor has been weighed in arriving at the conclusions and recommendations of this report, no factor has had a determining influence on the study's conclusions and recommendations.

Identifying Exempt Wastes: Chapter II, "Overview of the Industry," interprets the scope of the exemption as defined in the statute.

Specifying the Sources and Volumes of Wastes: Estimates of volumes of wastes are also presented in Chapter II.

Characterizing Wastes: EPA conducted a national screening type of sampling program of facilities to compile relevant data on waste characteristics. Simultaneously, the American Petroleum Institute (API) sampled the same sites except for central treatment locations and central pit locations, and wastes covered by the EPA survey. Chapter II of this report summarizes the results of these programs.

Describing Current Disposal Practices: The Agency has described the principal and common methods of managing field-generated wastes and discusses these practices in general qualitative terms in relation to their effectiveness in protecting human health and the environment. This discussion is presented in Chapter III, "Current and Alternative Practices."

Documenting Evidence of Damage to Human Health and the Environment Caused by Oil and Gas Wastes: Chapter IV, "Damage Cases," summarizes EPA's effort to collect documented evidence of danger to human health or damage to the environment or valuable resources. This collection of case studies is not intended to estimate the frequency or extent of damages associated with typical operations, nor to judge the effectiveness of current State programs in preventing these damages. It is intended only to define the nature and range of damages that are known to have occurred.

Assessing Potential Danger to Human Health or the Environment from the Wastes: Qualitative and quantitative risk modeling is presented in Chapter V, "Risk Modeling."

Reviewing the Adequacy of Government and Private Measures to Prevent and/or Mitigate Adverse Effects: This review is based on both a qualitative assessment of all the materials gathered during the course of assembling the report and a review of State and other Federal regulatory programs presented in Chapter VII, "Current Regulatory Programs." Chapter VII reviews the elements of programs and highlights possible inconsistencies, lack of specificity, potential problems in implementation, or gaps in coverage. Interpretation of the adequacy of these control efforts is presented in Chapter VIII, "Conclusions."

Identifying Alternatives to Current Waste Management Practices: EPA's discussion in response to this study factor is incorporated in Chapter III, "Current and Alternative Practices." This chapter merges the concepts of current and alternative waste management practices.

Estimating the Costs of Alternative Practices: The first several sections of Chapter VI, "Economic Impacts of Alternative Waste Management Practices," present the Agency's analysis of this study factor.

Estimating the Economic Impacts on Industry of Alternative Practices: The final two sections of Chapter VI present the Agency's analysis of the potential economic impacts of nationwide imposition of the hypothetical control scenarios analyzed at the project level.

ISSUES SPECIFIC TO THE OIL AND GAS INDUSTRY

To bring this study into perspective, it is important to note a number of issues specific to the oil and gas industry that affect how this study was conducted and how Congress may interpret its results.

First, the oil and gas industry is extremely large and varied. In 1985, there were approximately 842,000 producing oil and gas wells in the U.S., distributed throughout 38 States. They produced 8.4 million barrels of oil, 1.6 million barrels of natural gas liquids, and 44 billion cubic feet of natural gas daily. The petroleum exploration, development, and production industries employed approximately 421,000 people in 1985.

All aspects of exploration, development, and production vary markedly from region to region and from State to State. Well depths range from as little as 30 feet to over 30,000 feet. Pennsylvania has been producing oil for 128 years; Alaska for only 15 years. Maryland has approximately 14 producing wells; Texas has over 269,000 and completed another 25,721 in 1985 alone. Production from a single well can vary from a high of about 11,500 barrels per day (the 1985 average for wells on the Alaska North Slope) to less than 10 barrels per day in many thousands of "stripper" wells. (Overall, 70 percent of U.S. oil wells are strippers, which account for roughly 14 percent of total U.S. production.)

These variations make it extremely difficult to fully represent the scope and breadth of the industry in detail at the national level. EPA has consulted extensively with State regulatory agencies, other Federal agencies, and industry in assembling data and materials on which to base this report. The generalizations that it must necessarily draw in order to respond to Congress' directives are, however, the Agency's own.

Second, although wastes from the oil and gas industry have never been subject to RCRA regulation as hazardous wastes, they have long been regulated at the State level and are also regulated in part under the Federal Clean Water Act and the Federal Safe Drinking Water Act. The questions posed by Section 8002(m) must therefore be interpreted in relation to a complex and long-established background of existing requirements. Furthermore, State programs controlling the management of high-volume wastes have improved significantly over the past decade and, especially over the last 2 or 3 years, have reflected the national trend of increased concern about environmental protection. However, judging the environmental success of these recent improvements is difficult. EPA recognizes the difficulty of analyzing changing State requirements in relation to the regional variations of the industry and therefore wishes to pursue this issue further before arriving at a final regulatory determination on these wastes.

DEFINITION OF EXEMPT WASTES

The following discussion presents EPA's tentative working definition of the scope of the exemption.

Scope of the Exemption

The current statutory exemption originated in EPA's proposed hazardous waste regulations of December 8, 1978 (43 FR 58946). Proposed

40 CFR 250.46 contained standards for "special wastes," which reduced requirements for several types of wastes that are produced in large volume and that EPA believed may be lower in toxicity than other wastes regulated as hazardous wastes under RCRA. One of these categories of special wastes was "gas and oil drilling muds and oil production brines."

In the RCRA amendments of 1980, Congress exempted most of these special wastes from the hazardous waste requirements of Subtitle C, pending further study by EPA. The oil and gas exemption, Section 3001(b)(2)(A), is directed at "drilling fluids, produced waters, and other wastes associated with the exploration, development, or production of crude oil or natural gas." EPA defined the exemption in its regulations at 40 CFR 261.4(6) to include these wastes. The legislative history does not elaborate on the definition of drilling fluids or produced waters, but it does discuss "other wastes" as follows:

> The term "other wastes associated" is specifically included to designate waste materials intrinsically derived from primary field operations associated with the exploration, development, or production of crude oil, natural gas or geothermal energy. It would cover such substances as: hydrocarbon bearing soil in and around related facilities; drill cuttings; and materials (such as hydrocarbons, water, sand, and emulsion) produced from a well in conjunction with crude oil, natural gas or geothermal energy; and the accumulated material (such as hydrocarbons, water, sand and emulsion) from production separators, fluid treating vessels, storage vessels, and production impoundments.
>
> The phrase "intrinsically derived from the primary field operations" is intended to differentiate exploration, development, and production operations from transportation (from the point of custody transfer or of production separation and dehydration) and manufacturing operations.

In order to arrive at a clear working definition of the scope of the exemption under Section 8002(m), EPA has used these statements in conjunction with the definitions and guidelines included in statutory language of RCRA as a basis for determining which oil and gas wastes should be included in the present study.

The test of whether a particular waste qualifies under the exemption can be made in relation to the following three separate criteria. No one criterion can be used as a standard when defining specific waste streams that are exempt. These criteria are as follows:

1. Exempt wastes must be associated with measures (1) to locate oil or gas deposits, (2) to remove oil or natural gas from the ground, or (3) to remove impurities from such substances, provided that the purification process is an integral part of primary field operations.[1]

2. Only waste streams intrinsic to the exploration for, or the development and production of, crude oil or natural gas are subject to exemption. Waste streams generated at oil or gas facilities that are not uniquely associated with exploration, development, or production activities are not exempt. (Examples would include spent solvents from equipment cleanup, or air emissions from diesel engines used to operate drilling rigs.)

   Those substances that are extracted from the ground or injected into the ground to facilitate the drilling, operation, or maintenance of a well or to enhance the recovery of oil and gas are considered to be uniquely associated with exploration, development, or production activities. Additionally, the injection into the wellbore of materials that keep the pipes from freezing or serve as solvents to prevent paraffin accumulation is intrinsically associated with exploration, development, or production activities. With regard to injection for enhanced recovery, the injected materials must function primarily to enhance recovery of oil and gas and must be recognized by the Agency as being appropriate for enhanced recovery. An example would be produced water. In this context, "function primarily" means that the main reason for injecting the materials is to enhance recovery of oil and gas rather than to serve as a means for disposing of the injected materials.

3. Drilling fluids, produced waters, and other wastes intrinsically derived from primary field operations associated with the exploration, development, or production of crude oil, natural gas or geothermal energy are subject to exemption. Primary field operations encompass production-related activities but not transportation or manufacturing activities. With respect to oil production, primary field operations encompass those activities usually occurring at or near the wellhead, but prior to the

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[1] Thus, wastes associated with such processes as oil refining and petrochemical-related manufacturing are not exempt because those processes are not an integral part of primary field operations.

transfer of oil from an individual field facility or a centrally located facility to a carrier (i.e., pipeline or trucking concern) for transport to a refinery or to a refiner.

With respect to natural gas production, primary field operations are those activities occurring at or near the wellhead or at the gas plant but prior to the point at which the gas is transferred from an individual field facility, a centrally located facility, or a gas plant to a carrier for transport to market. Primary field operations encompass the primary, secondary, and tertiary production of oil or gas.

Wastes generated by the transportation process itself are not exempt because they are not intrinsically associated with primary field operations. An example would be pigging waste from pipeline pumping stations. Transportation (for the oil and gas industry) may be for short or long distances.

Wastes associated with manufacturing are not exempt because they are not associated with exploration, development, or production and hence are not intrinsically associated with primary field operations. Manufacturing (for the oil and gas industry) is defined as any activity occurring within a refinery or other manufacturing facility the purpose of which is to render the product commercially saleable.

Using these definitions, Table 1 presents definitions of exempt wastes as defined by EPA for the purposes of this study. Note that this is only a partial list. Although it includes all the major waste streams that EPA has considered in the preparation of this report, others may exist. In that case, the definitions listed above would be applied to determine the status of these wastes under Section 8002(m).

CHARACTERIZATION OF WASTES

Organic constituents, present at levels of potential concern in oil and gas wastes, are shown on Table 2. These include the hydrocarbons benzene and phenanthrene. Inorganic constituents of concern include lead, arsenic, barium, antimony, and fluoride.

Table 1

EXEMPT WASTES

ill cuttings

illing fluids

ll completion, treatment, d stimulation fluids

cking fluids

nd, hydrocarbon solids, d other deposits removed om production wells

ipe scale, hydrocarbon lids, hydrates, and other posits removed from iping and equipment

drocarbon-bearing soil

igging wastes from athering lines

astes from subsurface as storage and retrieval

Basic sediment and water and other tank bottoms from storage facilities and separators

Produced water

Constituents removed from produced water before it is injected or otherwise disposed of

Accumulated materials (such as hydrocarbons, solids, sand, and emulsion) from production separators, fluid-treating vessels, and production impoundments that are not mixed with separation or treatment media

Drilling muds from offshore operations

Appropriate fluids injected downhole for secondary and tertiary recovery operations

Liquid hydrocarbons removed from the production stream but not from oil refining

Gases removed from the production stream, such as hydrogen sulfide, carbon dioxide, and volatilized hydrocarbons

Materials ejected from a production well during well blowdown

Waste crude oil from primary field operations

Light organics volatilized from recovered hydrocarbons or from solvents or other chemicals used for cleaning, fracturing, or well completi

NONEXEMPT WASTES

aste lubricants, hydraulic luids, motor oil, and aint

aste solvents from clean- p operations

ff-specification and nused materials intended or disposal

ncinerator ash

igging wastes from ransportation pipelines

Sanitary wastes, trash, and gray water

Gases, such as SOx, NOx, and particulates from gas turbines or other machinery

Drums - (filled, partially filled, or cleaned) whose contents are not intended for use

Waste iron sponge, glycol, a other separation media

Filters

Spent catalysts

Wastes from truck- and drum- cleaning operations

Waste solvents from equipmen maintenance

Spills from pipelines or other transport methods

	Production			Central treatment			Central pit	Drilling		
	Midpoint	Tank bottom	Endpoint	Influent	Tank	Effluent	Central pit	Drilling mud	Tank bottoms	Pit
Chemical Constituents **Primary concern**										
Benzene	L #	S# S+	L L#•		S#	L S	S#		S#	S S•
Phenanthrene		S #	L L#•		S#		S #	S	S #	
Lead				S#		S#	S#		L#	L# L• S# S#•
Barium			L	S#	S#	S#	S#	S#	L	L# L#• S# S#•
Secondary concern										
Arsenic		S	L			S	S			S S•
Fluoride				S		S	S			L S
Antimony			L•							

Legend:
- L: Liquid sample > 100 x health-based number
- S: Sludge sample > 100 x health-based number
- #: Denotes > 1,000 x health-based number
- L,S: EPA samples
- L•,S•: API samples
- +: TCLP extraction
- — All values determined from direct samples except as denoted by "+"

Table 2 Constituents of Concern Found in Waste Streams Sampled by EPA and API

WASTE VOLUME ESTIMATION METHODOLOGY AND ESTIMATED VOLUMES

Information concerning volumes of wastes from oil and gas exploration, development, and production operations is not routinely collected nationwide, making it necessary to develop a means for estimating these volumes by indirect methods in order to comply with the Section 8002(m) requirement to present such estimates to Congress.

After careful review, estimates of waste volumes compiled by API were used in the Quantitative Analyses in this report. API estimates that 361 million barrels of drilling waste were generated from drilling 69,734 wells, for an average of 5,183 barrels of waste per well in 1985 and that 20.9 billion barrels of produced water were generated in 1985.

CURRENT AND ALTERNATIVE WASTE MANAGEMENT PRACTICES

It is convenient to divide oil and gas wastes into two broad categories. The first category includes drilling muds, wellbore cuttings, and chemical additives related to the drilling and well completion process; the second includes all wastes associated with oil and gas production, primarily produced water.

Section 8002 (m) requires EPA to consider both current and alternative technologies in carrying out the present study. Sharp distinctions are difficult to make because of the wide variation in practices among States and among different types of operations. Waste management technology in the oil and gas industry is fairly simple. For the major high-volume streams, EPA has found no newly invented technologies in the research or development stage that offer promise for wide application in the near term. Virtually every waste management practice that exists can be considered "current" in one specific situation or another.

Of the waste management methods in common use today, some pose the potential for adverse environmental impact if improperly implemented.

Reserve Pits

Reserve pits are an integral part of the drilling process. Usually one reserve pit is constructed per drill site. Where pits are unlined and constructed above unconfined ground-water aquifers, the potential exists for ground-water degradation because of leaching of reserve pit constituents into ground water.

Annular Disposal of Produced Waters

Although it is not a very widespread practice, some produced water is disposed of through the use of annular injection into producing wells. Using this method, produced water is injected through the annular space between the production casing and the production tubing. This method has the potential to adversely affect underground sources of drinking water (USDWs) because of the vulnerability of the single protective string of casing. However, it is usually restricted to low-volume wastes injected at little or no pressure. Testing of annular disposal wells is involved and expensive.

Disposal of Produced Water in Injection Wells

Injection wells used for the disposal of produced water have the potential to degrade fresh ground water in the vicinity if they are inadequately designed, constructed, or operated. Highly mobile chloride ions can migrate into freshwater aquifers through corrosion holes in injection tubing, casing, and cement. The Federal Underground Injection Control (UIC) program requires mechanical integrity testing of all Class II injection wells every 5 years. All States meet this requirement, although some States have requirements for more frequent testing.

Many States have primacy for the UIC program. Both the criteria used for passing or failing an integrity test for a Class II well and the testing procedure itself can vary. There is considerable variation in the actual construction of Class II wells in operation nationwide, both because many wells in operation today were constructed prior to the enactment of current programs and because current State programs vary significantly. State requirements for new injection wells can be quite extensive. However, State requirements for construction of injection wells prior to the enactment of the UIC program have evolved over time, and construction ranges from injection wells in which all ground-water zones are fully protected with casing and cementing to shallow injection wells with one casing string and little or no cement.

Disposal of Produced Water in Unlined Pits

Use of unlined pits for the disposal of produced water is now allowed in only a few States. The use of these pits has the potential to degrade usable ground water through seepage of produced water constituents into unconfined, freshwater aquifers underlying such a pit.

Discharge of Produced Water to Sensitive Surface Waters

Discharge of produced waters to surface water bodies must meet State or Federal permit standards. Although pollutants such as total organic carbon are limited in these discharges, large volumes of discharges containing low levels of such pollutants may be damaging to aquatic communities.

Drilling Wastes on the Alaska North Slope

Drilling waste disposal practices on the North Slope of Alaska are very different from disposal practices elsewhere. Production-related reserve pits on the North Slope are semipermanent, and their contents need to be disposed of periodically. This is generally done by pumping the aqueous phase of the pit onto the tundra after the pit contents have been allowed to settle for a period of 1 year. This discharge is done under permitted effluent limits set by the State of Alaska. The National Pollutant Discharge Elimination System (NPDES) currently does not regulate these discharges. The long-term effects of discharging large quantities of liquid reserve pit waste on the sensitive tundra environment is of concern to EPA, Alaska Department of Environmental Conservation, and officials from other Federal agencies. The existing body of scientific evidence is insufficient to conclusively demonstrate whether or not there are adverse environmental impacts resulting from this practice.

Improperly Plugged and Unplugged Abandoned Wells

There are an estimated 1,200,000 abandoned oil or gas wells in the United States. To avoid degradation of ground water it is vital that abandoned wells be properly plugged. Lack of plugging or improper plugging of a well may allow high-chloride produced water or injected wastes to migrate to freshwater aquifers.

DAMAGE CASES

The purpose of the damage case study was to respond to the requirements of Section 8002(m)(1)(C) by providing an overview of the nature of damages associated with oil and gas exploration, development, or production activities. In general, case studies were used to gain familiarity with ranges of issues involved in a particular study topic, not to provide a statistical representation of the scope or nature of damages. In addition, although many of the cases involved violations of State or Federal regulations, or would involve violations of a State or

Federal regulation if they were to occur today, EPA did not consider this to be relevant to whether or not those cases should be included in this report.

Types of damage of concern to this study were human health effects (acute and chronic), environmental effects, effects on wildlife, effects on livestock, and impairment of other natural resources. Case information was assembled from the major petroleum-producing States: Alaska, Arkansas, California, Kansas, Louisiana, Michigan, New Mexico, Ohio, Oklahoma, Pennsylvania, Texas, West Virginia and Wyoming. The damage case effort focused on gathering information on cases that had occurred most recently. Ninety-five percent of all cases used in the report date from 1981 to the present, and approximately half of these involved violations of State regulations.

Test of Proof for Cases Used in the Study

All cases were classified according to whether they met one or more formal tests of proof, a classification that was to some extent judgmental. Three tests were used; cases were considered to meet the documentation standards of Section 8002(m)(1)(C) if they met one or more of them, and most met more than one. The tests were as follows:

1. Scientific investigation: Scientific investigations could include either a qualitative scientific evaluation of a case, in which a conclusion of damage might be reached by the author(s) of the study, or through the results of scientific measurements, such as a monitoring study, or both. In the latter event, damage could be accepted as documented if the levels of contamination reported exceeded applicable State or Federal standards or guidelines for the pollutant involved.

2. Administrative finding: Damage was accepted as documented if it was reported by a State or Federal official in the course of official duties and if that report was not later invalidated or withdrawn.

3. Court decision: Court rulings finding presence of health or environmental damages were accepted as conclusive.

EPA distributed draft versions of the case studies, based on an interpretation of the documentation gathered in the initial phases of the study, for review and validation. The Agency received voluminous responses on these cases from the States, from industry, and sometimes from third parties. The cases were extensively revised and expanded to incorporate all commentary; where issues of fact or interpretation could not be resolved, EPA has provided numerous footnotes within the report so as to present all sides of the issues.

Several patterns became apparent after analysis was performed on the damage cases collected. They are described below:

Ground-Water Degradation

Degradation of ground water from improper operation of injection wells for the purpose of disposal or enhanced recovery is a potential hazard and has important implications given the large number of wells used for injection, either for enhanced recovery of oil or for final disposal of oil and gas wastes. Damage to ground water from improperly operated injection wells tends to be long-term since it is difficult and costly to remediate contaminated ground water. Such damage can result in loss of domestic water supplies and damage to agricultural land and crops through irrigation with saline water.

Many States have primacy under the Federal Underground Injection Control program. In order to obtain primacy, the State has to demonstrate that its programs are effective in protecting underground sources of drinking water, meet all requirements of Section 1421 (b)(1)(A) through (D) of the Safe Drinking Water Act (SDWA) and in general conform to guidance issued by EPA pursuant to Section 1425 of

SDWA. Individual State programs however, may vary in their specific requirements within the discretion allowed under this program.

The only State with significant oil and gas production that allows annular disposal of produced water is Ohio. This practice makes ground water in the vicinity of a disposal well especially vulnerable to degradation because the ground water is protected with only one string of casing.

Ground-Water Contamination from Leaching of Reserve Pit Contents

Contamination of ground water from leaching of reserve pit contents is a situation found in many areas of the U.S. Where reserve pits are overlying unconfined aquifers, the potential exists for seepage or leaching of potentially toxic reserve pit constituents into the ground water. Such leaching can result in lost domestic and agricultural water supplies and irrigation water supplies and can endanger human health. Reserve pits may contain high levels of chlorides, barium, chromium, cadmium, copper, arsenic, lead, zinc, and organic toxic constituents, which can be mobile in ground water.

Discharge of Drilling Fluids and Produced Water into Bays and Estuaries

Discharge of waste drilling mud and produced water into bays and estuaries of the Gulf of Mexico is allowed by Gulf Coast States (Texas and Louisiana). This practice has been shown to be detrimental to aquatic life in the affected bays and estuaries, with the potential for contamination of aquatic life and bird life with heavy metals and polycyclic aromatic hydrocarbons (PAHs). Of greater concern is the potential for heavy metals, taken up in such organisms as clams and oysters, to travel up the food chain, possibly endangering human health through consumption of contaminated fish and shellfish. EPA has not yet issued NPDES permits for these discharges. Permits for such discharges may be issued by the States.

Discharge of Oily Wastes to Unlined Pits

California permits the discharge of oily wastes to large, unlined sumps or pits and ephemeral streams. This practice has resulted in mortality to wildlife, including some endangered species, when exposed to the oily waste.

Unlined Produced Water Disposal Pits

The use of unlined produced water disposal pits is still allowed in some western States. Studies have illustrated how produced water constituents, including benzene and chlorides, migrate into unconsolidated soil surrounding some such disposal pits and seep into shallow ground water.

Discharge of Produced Water to Surface Streams

Under the NPDES permit system, discharge of produced water to live and ephemeral streams is allowed in some western states. Studies have shown that high-volume discharges containing low levels of organic carbon can have severe impacts on fish in receiving streams.

Illegal Disposal

Illegal disposal is a pervasive problem that may result in damage to surface water, wetlands, native aquatic life, soil, ground water, wildlife, crops, and livestock and may endanger human health. Damages may be temporary, but they can be significant at the time of the incident. Incidents of illegal disposal of oil and gas wastes are found throughout the U.S. About half the damage cases used in the Report appear to involve violations of State regulations, and a smaller number involve violations of Federal regulations. Detailed information on compliance status was not always available and, in many cases, practices that may have been legal at the time of an incident may now be illegal under revised State regulations.

Practices on the Alaska North Slope

Waste disposal practices on the North Slope of Alaska are very different from those in other areas of the U.S. Discharge of excess liquid directly onto the tundra and roads from production reserve pits is permitted under regulations of the Alaska Department of Environmental Conservation (ADEC). ADEC estimates that 100 million gallons of this liquid are pumped onto the tundra and roadways on the North Slope each year, potentially carrying with it reserve pit constituents such as chromium, barium, chlorides, and oil. Scientists who have studied the area believe this practice has the potential to lead to bioaccumulation of heavy metals and other contaminants in local wildlife, thus affecting the food chain. Results from recently released studies suggest that the possibility exists for adverse impact on Arctic wildlife because of discharge of reserve pit liquid to the tundra; however, these studies are inconclusive. New regulations recently enacted by the State of Alaska should significantly reduce the potential for tundra and wildlife impacts.

Improperly Plugged and Unplugged Abandoned Wells

Degradation of ground water caused by waste seepage through improperly plugged and unplugged abandoned wells is known to occur in various parts of the U.S. Improperly plugged and unplugged abandoned wells can also enable native brine to migrate up the wellbore and into freshwater aquifers. The damage to ground water can be extensive, resulting in lost domestic water and irrigation water supplies. When agricultural land is irrigated with this water, long-term damage to the soil is sustained. Because thousands of wells were abandoned throughout the U.S. before there were any State regulatory plugging requirements, the potential for environmental and resource damage through ground-water degradation is high. Existing State regulations concerning plugging and abandonment of oil and gas wells vary widely. Some States have adequate regulations currently in place.

RISK MODELING

EPA used quantitative modeling and a review of scientific literature to evaluate health and environmental risks associated with management of oil and gas wastes. The Agency did not attempt to estimate absolute risks in terms of the number of persons in the U.S. likely to experience health problems, or the volume of ground water likely to suffer various degrees of degradation, because of a lack of adequate sample data on regional waste characterization and inadequate empirical information on waste management system failure probabilities. Rather, the principal purpose of this effort was to investigate and compare potential risks to human health and the environment under a wide variety of current waste management conditions.

The specific objectives of the risk analysis were to (1) characterize and classify the major risk-influencing factors (e.g., waste types, waste management practices, environmental settings) associated with current operations at oil and gas facilities; (2) estimate distributions of these risk-influencing factors across the population of oil and gas facilities within various geographic zones; (3) evaluate these factors in terms of their relative effect on risks; and (4) develop, for different geographic zones of the U.S., initial quantitative estimates of the possible range of baseline health and environmental risks for the variety of conditions found. A qualitative review of the potential human health and ecological damage on Alaska's North Slope, and of the proximity of oil and gas activities to environments of special interest (i.e., endangered species habitats, wetlands, and public lands).

Methodology

Model scenarios were defined to simulate over 3,000 realistic combinations of variables representing waste streams, management practices, and environmental settings at oil and gas facilities. The focus was on the principal large-volume waste streams, including mixed drilling muds, liquids, and cuttings managed in conventional lined and unlined reserve pits, and produced water disposed by injection in Class II deep injection wells and by surface water discharge. Several other waste streams and current management practices were not included in the quantitative modeling analysis, but the ones considered represent the major waste streams and the most common management practices within the scope of this study. Also, no attempt was made to examine all release and migration pathways for the waste streams that were considered.[2] EPA evaluated scenarios under both "best-estimate" (typical) and "conservative" (i.e., higher risk, but not necessarily worst-case) assumptions. In general, the practices modeled correspond reasonably well with the baseline requirements of existing State and Federal regulatory programs. Risks from illegal disposal or other compliance problems were not specifically studied in this modeling project.

EPA selected eight constituents for modeling: arsenic, benzene, boron, sodium, chloride, cadmium, chromium, and mobile ions (including chloride, sodium, potassium, calcium, magnesium, and sulfate). The constituents were selected because they were detected frequently and in elevated concentrations in EPA's waste samples, and because they have a relatively high potential to migrate through ground water and cause adverse environmental and human health effects. The Agency modeled median and upper 90th percentile concentrations of these constituents

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[2] For instance, no attempt was made to model the migration of reinjected produced water along fractures, or through unplugged abandoned wells, after being injected underground.

based on existing sample data. Waste releases, environmental transport and fate, and risks effects via ground-water and surface water pathways were modeled for a 200-year period using a modified version of the Agency's Liner Location Risk and Cost Analysis Model (LLM). Chemical transport in rivers was modeled using equations developed for performing waste load allocations in rivers and streams. All risks were calculated for the "most exposed individual" at downgradient center line plume concentrations.

General Findings

- For the vast majority of model scenarios evaluated in this study, only very small to negligible risks would be expected to occur even under the conservative set of assumptions modeled in this analysis. Risk levels of concern would be expected at only a small percentage of oil and gas sites.
- Of the hundreds of chemical constituents detected in both reserve pits and produced water, only a few from either source appear to be of primary concern relative to health or environmental damage.
- Both for reserve pit waste and produced water, there is a wide (generally five or more orders of magnitude) variation in estimated health risks across model scenarios, depending on concentrations of toxic chemicals present, hydrogeologic parameters, waste amounts, management practices, and distances to exposure points.
- Modeling of resource damages to surface water, in terms of both ecological impact and resource degradation, generally did not show significant risk values.

Drilling Waste Disposal in Onsite Reserve Pits

- Health risk estimates for cancer (arsenic) never exceeded 1×10^{-5} (one in 100,000) for reserve pit wastes. Roughly 2 percent of the reserve pit scenarios, analyzed under a conservative set of assumptions, had cancer risks greater than 1×10^{-7}. For noncancer effects, sodium concentrations in drinking water exceeded threshold levels for hypertension in only 1 to 2 percent of the scenarios examined. The highest sodium concentration estimated at an exposure point was 32 times the threshold. The higher risk cases occurred for a large unlined reserve pit, a 60-meter exposure distance, and high subsurface permeability and infiltration.

- Differences in risk across geographic zones generally did not vary by more than one order of magnitude, but this may have reflected limitations of the study approach to estimating regional risk distributions and lack of data on regional variation in waste composition.

- Ground-water flow field type and exposure distances had the greatest influence on risk (several orders of magnitude). Recharge rate, subsurface permeability, and pit size had less impact. Depth to ground water and presence/absence of a single synthetic liner had virtually no measurable influence over the 200-year modeling period; however, risk estimated over shorter time periods, such as 50 years, would likely be lower for lined pits compared to unlined pits.

- Ground-water resource risk from leaching of reserve pit contents was very limited and was confined to the closest modeling distance (60 meters). No surface-water damage was predicted for the seepage of leachate-contaminated ground water into flowing surface water.

Produced Water Disposal in Injection Wells

- Health risk estimates for both cancer and noncancer effects were substantially below levels of possible concern in a majority of scenarios under both best-estimate and conservative modeling assumptions. Under conservative assumptions, from 22 to 35 percent of the scenarios had cancer risks (caused by the ingestion of arsenic and benzene) greater than 1×10^{-7}, and from 0.4 to 5 percent of the scenarios had cancer risks greater than 1×10^{-4}. The highest cancer risk estimate was 9×10^{-4}. Also under the conservative modeling assumptions, the sodium concentration in drinking water wells was predicted to exceed the threshold for hypertension for a maximum of 22 percent of the scenarios

- In general, the highest risk scenarios correspond to a short (60-meter) exposure distance, as relatively high injection pressure or rate, and a few specific ground-water flow fields. The highest cancer risks were associated with relatively high ground-water velocities and flow rates, while the highest noncancer risks were associated with relatively low ground-water velocities and flow rates.

- As for the reserve pit results, there was little variation of risk among zones.

- Exposure distance and ground-water velocity flow had the greatest influence on risk. Injection rate and pressure had less, but still measurable, influence.

- Risk of ground-water degradation from injection well failure was predicted to be extremely limited, but modeling did not take into account seepage through abandoned boreholes or fractures in confining layers, leaching from brine pits, or spills.

- No risk of degradation of surface water was predicted for seepage into flowing surface water of ground water contaminated by direct release from injection wells.

Discharge of Produced Water to Surface Water by Stripper Wells

- Substantial risks to human health or aquatic habitats were not predicted by the model scenarios for the normal range of stripper well discharges (under 100 barrels per day), except for the possible combination of high (90th percentile) waste concentrations and very small (generally less than 5 cubic feet per second) receiving water stream flows.

Drilling and Production Wastes Disposed on Alaska's North Slope

- Adverse effects to human health caused by drilling and production wastes on the North Slope are expected to be negligible. The greatest potential for adverse environmental impacts is caused by discharge and seepage of reserve pit fluids containing toxic substances onto the tundra. A 1983 Fish and Wildlife Service study and industry investigations indicate that these fluids can adversely effect water quality, vegetation, and tundra invertebrates in nearby surrounding areas. Strengthened State regulations concerning drilling waste disposal, however, reduce the potential for these impacts today. The Fish and Wildlife Service is in the process of studying the effects of reserve pit fluids on tundra organisms, and these studies need to be completed before more definitive conclusions can be made with respect to environmental impacts on the North Slope.

Locations of Oil and Gas Activities in Relation to Environments of Special Interest

- As would be expected with any large and widespread industry, there are numerous oil and gas sites in the vicinity of endangered and threatened species habitats and wetlands. In accordance with existing controls for the management of public lands, a small portion of the country's National Forests and Parks also have existing and potential oil and gas activities within their boundaries. More detailed study is needed to determine what effect, if any, oil and gas wastes may actually have on these environments of special interest.

COST AND ECONOMIC IMPACTS

EPA developed estimates of the compliance costs and economic impacts of implementing alternative waste management practices in the oil and gas industry by modeling three waste management scenarios: (1) a "baseline" scenario reflecting current waste management practices; (2) an "intermediate" scenario, in which somewhat stricter controls on waste disposal practices are assumed, and (3) a "Subtitle C" scenario, in which full RCRA requirements must be met. EPA estimated total annual costs for each scenario based on the cost of management using practices that conform to the requirements of the scenario.

The Baseline Scenario represents the current situation and encompasses the waste management practices now permitted under State and Federal regulations. These waste management practices are principally disposal onsite in lined and unlined pits for drilling wastes and either deepwell injection (for disposal or enhanced energy recovery) or surface disposal (e.g., discharge to water bodies, evaporation pits, or land) for produced water.

The hypothetical alternative regulatory scenarios require additional waste management controls on wastes considered hazardous. In the absence of regulatory determination or detailed regional waste categorization, EPA made two separate estimates of the costs of each scenario based on rough assumptions that either 10 percent of 70 percent of wastes would be considered hazardous for costing purposes.

In the Intermediate Scenario, hazardous drilling wastes would be disposed of in reserve pits with single synthetic liners, and hazardous produced waters would be injected into Class II wells. For the Subtitle C Scenario, all wastes considered hazardous (using the same 10 percent and 70 percent assumptions) would have to meet pollution control requirements consistent with existing Subtitle C regulations. Under this scenario, drilling wastes considered hazardous would be disposed of in Subtitle C facilities (e.g., a synthetic lined facility with leachate collection and monitoring (SCLC) impoundment, hazardous waste incinerator), and hazardous produced water would be injected into Class I injection wells.

A second Subtitle C scenario (the Subtitle C-1 Scenario) was also considered. The requirements of this scenario are exactly the same as those of the Subtitle C Scenario, except that produced water used in waterflood operations for enhanced oil recovery (EOR) is considered part of the production process. Under this scenario, produced water injected into producing zones for oil recovery would not be considered a waste and would therefore be exempt from Subtitle C (i.e., Class I disposal well) requirements. Produced water injected for disposal purposes would still be subject to Subtitle C requirements.

The Subtitle C Scenarios do not, however, impose all of the potential technological requirements of the Solid Waste Act amendments, such as the land ban and corrective action requirements, for which EPA regulatory proposals are currently under development.

To determine the incremental cost of waste disposal under the alternative waste management scenarios, the Agency calculated capital and operating costs for the array of individual waste management practices that might be used in the different scenarios. These costs were developed using literature sources, EPA engineering models, original engineering estimates, vendor quotations, and other sources. Capital costs were annualized at an 8 percent discount rate, the approximate after-tax real costs of capital in the industry, and were added to O&M costs. The results are expressed in dollar-per-barrel disposal costs and are presented in Table 3 for the lower 48 States (Lower 48).

Drilling waste disposal costs for the Lower 48 were found to range from $2.04 per barrel for onsite unlined pit disposal to $157.50 per barrel for incineration. Costs of injecting produced water were estimated to vary between $0.10 per barrel for Class II disposal and $0.92 per barrel for Class I disposal. Costs for Class I facilities are substantially higher because of increased drilling, completion, monitoring, and surface equipment costs associated with waste management facilities that accept hazardous waste.

After selecting the waste management practices appropriate under each scenario, the least-cost methods for each scenario were identified. In this way, such options as landfarming or incineration under the Subtitle C scenario were eliminated as viable waste management options.

EPA then estimated the incremental costs of these alternative waste disposal practices under each scenario for representative oil and gas projects in each of 9 major regions of the U.S. For each "model project," the after-tax rate of return and the cost of production per barrel of oil were calculated under each scenario, including the baseline. Table 4 shows the impacts of waste management costs on a weighted average model oil and gas project designed to represent the Lower 48 States, for each of the six alternative regulatory scenarios relative to the 1985 baseline.

National costs for each scenario were estimated by extrapolating the waste management costs for model projects in each region to the national level. Table 4 shows these annual national costs to range from $49 million in the Intermediate 10% case to over $12 billion for the Subtitle C 70% case.

Table 3 Cost of Waste Disposal Options in the Lower 48 States

Disposal Option	$/bbl
<u>Drilling Wastes</u>	
Surface impoundment	
- unlined (0.25 acre)	2.04
- single liner (0.25 acre)	4.46
- SCLC facility (15 acre)[a]	15.42
Landfarming	
- current	15.47
- Subtitle C	37.12
Solidification	8.00
Incineration	157.50
Volume Reduction [a]	
- single liner disposal	6.74
- SCLC disposal	11.95
<u>Produced Water</u>	
Class II injection	
- EOR	0.10
- disposal	0.14
Class I injection	
- EOR	0.78
- disposal[b]	0.92

Note: Base year for costs is 1985.

[a] Costs include equipment rental, transport and disposal of reduced volume of waste. All costs are allocated over the original volume of waste so that per-barrel costs of waste disposal are comparable to the other cost estimates in the table.

[b] Includes transportation and loading/unloading charges.

Table 4 Impact of Waste Management Cost on Oil and Gas Projects

Factor	Baseline	Intermediate 10%	Intermediate 70%	Subtitle C 10%	Subtitle C 70%	Subtitle C-1 10%	Subtitle C-1 70%
Weighted average internal rate of return (%)[a]	28.9	28.8	28.0	26.6	13.0	27.6	19.7
Weighted average incremental cost of production ($/BOE)[a]	----	$0.01	$0.11	$0.40	$2.88	$0.20	$0.55
Total annual national compliance cost ($ million)	---	$49	$420	$1,710	$12,125	$980	$6,671

Note: Base year for costs is 1985.

[a] For typical lower 48 oil and gas projects.

EPA then estimated short-term and long-term production declines that could be linked to these increased waste disposal costs using Department of Energy production forecasting models. Long-term results are shown in Table 5. In the year 2000, no detectable change was seen for the intermediate scenario when 10 percent of the wastes were considered hazardous; the decline was 1 percent, however, when 70 percent of wastes were assumed hazardous. Under the Subtitle C scenario, production decline ranged from 4 to 18 percent in the year 2000; under the Subtitle C-1 Scenario (waterflooding operations exempt from Subtitle C requirements), the projected decline ranged from 1 to 12.5 percent.

The Agency estimated the impact of the projected production declines on several economic aggregates, including oil price, balance of trade, oil imports, Federal revenues, and State revenues. The impacts vary greatly, depending on the cost of the waste management scenarios. Increases in oil imports range from a "not detectable" level to 1.1 million barrels per day because of the U.S. production decline. Increases in oil prices under the alternative scenarios range from a negligible change to $1.08 per barrel because of the declining supply and increasing cost of U.S. production. This shifting of oil supply and price results in a deterioration in the U.S. balance of trade ranging from "not detectable" to $17.5 billion per year and a cost to U.S. consumers of up to $6.4 billion per year.

CURRENT STATE AND FEDERAL REGULATORY PROGRAMS

A variety of programs exist at the State level to control the environmental impacts of waste management related to the oil and gas industry. State programs have been in effect for many years, and many have evolved significantly over the last decade. Chapter VII provides a brief overview of the requirements of these programs and presents summary statistics on the implementation of these programs, contrasting the

Table 5 Long-term Impacts on Production of Cost Increases Under Waste Management Scenarios (Percent decrease from Baseline)

Scenario	1990	2000	2010
Intermediate 10%	ND	ND	ND
Intermediate 70%	ND	1.4%	1.6%
Subtitle C 10%	ND	4.2%	6.3%
Subtitle C 70%	3.2%	18.1%	28.6%
Subtitle C-1 10%	ND	1.4%	3.2%
Subtitle C-1 70%	2.1%	12.5%	19.0%

ND = Not detected.

numbers of wells and other operations regulated by these programs with resources available to implement regulatory requirements. In an effort to characterize these State programs, EPA evaluated programs in the major oil- and gas-producing States: Alaska, Arkansas, California, Colorado, Kansas, Louisiana, Michigan, New Mexico, Ohio, Oklahoma, Texas, West Virginia, and Wyoming. Chapter VII presents the results of this analysis.

Almost all of the States evaluated have general performance standards that require reserve and produced water pits to be designed and operated to prevent ground-water or surface-water degradation. Furthermore, most of the States have liner and permit requirements for these pits. Specific pit requirements generally depend on the pit's location, size, and contents. Deadlines for pit closure range from 60 days to 1 year after drilling has ceased.

Practices for the disposal of reserve pit wastes vary widely across the nation. Most of the States studied in this report have established concentration limits for land application and surface-water discharge of reserve pit contents, while a few States prohibit these disposal methods altogether. Nearly all of the States allow annular injection of reserve pits contents but place limits on the injection pressure and require that the surface casing extend below freshwater aquifers.

Disposal of produced water is also closely regulated by many of the States studied in this report. A majority of the States do not allow produced water discharge by nonstripper wells to onshore surface waters; however, discharge to coastal waters and discharges for beneficial uses are more common. Where discharges are allowed, the States generally require permits and compliance with established concentration limits.

Most of the surveyed States have general standards that require underground injection operations to be protective of freshwater aquifers. These States generally require casings that extend below the lowest underground sources of drinking water and mechanical integrity tests that must be conducted before injection begins and every 5 years thereafter. Areas of review for identification of improperly plugged abandoned wells range from 1/4 mile to 2 1/2 miles. Finally, all of the surveyed States require plugging of oil and gas wells within 60 days to 1 year from the time at which operations ceased.

The only current information on implementation of these programs that EPA was able to gather relates to enforcement capabilities. The surveyed States have designated from 8 to 120 positions per State for enforcement of their oil and gas waste requirements.

The Federal Underground Injection Control Program

The Underground Injection Control (UIC) program was established under Part C of the Safe Drinking Water Act (SDWA) to protect USDWs from endangerment by subsurface emplacement of fluids. Part C of the SDWA requires EPA to promulgate regulations establishing minimum requirements for State programs and, in cases where States cannot or will not assume primary enforcement responsibility, to promulgate State-specific Federal regulations.

In 1980, Congress amended the SDWA by adding Section 1425. This section allows States to demonstrate the effectiveness of their in-place regulatory programs for Class II (oil- and gas-related) wells in lieu of demonstrating that they meet the minimum requirements specified in the UIC regulations. In order to be deemed effective, State Class II programs have to meet the same statutory requirements as the other classes of wells, including prohibition of unauthorized injection and protection of USDWs. All Class II programs currently approved by EPA were approved under Section 1425.

Because of the large number of Class II wells, the Federal regulations allow for authorization by rule for existing enhanced recovery wells (i.e., wells that were injecting at the time that a State program was approved or prescribed by EPA). Wells authorized by rule are subject to requirements similar to those of permitted wells but are not subject to the administrative difficulties of obtaining a permit. During the first 5 years of the program, EPA and the States have been conducting file reviews on all wells authorized by rule. File reviews are assessments of technical issues that would normally be part of a permit decision and are conducted to ensure that injection wells not subject to permitting are technically adequate and will not endanger USDWs.

In approving programs under Section 1425 the Agency has accepted variations among States. This is consistent with the requirements of the SDWA. However, the program has been in place for several years now and the Agency has acquired experience in implementation of the regulations. Based on this experience, the Agency has begun to look at the adequacy of the current requirements and may eventually require more specificity and less variation among States.

Bureau of Land Management

Exploration, development, drilling, and production of onshore oil and gas on Federal and Indian lands are regulated separately from non-Federal lands. This separation of authority is significant for western States where oil and gas activity on Federal and Indian lands is a large portion of statewide activity. The Department of Interior administers its regulatory program through the Bureau of Land Management (BLM) offices in the producing States. These offices generally have procedures in place for coordination with State agencies on regulatory requirements. The Bureau works closely with the U.S. Forest Service to define surface stipulations for using Federal forests and Federal grasslands.

Historically, BLM has controlled oil and gas activities through Notices to Lessees (NTLs) and through the issuance of permits. Leases, where drilling is to take place, must be covered by a bond. A single lease bond is currently $10,000. Statewide bonds are $25,000; nationwide bonds are $150,000. BLM considers reserve pits to be temporary, and except in special circumstances they do not have to be lined. Produced waters may be disposed of by underground injection, by disposal into lined pits, or "by other acceptable methods." When a dry hole is drilled, plugging must take place before removal of the drilling equipment. Ninety days after a well ceases production, the operator may request approval for temporary abandonment. Thereafter, reapproval for abandonment status may be required every 1 to 2 years. Plugging requirements for wells are determined by the BLM District Office.

Implementation of State and Federal Programs

Tables 6 and 7 present statistics for State and Federal implementation of regulatory programs.

CONCLUSIONS

From the analysis conducted for this report, it is possible to draw a number of general conclusions concerning the management of oil and gas wastes. The conclusions are presented below.

Available waste management practices vary in their environmental performance.

Based on its review of current and alternative waste management practices, EPA concludes that the environmental performance of existing waste management practices and technologies varies significantly. The reliability of waste management practices will depend largely on the environmental setting. However, some methods will generally be less

Table 6 State Enforcement Matrix

State	Gas Production	Oil Production	Gas wells	Oil wells	Injection wells	New wells	Agency	Personnel*
Alaska	316,000 Mmcf 1986	681,309,821 bbl 1986	104	1,191	472 Class II 425 EOR 47 Disposal	100 new onshore wells completed in 1985	Oil and Gas Conservation Commission Department of Environmental Conservation	8 enforcement positions 8 enforcement positions
Arkansas	194,483 Mmcf 1985	19,715,691 bbl 1985	2,492	9,490	1,211 Class II 239 EOR 972 Disposal	1,055 new wells completed in 1985	Arkansas Oil and Gas Commission Department of Pollution Control and Ecology	7 enforcement positions 2 enforcement positions
California	493,000 Mmcf 1985	423,900,000 bbl 1985	1,566	55,079	11,066 Class II 10,047 EOR 1,019 Disposal	3,413 new wells completed in 1985	Conservation Dept., Division of Oil and Gas Department of Fish and Game	31 enforcement positions
Kansas	466,600 Mmcf 1984	75,723,000 bbl 1984	12,680	57,633	14,902 Class II 9,366 EOR 5,536 Disposal	6,025 new wells completed in 1985	Kansas Corporation Commission	30 enforcement positions
Louisiana	5,867,000 Mmcf 1984	449,545,000 bbl 1984	14,436	25,823	4,436 Class II 1,283 EOR 3,153 Disposal	5,447 new onshore wells completed 1985	Department of Environmental Quality Office of Conservation - Injection and Mining	32 enforcement positions 36 enforcement positions
New Mexico	893,300 Mmcf 1985	78,500,000 bbl 1985	18,308	21,986	3,871 Class II 3,508 EOR 363 Disposal	1,747 new wells completed in 1985	Energy and Minerals Department, Oil Conservation Division	10 enforcement positions
Ohio	182,200 Mmcf 1985	14,987,592 bbl 1985	31,343	29,210	3,956 Class II 127 EOR 3,829 Disposal	6,297 new wells completed in 1985	Ohio Department of Natural Resources, Division of Oil and Gas	66 enforcement positions
Oklahoma	1,996,000 Mmcf 1984	153,250,000 bbl 1984	23,647	99,030	22,803 Class II 14,901 EOR 7,902 Disposal	9,176 new wells completed in 1985	Oklahoma Corporation Commission	52 enforcement positions
Pennsylvania	166,000 Mmcf 1984	4,825,000 bbl 1984	24,050	20,739	6,183 Class II 4,315 EOR 1,868 Disposal	4,627 new wells completed in 1985	Department of Environmental Resources, Bureau of Oil and Gas Management	34 enforcement positions
Texas	5,805,000 Mmcf 1985	830,000,000 bbl 1985	68,811	210,000	53,141 Class II 45,223 EOR 7,918 Disposal	25,721 new wells completed in 1985	Texas Railroad Commission	120 enforcement positions
West Virginia	142,500 Mmcf 1986	3,600,000 bbl 1986	32,500	15,895	761 Class II 687 EOR 74 Disposal	1,839 new wells completed in 1985	West Virginia Department of Energy	15 enforcement positions
Wyoming	597,896 Mmcf 1985	130,984,917 bbl 1985	2,220	12,218	5,880 Class II 5,257 EOR 623 Disposal	1,735 new wells completed in 1985	Oil and Gas Conservation Commission Department of Environmental Quality	7 enforcement positions 4.5 enforcement positions

*Only field staff are included in total enforcement positions.

Historically, BLM has controlled oil and gas activities through Notices to Lessees (NTLs) and through the issuance of permits. Leases, where drilling is to take place, must be covered by a bond. A single lease bond is currently $10,000. Statewide bonds are $25,000; nationwide bonds are $150,000. BLM considers reserve pits to be temporary, and except in special circumstances they do not have to be lined. Produced waters may be disposed of by underground injection, by disposal into lined pits, or "by other acceptable methods." When a dry hole is drilled, plugging must take place before removal of the drilling equipment. Ninety days after a well ceases production, the operator may request approval for temporary abandonment. Thereafter, reapproval for abandonment status may be required every 1 to 2 years. Plugging requirements for wells are determined by the BLM District Office.

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*Only field staff are included in total enforcement positions.

Table 7 BLM Enforcement Matrix*

Office location	Other States for which office is responsible	Producing oil and gas leases	Nonproducing oil and gas leases**	Personnel (for producing leases only)
Alaska		43	8,443	1 enforcement position
California		305	1,383	7 enforcement positions
Colorado		3,973	4,463	10 enforcement positions
Idaho		0	471	0 enforcement positions
Mississippi		116	1,519	
	Alabama	12	567	
	Arkansas	161	1,099	
	Florida	1	0	
	Kentucky	13	65	
	Louisiana	121	487	
	Virginia	1	523	
	Total	425	4,260	3 enforcement positions
Montana		958	4,721	
	North Dakota	456	1,991	
	South Dakota	98	572	
	Total	1,512	7,284	12 enforcement positions
Nevada		43	3,045	1 enforcement position
New Mexico		5,725	9,306	
	Arizona	10	386	
	Kansas	150	227	
	Oklahoma	2,767	2,754	
	Texas	61	279	
	Total	8,713	12,952	43 enforcement positions
Oregon		0	1,513	0
Utah		1,654	7,222	10 enforcement positions
Wisconsin		0	0	
	Maryland	2	11	
	Michigan	28	603	
	Missouri	1	6	
	Ohio	33	69	
	Pennsylania	6	1	
	West Virginia	46	54	
	Total	116	844	1 enforcement position
Wyoming		5,037	28,044	
	Nebraska	42	582	
	Total	5,079	28,626	27 enforcement positions
	Total	22,037	102,251	115 enforcement positions

* Oil and gas inspectors working in the field as of March 30, 1987. At that time there were eight vacancies nationwide.

** Includes leases that have never been drilled, have been drilled and abandoned, or are producing wells that have been temporarily shut down.

reliable than others because of more direct routes of potential exposure to contaminants, lower maintenance and operational requirements, inferiority of design, or other factors. Dependence on less reliable methods can in certain vulnerable locations increase the potential for environmental damage related to malfunctions and improper maintenance. Examples of technologies or practices that are less reliable in locations vulnerable to environmental damage include:

- Annular disposal of produced water (see damage case OH 38, page IV-16);
- Landspreading or roadspreading of reserve pit contents (see damage case WV 13, page IV-24);
- Use of produced water storage pits (see damage case AR 10, page IV-36); and
- Surface discharges of drilling waste and produced water to sensitive systems such as estuaries or ephemeral streams (see damage cases TX 55, page IV-49; TX 31, page IV-50; TX 29, page IV-51; WY 07, page IV-60; and CA 21, page IV-68).

Any program to improve management of oil and gas wastes in the near term will be based largely on technologies and practices in current use.

Current technologies and practices for the management of wastes from oil and gas operations are well established, and their environmental performance is generally understood. Improvements in State regulatory requirements over the past several years are tending to increase use of more desirable technologies and practices and reduce reliance on others. Examples include increased use of closed systems and underground injection and reduced reliance on produced water storage and disposal pits.

Long-term improvements in waste management need not rely, however, purely on increasing the use of better existing technology. The Agency does foresee the possibility of significant technical improvements in future technologies and practices. Examples include incineration and other thermal treatment processes for drilling fluids; conservation, recycling, reuse, and other waste minimization techniques; and wet air oxidation and other proven technologies that have not yet been applied to oil and gas operations.

Because of Alaska's unique and sensitive tundra environment, there has been special concern about the environmental performance of waste management practices on the North Slope. Although there are limited and preliminary data that indicate some environmental impacts may occur, these data and EPA's initial analysis do not indicate the need to curtail current or future oil exploration, development, and production operations on the North Slope. However, there is a need for more environmental data on the performance of existing technology to provide assurance that future operations can proceed with minimal possible adverse impacts on this sensitive and unique environment. The State of Alaska has recently enacted new regulations which will provide additional data on these practices.

EPA is concerned in particular about the environmental desirability of two waste management practices used in Alaska: discharge of reserve pit supernatant onto tundra and road application of reserve pit contents as a dust suppressant. Available data suggest that applicable discharge limits have sometimes been exceeded. This, coupled with preliminary biological data on wildlife impacts and tundra and surface water impairment, suggests the need for further examination of these two practices with respect to current and future operations. The new regulations recently enacted by the State of Alaska should significantly reduce the potential for tundra and wildlife impacts.

Increased segregation of waste may help improve management of oil and gas wastes.

The scope of the exemption, as interpreted by EPA in Chapter II of this report, excludes certain relatively low-volume but possibly high-toxicity wastes, such as unused pipe dope, motor oil, and similar materials. Because some such wastes could be hazardous and could be segregated from the large-volume wastes, it may be appropriate to require that they be segregated and that some of these low-volume wastes be managed in accordance with hazardous waste regulations. While the Agency recognizes that small amounts of these materials may necessarily become mixed with exempt wastes through normal operations, it seeks to avoid any deliberate and unnecessary use of reserve pits as a disposal mechanism. Segregation of these wastes from high-volume exempt wastes appears to be desirable and should be encouraged where practical.

Although this issue is not explicitly covered in Chapter VII, EPA is aware that some States do require segregation of certain of these low-volume wastes. EPA does not have adequate data on which to judge whether these State requirements are adequate in coverage, are enforceable, are environmentally effective, or could be extended to general operations across the country. The Agency concludes that further study of this issue is desirable.

Stripper operations constitute a special subcategory of the oil and gas industry.

Strippers cumulatively contribute approximately 14 percent of total domestic oil production. As such, they represent an economically important component of the U.S. petroleum industry. Two aspects of the stripper industry raise issues of consequence to this study.

First, generation of production wastes by strippers is more significant than their total petroleum production would indicate. Some stripper wells yield more than 100 barrels of produced water for each barrel of oil, far higher on a percentage production basis than a typical new well, which may produce little or no water for each barrel of oil.

Second, stripper operations as a rule are highly sensitive to small fluctuations in market prices and cannot easily absorb additional costs for waste management.

Because of these two factors--inherently high waste-production rates coupled with economic vulnerability--EPA concludes that stripper operations constitute a special subcategory of the oil and gas industry that should be considered independently when developing recommendations for possible improvements in the management of oil and gas wastes. In the event that additional Federal regulatory action is contemplated, such special consideration could indicate the need for separate regulatory actions specifically tailored to stripper operations.

Documented damage cases and quantitative modeling results indicate that, when managed in accordance with State and Federal requirements, exempted oil and gas wastes rarely pose significant threats to human health and the environment.

Generalized modeling of human health risks from current waste management practices suggests that risks from properly managed operations are low. The damage cases researched in the course of this project, however, indicate that exempt wastes from oil and gas exploration, development, and production can endanger human health and cause environmental damage when managed in violation of existing State requirements.

Damage Cases

In a large portion of the cases developed for this study, the types of mismanagement that lead to such damages are illegal under current State regulations although a few were legal under State programs at the time when the damage originally occurred. Evidence suggests that violations of regulations do lead to damages. It is not possible to determine from available data how frequently violations occur or whether violations would be less frequent if new Federal regulations were imposed.

Documented damages suggest that all major types of wastes and waste management practices have been associated to some degree with endangerment of human health and damage to the environment. The principal types of wastes responsible for the damage cases include general reserve pit wastes (primarily drilling fluids and drill cuttings, but also miscellaneous wastes such as pipe dope, rigwash, diesel fuel, and crude oil); fracturing fluids; production chemicals; waste crude oil; produced water; and a variety of miscellaneous wastes associated with exploration, development, or production. The principal types of damage sometimes caused by these wastes include contamination of drinking-water aquifers and foods above levels considered safe for consumption, chemical contamination of livestock, reduction of property values, damage to native vegetation, destruction of wetlands, and endangerment of wildlife and impairment of wildlife habitat.

Risk Modeling

The results of the risk modeling suggest that of the hundreds of chemical constituents detected in both reserve pits and produced fluids, only a few from either source appear to be of concern to human health and the environment via ground-water and surface water pathways. The principal constituents of potential concern, based on an analysis of their toxicological data, their frequency of occurrence, and their mobility in ground water, include arsenic, benzene, sodium, chloride, boron, cadmium, chromium, and mobile salts. All of these constituents were included in the quantitative risk modeling; however, boron, cadmium, and chromium did not produce risks or resource damages under the conditions modeled.

For these constituents of potential concern, the quantitative risk modeling indicates that risks to human health and the environment are very small to negligible when wastes are properly managed. However, although the risk modeling employed several conservative assumptions, it was based on a relatively small sample of sites and was limited in scope to the management of drilling waste in reserve pits, the underground injection of produced water, and the surface water discharge of produced water from stripper wells. Also, the risk analysis did not consider migration of produced water contaminants through fractures or unplugged or improperly plugged and abandoned wells. Nevertheless, the relatively low risks calculated by the risk modeling effort suggest that complete adherence to existing State requirements would preclude most types of damages.

Damages may occur in some instances even where wastes are managed in accordance with currently applicable State and Federal requirements.

There appear to be some instances in which endangerment of human health and damage to the environment may occur even where operations are in compliance with currently applicable State and Federal requirements.

Damage Cases

Some documented damage cases illustrate the potential for human health endangerment or environmental damage from such legal practices as discharge to ephemeral streams, surface water discharges in estuaries in the Gulf Coast region, road application of reserve pit contents and discharge to tundra in the Arctic, annular disposal of produced waters, and landspreading of reserve pit contents.

Risk Modeling

For the constituents of potential concern, the quantitative evaluation did indicate some situations (less than 5 percent of those studied) with carcinogenic risks to maximally exposed individuals higher then 1 in 10,000 ($1x10^{-4}$) and sodium levels in excess of interim limits for public drinking water supplies. Although these higher risks resulted only under conservative modeling assumptions, including high (90th percentile) concentration levels for the toxic constituents, they do indicate potential for health or environmental impairment even under the general assumption of compliance with standard waste management procedures and applicable State and Federal requirements. Quantitative risk modeling indicates that there is an extremely wide variation (six or more orders of magnitude) in health and environmental damage potential among different sites and locations, depending on waste volumes, wide differences in measured toxic constituent concentrations, management practices, local hydrogeological conditions, and distances to exposure points.

Unplugged and improperly plugged abandoned wells can pose significant environmental problems.

Documentation assembled for the damage cases and contacts with State officials indicate that ground-water damages associated with unplugged and improperly plugged abandoned wells are a significant concern. Abandoned disposal wells may leak disposed wastes back to the surface or to usable ground water. Abandoned production wells may leak native brine, potentially leading to contamination of usable subsurface strata or surface waters.

Many older wells, drilled and abandoned prior to current improved requirements on well closure, have never been properly plugged. Many States have adequate regulations currently in place; however, even under some States' current regulations, wells are abandoned every year without being properly plugged.

Occasionally companies may file for bankruptcy prior to implementing correct plugging procedures and neglect to plug wells. Even when wells are correctly plugged, they may eventually leak in some circumstances in the presence of corrosive produced waters. The potential for environmental damage occurs wherever a well can act as a conduit between usable ground-water supplies and strata containing water with high chloride levels. This may occur when the high-chloride strata are pressurized naturally or are pressurized artificially by disposal or enhanced recovery operations, thereby allowing the chloride-rich waters to migrate easily into usable ground water.

Discharges of drilling muds and produced waters to surface waters have caused locally significant environmental damage where discharges are not in compliance with State and Federal statutes and regulations or where NPDES permits have not been issued.

Damage cases indicate that surface water discharges of wastes from exploration, development, and production operations have caused damage or danger to lakes, ephemeral streams, estuaries, and sensitive environments when such discharges are not carried out properly under applicable Federal and State programs and regulations. This is particularly an issue in areas where operations have not yet received permits under the Federal NPDES program, particularly along the Gulf Coast, where permit applications have been received but permits have not yet been issued, and on the Alaskan North Slope, where no NPDES permits have been issued.

For the Nation as a whole, Regulation of all oil and gas field wastes under unmodified Subtitle C of RCRA would have a substantial impact on the U.S. economy.

The most costly hypothetical hazardous waste management program evaluated by EPA could reduce total domestic oil production by as much as 18 percent by the year 2000. Because of attendant world price increases, this would result in an annual direct cost passed on to consumers of over $6 billion per year. This scenario assumes that 70 percent of all drilling and production wastes would be subject to the current requirements of Subtitle C of RCRA. If only 10 percent of drilling wastes and produced waters were found to be hazardous, Subtitle C regulation would result in a decline of 4 percent in U.S. production and a $1.2 billion cost increase to consumers, compared with baseline costs, in the year 2000.

EPA also examined the cost of a Subtitle C scenario in which produced waters injected for the purpose of enhanced oil recovery would be exempt from Subtitle C requirements. This scenario yielded production declines ranging from about 1.4 to 12 percent and costs passed on to consumers ranging from $0.7 to $4.5 billion per year, depending on whether 10 percent or 70 percent of the wastes (excluding produced waters injected for enhanced oil recovery) were regulated as hazardous wastes.

These Subtitle C estimates do not, however, factor in all of the Hazardous and Solid Waste Act Amendments relating to Subtitle C land disposal restrictions and corrective action requirements currently under regulatory development. If these two requirements were to apply to oil and gas field wastes, the impacts of Subtitle C regulation would be substantially increased.

The Agency also evaluated compliance costs and economic impacts for an intermediate regulatory scenario in which moderately toxic drilling wastes and produced waters would be subject to special RCRA requirements less stringent than those of Subtitle C. Under this scenario, affeted drilling wastes would be managed in pits with synthetic liners, caps, and ground-water monitoring programs and regulated produced waters would continue to be injected into Class II wells (with no surface discharges allowed for produced waters exceeding prescribed constituent concentration limits). This scenario would result in a domestic production decline, and a cost passed on to consumers in the year 2000, of 1.4 percent and $400 million per year, respectively, if 70 percent of the wastes were regulated. If only 10 percent of the wastes were subject to regulation, this intermediate scenario would result in a production decline of less than 1 percent and an increased cost to consumers of under $100 million per year.

The economic impact analysis also estimates effects on U.S. foreign trade and State tax revenues. By the year 2000, based on U.S. Department of Energy models, the EPA cost results projected an increase in national petroleum imports ranging from less than 100 thousand to 1.1 million barrels per day and a corresponding increase in the U.S. balance of payments deficit ranging from less than $100 thousand to $18 billion annually, depending on differences in regulatory scenarios evaluated. Because of the decline in domestic production, aggregated State tax revenues would be depressed by an annual amount ranging from a few million to almost a billion dollars, depending on regulatory assumptions.

Regulation of all exempt wastes under full, unmodified RCRA Subtitle C appears unnecessary and impractical at this time.

There appears to be no need for the imposition of full, unmodified RCRA Subtitle C regulation of hazardous waste for all high-volume exempt oil and gas wastes. Based on knowledge of the size and diversity of the industry, such regulations could be logistically difficult to enforce and could pose a substantial financial burden on the oil and gas industry, particularly on small producers and stripper operations. Nevertheless, elements of the Subtitle C regulatory program may be appropriate in select circumstances. Reasons for the above tentative conclusion are described below.

The Agency considers imposition of full, unmodified Subtitle C regulations for all oil and gas exploration, development, and production wastes to be <u>unnecessary</u> because of factors such as the following.

- Damages and risks posed by oil and gas operations appear to be linked, in the majority of cases, to violations of existing State and Federal regulations. This suggests that implementation and enforcement of existing authorities are critical to proper management of these wastes. Significant additional environmental protection could be achieved through a program to enhance compliance with existing requirements.

- State programs exist to regulate the management of oil and gas wastes. Although improvements may be needed in some areas of design, implementation, or enforcement of these programs, EPA believes that these deficiencies are correctable.

- Existing Federal programs to control underground injection and surface water discharges provide sufficient legal authority to handle most problems posed by oil and gas wastes within their purview.

The Agency considers the imposition of full Subtitle C regulations for all oil and gas exploration, development, and production wastes to be impractical because of factors such as the following:

- EPA estimates that the economic impacts of imposition of full Subtitle C regulations (excluding the corrective action and land disposal restriction requirements), as they would apply without modification, would significantly reduce U.S. oil and gas production, possibly by as much as 18 percent.

- If reserve pits were considered to be hazardous waste management facilities, requiring permitting as Subtitle C land disposal facilities, the administrative procedures and lengthy application processes necessary to issue these permits would have a drastic impact on development and production.

- Adding oil and gas operations to the universe of hazardous waste generators would potentially add hundreds of thousands of sites to the universe of hazardous waste generators, with many thousands of units being added and subtracted annually.

- Manifesting of all drilling fluids and produced waters offsite to RCRA Subtitle C disposal facilities would pose difficult logistical and administrative problems, especially for stripper operations, because of the large number of wells now in operation.

States have adopted variable approaches to waste management.

State regulations governing proper management of Federally exempt oil and gas wastes vary to some extent to accommodate important regional differences in geological and climatic conditions, but these regional environmental variations do not fully explain significant variations in the content, specificity, and coverage of State regulations. For example, State well-plugging requirements for abandoned production wells range from a requirement to plug within 6 months of shutdown of operations to no time limit on plugging prior to abandonment.

Implementation of existing State and Federal requirements is a central issue in formulating recommendations in response to Section 8002(m).

A preliminary review of State and Federal programs indicates that most States have adequate regulations to control the management of oil and gas wastes. Generally, these State programs are improving. Alaska, for example, has just promulgated new regulations. It would be desirable, however, to enhance the implementation of, and compliance with, certain waste management requirements.

Regulations exist in most States to prohibit the use of improper waste management practices that have been shown by the damage cases to lead to environmental damages and endangerment of human health. Nevertheless, the extent to which these regulations are implemented and enforced must be one of the key factors in forming recommendations to Congress on appropriate Federal and non-Federal actions.

RECOMMENDATIONS

Following public hearings on this report, EPA will draw more specific conclusions and make final recommendations to Congress regarding whether there is a need for new Federal regulations or other actions. These recommendations will be made to Congress and the public within 6 months of the publication of this report.

Use of Subtitle D and other Federal and State authorities should be explored as a means for implementing any necessary additional controls on oil and gas wastes.

EPA has concluded that imposition of full, unmodified RCRA Subtitle C regulation of hazardous waste for all exempt oil and gas wastes may be neither desirable nor feasible. The Agency believes, however, that further review of the current and potential additional future use of other Federal and State authorities (such as Subtitle D authority under RCRA and authorities under the Clean Water Act and the Safe Drinking Water Act) is desirable. These authorities could be appropriate for improved management of both exempt and nonexempt, high-volume or low-volume oil and gas wastes.

EPA may consider undertaking cooperative efforts with States to review and improve the design, implementation, and enforcement of existing State and Federal programs to manage oil and gas wastes.

EPA has concluded that most States have adequate regulations to control most impacts associated with the management of oil and gas wastes, but it would be desirable to enhance the implementation of, and compliance with, existing waste management requirements. EPA has also concluded that variations among States in the design and implementation of regulatory programs warrant review to identify successful measures in some States that might be attractive to other States. For example, EPA may want to explore whether changes in State regulatory reporting requirements would make enforcement easier or more effective. EPA therefore recommends additional work, in cooperation with the States, to explore these issues and to develop improvements in the design, implementation, and enforcement of State programs.

During this review, EPA and the States should also explore nonregulatory approaches to support current programs. These might include development of training standards, inspector training and certification programs, or technical assistance efforts. They might also involve development of interstate commissions or other organizational approaches to address waste management issues common to operations in major geological regions (such as the Gulf Coast, Appalachia, or the Southwest). Such commissions might serve as a forum for discussion of regional waste management efforts and provide a focus for development and delivery of nonregulatory programs.

The industry should explore the potential use of waste minimization, recycling, waste treatment, innovative technologies, and materials substitution as long-term improvements in the management of oil and gas wastes.

Although in the near term it appears that no new technologies are available for making significant technical improvements in the management of exempt wastes from oil and gas operations, over the long term various innovative technologies and practices may emerge. The industry should explore the use of innovative approaches, which might include conservation and waste minimization techniques for reducing generation of drilling fluid wastes, use of incineration or other treatment technologies, and substitution of less toxic compounds wherever possible in oil and gas operations generally.

EXECUTIVE SUMMARY

MANAGEMENT OF WASTES FROM GEOTHERMAL ENERGY

Under Section 3001(b)(2)(A) of the 1980 Amendments to the Resource Conservation and Recovery Act (RCRA), Congress temporarily exempted several types of solid wastes from regulation as hazardous wastes, pending further study by the Environmental Protection Agency (EPA). Among the categories of exempt wastes were "drilling fluids, produced waters, and other wastes associated with the exploration, development, or production of crude oil or natural gas or geothermal energy." Section 8002(m) of the 1980 Amendments requires the Administrator to study these wastes and submit a final report to Congress. This report is in partial response to those requirements.

STUDY APPROACH AND STUDY FACTORS

EPA has gone to great lengths to respond to all of the study factors listed in the various paragraphs of Section 8002(m). Although each study factor has been considered in arriving at the conclusions and recommendations of this report, no single study factor has a determining influence on the results. The following study factors are considered in this report.

Defining exempt wastes: RCRA describes the exempt wastes in rather broad terms. Where the legislative history does not provide guidance, EPA has had to make assumptions and interpretations. These assumptions are set forth in Chapter III.

Specifying the sources and volumes of exempt wastes: Statistics on the volumes of exempt wastes from geothermal operations are not routinely collected nationwide, causing EPA to develop estimates of the sources and volumes of all exempt wastes; these are presented in Chapter III.

Characterizing wastes: Analysis of the principal high volume exempt wastes can help determine whether any of the wastes may be hazardous under the definitions of RCRA Subtitle C. This study is particularly concerned with toxicity, the factor most likely to contribute to potential health and environmental damage under field conditions.

Describing current disposal practices: Chapter IV summarizes EPA's review of current disposal practices for exempt wastes. The principal and common methods of managing field-generated wastes are listed, described, and discussed in general and qualitative terms.

Documenting evidence of damage to human health and the environment caused by management of geothermal wastes: No significant damage cases were found to have resulted from geothermal energy operations (see discussion in Chapter V).

Assessing potential danger to human health or the environment from the wastes: EPA has qualitatively assessed the risk associated with geothermal operations, primarily by comparing the risk-influencing factors at geothermal sites with those expected at oil and gas sites. The results of the geothermal risk assessment, presented in Chapter VI, are useful for characterizing the interactions of technological, geological, and climatic differences as they influence the potential damages.

Reviewing the adequacy of government and private measures to prevent and/or mitigate any adverse effects: Because it is impossible to compare damages in any quantitative way to the presence and effectiveness of control efforts, EPA has assessed current regulatory programs in a qualitative manner (Chapter VII). The approach has been to review the elements of existing regulatory programs so as to highlight areas of coverage and approaches to implementation.

Defining alternatives to current waste management practices: Waste management technology in the geothermal industry is fairly simple; there are no significant "innovative" or "emerging" technologies. Utilizing this background knowledge, Chapter IV addresses alternative waste management practices and the basis for future improvements in waste management.

Estimating the costs of alternative practices: Because the geothermal industry is not considering alternative waste management practices, EPA has postulated a number of alternative approaches, many of which are simply more stringent applications of current practices. These alternatives are presented in Chapter IV.

Estimating the economic impacts of alternative practices on industry: The Agency's analysis of the potential economic impacts of nationwide imposition of alternative practices is included in Chapter IV. However, the price of fossil fuels and alternative fuels has a major influence on the economics of the geothermal industry, and it is difficult to draw conclusions concerning the impacts of modified waste management practices.

DESCRIPTION OF THE GEOTHERMAL INDUSTRY

Geothermal Exploration and Development Operations

The category of geothermal energy receiving the most attention is hydrothermal systems because the technology is available to economically extract energy from these systems. The locations of hydrothermal and geopressured resource areas are shown in Figure 1.

Geothermal Well Drilling

Rapid, low-cost surface reconnaissance techniques are employed in the early stages of geothermal exploration to screen large land areas for commercial potential. Surface reconnaissance may include geophysical, geological, geochemical, and remote-sensing surveys. Wells are drilled only after potential geothermal resources are identified. Table 1 presents data on the locations of geothermal drilling activities in the United States during the years 1981 through 1985.

Drilling Mud

Methods and equipment used for geothermal well drilling are similar to those used in the petroleum industry. The drilling fluid, usually mud, is a formulation of clay and chemical additives in a water base. Drilling mud serves multiple purposes. It cools and lubricates the drill bit, flushes rock chips from the borehole, and helps prevent blowouts. Liquid-dominated geothermal systems are usually drilled with conventional drilling muds. Compressed air rather than mud is sometimes used as the circulating medium for vapor-dominated systems because water-based muds can solidify and damage the producing formation. After drilling operations are completed, the used drilling fluids constitute the major waste source.

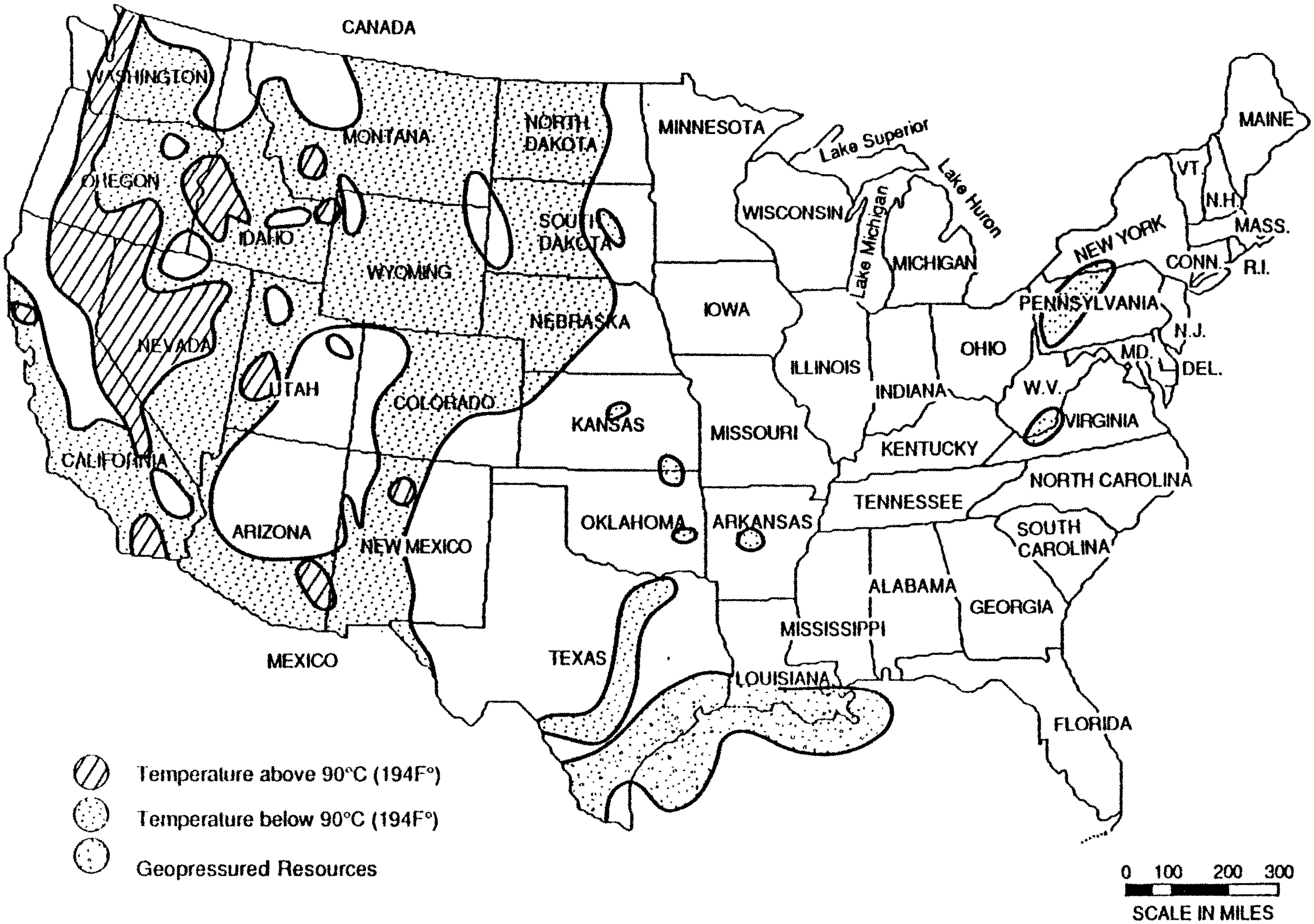

Figure 1 Known and Potential Geothermal Resources

Table 1 Summary of Geothermal Drilling Activity by State from 1981 to 1985, Including Production, Injection, and Wildcat Wells

Number of wells

	1981	1982	1983	1984	1985	Total
Alaska	-	4	-	-	-	4
California	55	67	47	88	64	321
Colorado	1	-	-	-	-	1
Hawaii	2	1	-	-	-	3
Idaho	6	-	3	-	-	9
Louisiana	1	-	-	-	-	1
Montana	-	1	1	-	-	2
New Mexico	6	3	3	-	-	12
Nevada	14	2	4	3	3	26
New York	-	1	-	-	-	1
Oregon	3	-	1	-	1	5
Texas	-	1	1	-	-	2
Utah	-	2	1	2	-	5
Washington	2	1	-	-	-	3
Total	90	83	61	93	68	395

Source: Williams 1986.

Electrical Power Production Operations

The high-temperature steam found in vapor-dominated hydrothermal systems can be used directly to generate electricity. The steam provides direct power to drive the turbine generator. Hot, saline waters found in liquid-dominated geothermal systems can be converted to steam by a flash process, or can transfer heat to a secondary working fluid with the binary process.

The flash process uses the conventional steam cycle in which geothermal brine is converted ("flashed") to steam. Hot liquid brine is partially evaporated to steam by a sudden reduction of pressure in the system. The steam is then fed directly into the turbine.

The binary process is a simple binary cycle conversion consisting of three fluid loops: a geothermal fluid loop, a hydrocarbon working fluid loop, and a cooling water loop. Geothermal fluid is withdrawn from the reservoir into the production well. The fluid then passes through two parallel brine/hydrocarbon heat exchangers. The hydrocarbon vapor expands through the turbine, driving the electric generator.

Direct Use of Geothermal Energy

Heat exchangers are used to extract geothermal energy for direct use. Downhole heat exchangers consist of one- or two-tube loops suspended in the wellbore, in direct contact with the hydrothermal fluid. Water inside the heat exchanger cycles thermally, eliminating the need for fluid disposal. Surface heat exchangers require the extraction of geothermal fluid from the reservoir. Subsequently, they need some means of disposing of the spent fluid or brine.

IDENTIFICATION AND CHARACTERIZATION OF EXEMPT WASTES

Exempt versus Nonexempt Wastes

EPA has tentatively identified those waste streams resulting from geothermal exploration, development, and production operations that are exempt under RCRA 3001(b)(2). Exempt waste streams include: waste streams produced from materials passing through the turbine in dry-steam power generation; waste streams resulting from a geothermal fluid or gas that passed through the turbine in flashed-steam and binary power plants; waste streams resulting from the geothermal products, passing through only the heat exchanger in binary operations or through the flash separator in the flash process; and most direct use waste streams.

Exempt wastes include: drilling media and cuttings; fluids from geothermal reservoirs; piping scale and flash tank solids; precipitated solids from brine effluent; settling pond wastes; hydrogen sulfide wastes; cooling tower drift; and cooling tower blowdown. Nonexempt wastes include: wastes originating in the electric generator, waste lubricants, waste hydraulic fluids, waste solvents, waste paints, and sanitary wastes.

Geothermal Exploration and Development Waste Volumes

Well-drilling activities generate the bulk of the wastes from geothermal exploration and development operations. In general, exempt wastes from well drilling are drilling muds and drill cuttings, which are generated in large quantities during drilling operations. Documentation of the volumes of drilling muds and cuttings generated is very sparse. Because of this scarcity of data, a methodology was developed to estimate waste volumes of drilling muds and cuttings. Cuttings volumes for specific geothermal areas were calculated from the number of wells in the area and the average depths and diameters of the wells. An associated mud volume was computed from this calculation, based upon a cuttings/drilling mud conversion or correlation factor derived from site-specific drilling information. Table 2 summarizes the estimated cuttings and drilling mud waste volumes for the years 1981 through 1985.

Geothermal Power Plant Waste Volumes

Wastes generated from geothermal power production include spent brine, flash tank scale, separated solids from pre-injection treatment of spent brines, and hydrogen sulfide abatement wastes.

Liquid Waste Estimation

Very little information describing and quantifying these wastes was found in the literature review. Brine flows for both binary and flash power production processes were calculated from equations derived from a plot of hydrothermal fluid requirements versus fluid temperature. An annual operating factor of 90 to 95 percent was applied to the daily flow throughput to obtain brine volume for individual facilities (Table 3).

Solid Waste Estimation

No attempt was made to quantify the solid waste generated from power generation facilities because data are limited. Based on the review of the literature, several facilities in California are the sole source of any significant generation of solids.

Waste Generation from Direct Users

The primary waste generated from using geothermal energy as a direct source of heat is the spent geothermal fluid remaining after usable heat

Table 2 Estimated Waste Volumes for Drilling Activities Associated with Exploration and Development of Geothermal Resources

	Total mud and cuttings volume (thousands of barrels)				
State	1981	1982	1983	1984	1985
California	97.3	103.8	51.2	198.9	109.3
The Geysers	49.8	59.5	46.2	52.2	53.4
Imp. Valley	47.2	43.3	3.9	145.6	55.1
Other	0.3	1.0	1.1	1.1	0.8
Nevada	7.2	1.0	2.0	1.0	1.5
Idaho	0.6	NA	0.3	NA	NA
Montana	NA	0.1	0.1	NA	NA
New Mexico	2.8	1.4	NA	NA	NA
Oregon	0.3	0.1	0.1	NA	0.1
Washington	0.2	0.1	NA	NA	NA
Utah	NA	2.3	1.2	2.3	NA
Hawaii	5.1	2.5	NA	NA	NA
Total U.S.	113.5	111.3	54.9	202.2	110.9

NA - No Activity.

Source: See Appendix A.

Table 3 Estimated Liquid Waste Volumes from Both Binary and Flash Process Plants*

State	Number of sites	Billions of gallons per year
California	9	43.70
Nevada	5	9.26
New Mexico	1	.24
Hawaii	1	.06
Utah	2	3.17
Total	18	56.43

*Plants that are currently operational; does not include the estimated volume for three facilities under construction.

Source: See Appendix A.

has been extracted. The quality of the spent geothermal fluids is often high enough that these fluids can be discharged into nearby surface water bodies and even into community water supplies. Waste generated by direct applications was calculated similarly to waste quantities from power generation facilities. Industrial direct users were estimated to be operating about 80 percent of the year. All other types of direct users were estimated to operate 25 percent of the year or less. Table 4 shows estimated liquid waste volumes for 104 direct users in 12 States.

Waste Characterization

Analytical data found in the literature for both liquid and solid wastes were summarized and compared to current RCRA characteristic thresholds for those wastes.

Liquid Wastes

Liquid wastes of selected waste streams from geothermal plants, power generation, and direct use of geothermal energy were analyzed for temperature, pH, and chemical constituents. For facilities using the binary and flash processes, the concentration levels of various constituents were measured for the incoming brine, with the exception of temperature, which was the measured discharge value. Geothermal liquids from several test wells were also tested for major and trace constituents. Contaminants from the RCRA extraction procedure (EP) toxicity test for determining whether a waste is hazardous were included in the chemical analyses.

Solid Wastes

Preliminary analyses have been performed on solid wastes from several geothermal operations. Concentrations for major constituents were

Table 4 Estimated Liquid Waste Volumes Resulting from Direct Use of Geothermal Energy

State	Number of sites	Billions of gallons per year
California	18	1.41
Oregon	14	.60
Idaho	27	3.02
Montana	7	.09
South Dakota	4	.78
Utah	4	.31
Wyoming	3	.15
New Mexico	8	.50
Nevada	10	.61
Colorado	6	.50
New York	1	.01
Washington	2	.10
Totals	104	8.09

Source: See Appendix A.

analyzed for total constituent content, neutral and acid extractable values, pH, percent moisture, and radium concentrations. Trace constituents were also analyzed, including the eight EP toxicity contaminants.

Analysis of Waste Constituents

Analyses of the constituents from several exempt geothermal waste streams indicate that some of the wastes failed the EP characteristics test and could be considered hazardous wastes. The hazardous characteristics present include corrosivity and EP toxicity for certain metals. Sufficient data are not presently available to accurately characterize or precisely quantify the volumes of wastes generated from power production and drilling activities related to geothermal operations. Data are also insufficient to project future total volumes of wastes expected to be generated by the geothermal industry. To predict future waste disposal requirements and associated potential problems, information must be obtained concerning volume, characteristics, and chemical constituents of mud pit solids, drill cuttings, and injected fluids.

WASTE MANAGEMENT PRACTICES

Current Management Practices for Waste Products from Drilling Operations

The primary wastes from both geothermal and petroleum industry drilling activities are drilling muds and drill cuttings. Methods currently practiced by the geothermal industry for handling and disposing of these materials have largely been developed by the petroleum industry. In most cases, wastes from geothermal drilling activities are discharged into a reserve pit. Wastes can then be collected for offsite disposal or the reserve pit can be dewatered and backfilled. Any remaining liquids are allowed to evaporate during dewatering and before backfilling. Associated with this method, however, is the potential for future contamination that could result from leachate waste sludge which remains buried at the site. A vacuum truck is used to remove the waste from the reserve pit and transport it to an offsite pit.

Landfarming is another reserve pit disposal option. This practice involves the mechanical distribution and mixing of reserve pit waste into soils in the vicinity of the drill site.

Stringent permitting requirements and State prohibitions limit the downhole disposal of drilling wastes. This method is not particularly effective for geothermal drilling operations and might actually have an adverse effect on the development of the geothermal well.

Solidification of reserve pit wastes typically involves mixing fly ash or kiln dust with the wastes to decrease the overall moisture content and to stabilize the mixture. This method may be economically more attractive than backfilling the reserve pit wastes; however, there may be associated problems with leaching of constituents into ground water.

Practices for Power Generation Facilities

The literature describes seven types of liquid waste disposal for power generation facilities, four of which are being practiced or will be implemented at facilities that are currently operational or under construction.

Direct release of liquid wastes to surface waters is the simplest disposal method. This method consists of discharging spent fluid to local drainage systems. Current environmental constraints, however, have made this method almost nonexistent for facilities in the United States. Treatment and release to surface waters can be a relatively simple process, but it can become costly, depending on the type of treatment required. No power facilities were identified as using this type of brine treatment. In closed-cycle ponding, spent brine is cycled through one or more ponds to induce evaporation. While the practice is not in use at present, it does have potential application in arid climates.

The injection of liquid wastes into the producing horizon is necessary to maintain reservoir fluid volumes. It is the most frequently used liquid waste management practice for U.S. power generation facilities. Injection into a nonproducing zone is used where the production zone can be easily contaminated by the cooler injection fluid. This method involves drilling the injection well to a zone that is separated from the production well. The method has been tested successfully at one Utah facility. The treatment and injection method is used where brine quality may cause plugging or when a usable byproduct could be recovered from the brine. Several examples of pretreatment to prevent plugging are currently operational in the United States.

Consumptive secondary use is effective when the spent fluid can be reused as part of the power generation process or by some adjacent facility (i.e., used as makeup water to the cooling towers). Several facilities currently practice this disposal method.

Solid wastes can be managed by onsite or offsite disposal, or the solids may accumulate in brine holding ponds onsite; then the material is excavated and hauled to a landfill.

Practices for Direct Users

Only four of the liquid waste disposal methods for power generation facilities are utilized by direct users. These include: direct release to surface waters, injection of liquid wastes into the producing horizon, injection into a nonproducing zone, and consumptive secondary use.

Direct release to surface waters is the most common method of liquid waste disposal for direct users. The practice is safe and effective because of the low flow rates and the high quality of the geothermal fluid that is discharged. Injection of liquid wastes into the producing horizon is the second most common method of liquid disposal, whereas injection into a nonproducing zone is currently used at only one location. Consumptive secondary use is practiced at two locations where liquid wastes are discharged into holding basins and collected for irrigation.

Alternative Waste Management Practices

Although several refinements to existing processes have been mentioned in the literature, very little information is available on new disposal methods. Alternative, more stringent disposal methods might be developed if damage cases resulting from geothermal wastes begin to occur.

If alternative methods are developed, liquid wastes that are currently injected into Class V wells most likely would be injected into Class II wells. Solid nonhazardous wastes would be disposed of offsite in Class II or III waste management units, while facilities could landfarm, dispose of wastes offsite in Class I facilities, or solidify solid-designated wastes. Solid hazardous wastes could be disposed of through solidification. The Aquatech proprietary evaporation process is a new liquid waste disposal method. Small direct users could use this method if their flow rates are less than 16,800 gallons per day.

Economic Analysis of Waste Management Practices

The geothermal industry is not pursuing alternatives to the current practices of disposing of geothermal energy wastes. Nevertheless, some available cost data are presented and the gross cost impacts of the more likely alternative practices have been calculated. This analysis is limited to residual drilling wastes, however, because they comprise most of the exempt wastes. Although alternative treatment and disposal methods are not being pursued by the geothermal industry at present, alternative practices may be required in the future. The costs of several waste management practices for drilling wastes are presented in Table 5.

Under current energy market conditions, future development will be restricted to expanding existing economic fields. When existing older plants reach the end of their economic life and are phased out, geothermal electrical power generation capacity may actually decrease. Poor economics and higher economic risk may preclude the construction of new facilities in the current energy market. The future profitability of the geothermal industry is tied directly to the price of energy available from other sources, primarily hydrocarbon fuels. When the price of these fuels rises again, the level of new geothermal field development will increase as well.

DAMAGES CAUSED BY GEOTHERMAL OPERATIONS

No significant cases of damages were found associated with the exploration, development, or production of geothermal energy. The lack of significant damage cases indicates that existing regulatory programs are probably effective.

Table 5 Total Annual Cost of Alternative Waste Management Practices[a]
(In 1985 dollars, based on 1985 waste volumes)

	Location		
Waste management alternative	The Geysers	Imperial Valley	Other
One-quarter acre, unlined surface impoundment	$ 108,936	$ 112,404	$ 4,896
One-quarter acre, single-lined, surface impoundment	238,164	245,746	10,704
Fifteen acre, single-lined, surface impoundment	55,536	57,304	2,496
Fifteen acre, triple-lined, surface impoundment	363,120	374,680	16,320
Thirty-five acre, pre-interim status landfarm	853,866	881,049	38,376
Thirty-five acre, Part 264 compliance landfarm	1,942,692	2,004,538	87,312
Solidification[b,c]	320,400	330,600	14,400

[a]Transportation cost excluded from all alternatives.
[b]Final disposal cost not included.
[c]Based on an average cost of $6 per barrel.

RISK ASSOCIATED WITH GEOTHERMAL OPERATIONS

For the geothermal energy industry, a qualitative analysis rather than a quantitative risk modeling analysis was conducted. EPA has determined that the quantity and quality of data available do not warrant quantitative risk modeling at this time. The risk assessment report on the oil and gas industry prepared by EPA is based primarily on quantitative risk modeling. Because the waste types and waste management practices for the two industries are similar, EPA used the initial risk results for oil and gas activities as a reference for a qualitative assessment of the potential risks posed by the geothermal energy model facilities.

Characterization of Major Risk-Influencing Factors

The two large-volume waste types associated with geothermal drilling (i.e., exploration and development) and production are drilling pit wastes (drilling mud and well cuttings) and production waste fluids. Produced fluid wastes can be divided into two categories--power plant fluids and direct user fluids.

Waste Streams

Power plant wastes are categorized according to the processes used to convert geothermal energy into electric power: the conventional steam cycle, the binary process, and the flash process. In the conventional steam cycle process, the waste is generated downstream of the turbine when exhaust steam is condensed in direct contact condensers or in surface condensers located beneath the turbine.

In the binary process, hot geothermal fluids heat and vaporize a hydrocarbon heating medium. The hydrocarbon vapor then drives the power turbine. All fluid wastes produced are generated upstream of the turbine. Table 6 includes two model waste streams developed from produced fluid analyses from five binary process power plants. The first model waste stream contains the median concentration of each constituent in the five analyses and may be considered a "best estimate." The second stream may be considered a conservative waste stream because it is composed of the highest concentration of each constituent in the produced fluid analyses. Two constituents, benzene and arsenic, were not found in the geothermal fluid analyses, unlike the oil and gas model waste streams. Trace analyses of samples from several test wells, however, suggest that arsenic is likely to be present in these waste streams as a trace constituent.

In the flash process, steam is produced by subjecting fluids produced from a liquid-dominated reservoir to a sudden pressure reduction. The loss of some water to steam concentrates the dissolved solids in the remaining geothermal fluid. This remaining fluid is generated upstream of the power turbine and is an exempt waste. A waste stream analysis of the exempt fluid waste produced from one flash process power plant was used to analyze the risk associated with fluids produced from flash process power plants in general (Table 6). Although arsenic levels are not reported in the major constituent analysis, test well analyses indicate that arsenic is likely to be present in these wastes. The levels of arsenic may be higher in the waste stream than are shown in the test well analyses because flashing concentrates the dissolved solids in the fluid.

Direct User Fluid Wastes

Based on chemical analysis data, the produced fluid wastes from direct user applications generally contain lower levels of chemical constituents than do fluids from power plants. Table 6 shows the range

Table 6 Model Production Fluid Waste Stream Analyses

	Model oil and gas waste stream concentrations (mg/L)		Model geothermal power plant waste stream concentrations (mg/L)			Geothermal direct user operation waste stream concentrations (mg/L)[c]	
Waste stream constituent	Median	Upper 90th %	Binary process best estimate[a]	Binary process conservative[a]	Flash process[b]	Range	Median
Arsenic	0.0	1.7	NA[d]	NA	NA	NA	NA
Benzene	0.5	2.9	NA	NA	NA	NA	NA
Boron	9.9	120.0	5.0	49	210	0.0 - 277	0.6
Chloride	7,300	35,000	865	9,000	93,650	0.0 - 11,000	58
Sodium	9,400	67,000	653	4,720	36,340	4.0 - 7,000	195
Mobile Salts[e]	23,000	110,000	1,694	14,842	153,198	8.6 - 20,568	474

[a]Based on produced fluid analyses of samples from five binary process power plants.
[b]Based on the produced fluid sample analysis from a flash process power plant.
[c]Based on produced fluid sample analyses from 43 direct user operations in 13 States identified in the literature.
[d]NA = Not available. In the case of arsenic, however, trace analyses of samples from several test wells suggest that arsenic is present in produced geothermal fluids.
[e]Mobile Salts = Na + Cl + K + Mg + Ca + SO_4.

of concentrations and the median concentration of each major constituent found in analyses of produced fluids from 43 direct user operations in 13 States.

Drilling Pit Solid Wastes

Two model waste streams were characterized from analyses of drilling pit solid wastes from eight sites (Table 7). The first waste stream is a "best estimate" composed of the median concentration of each constituent; the second is a "conservative" model waste stream characterized by the maximum concentration of each constituent. Although arsenic concentrations are not given, extract analyses show the presence of arsenic in some geothermal drilling pit wastes.

Waste Management Practices

Waste management practices for the geothermal energy industry were characterized based on data compiled from a review of the literature and, in a few cases, data collected during site visits. When data were not available on the basic design, operating parameters, and/or unit size/waste throughput, EPA characterized waste management practices with the values used for similar practices in the oil and gas risk analysis.

Production Fluid Wastes--Power Plants

Methods currently used to dispose of produced fluids from geothermal energy power plants include direct release to surface waters, injection (or treatment and injection) into underground strata, and consumptive secondary use. Of the waste management practices in current use, injection is the most frequently employed. Injection is the primary geothermal fluid disposal method for 21 of the 23 operating power plants that generate exempt wastes. Because the overwhelming majority of power

Table 7 Drilling Pit Solid Wastes: Bulk Composition

	Model oil and gas waste stream concentrations Pit solids - Direct (mg/kg)		Geothermal energy drilling sites (mg/kg)[a]									
Waste stream constituent	Median	Upper 90th %	A	B	C	D	E	F	G	H	Best estimate	Conservative
Arsenic	0	0.01	NA[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium	2	5.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sodium	8,500	59,000	7,700	4,000	20,000	12,500	2,400	900	1,100	1,900	3,200	20,000
Chloride	17,000	88,000	9,800	1,000	53,000	20,000	1,000	100	100	400	1,000	53,000
Fluoride	[c]	[c]	240	340	290	420	230	180	240	150	235	420
Chromium VI	22	190	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mobile Salts[d]	100,000	250,000	32,600	36,700	111,600	77,000	27,800	33,200	26,300	31,600	32,900	111,600

[a]The constituent concentrations in waste streams A through H are based on analyses of drilling pit wastes at eight geothermal energy industry drilling sites These drilling sites are associated with geothermal energy power plants. The best-estimate waste stream comprises the median concentration of each constituent in waste streams A through H. The conservative waste stream comprises the highest concentration of each constituent in waste streams A through H.

[b]NA = Not available.

[c]Fluoride was not a model constituent in the oil and gas study.

[d]Mobile Salts = Na + Cl + K + Mg + Ca + SO_4.

generation facilities dispose of produced fluid wastes by underground injection, EPA analyzed the risks associated with this waste management practice at power plants. The two key variables that influence the risk posed by injection of wastes are injection rate per well and injection pressure.

Based on the limited data on injection rates and numbers of wells available for a few sites, EPA estimated the injection rate per well for a flash process facility and for a binary power plant. The estimated injection rates per well for binary process plants and flash process plants are 950 Mgal/yr and 610 Mgal/yr, respectively. Because no data were available on geothermal field injection pressures, EPA evaluated the potential risk posed by the reinjection of geothermal wastes for injection pressures ranging from 400 to 2,000 psi (taken from the modeled oil and gas scenarios).

Production Fluid Wastes--Direct Users

The primary disposal method for produced fluid wastes from direct users is direct discharge to surface water. The vast majority of these operations are covered under NPDES permits. Because these releases are regulated and permitted under a Federal program other than RCRA, they are not within the scope of this study. Injection is the second most frequently employed geothermal fluid waste management practice for direct users. For direct users injecting geothermal fluid wastes, the annual waste generation rate per facility ranges from 9 to 500 Mgal/yr; the median rate is 55 Mgal/yr. These fluid rates could be handled by one injection well at each site. Assuming one injection well at each site, the median rate was used to evaluate the potential risk from direct user injection. The injection pressure was assumed to vary between 400 and 2,000 psi, which is the same pressure used in the analysis of power plants.

Drilling Pit Solid Wastes

Data on the waste management practices for geothermal drilling wastes were not available to determine the one most frequently employed. Consequently, EPA elected to characterize model geothermal sites by the same disposal methods that are used to characterize the oil and gas sites. These methods are onsite burial of dewatered drilling pit solid wastes in unlined and synthetically lined pits. The two risk-influencing variables modeled for onsite reserve pits in the oil and gas analysis were pit size and the presence or absence of synthetic liners. The average volume of geothermal drilling waste per pit is 3,200 barrels, which falls between the medium-sized (5,900 barrels) and small-sized (1,650 barrels) oil and gas drilling pits modeled. Risks were evaluated for both the unlined and synthetic-lined pits modeled.

Environmental Settings

Based on previous risk analyses, EPA identified the following environmental variables as having significant potential for influencing risks resulting from waste releases to ground and surface water: hydrogeologic variables, surface water variables, and exposure point characteristics. The distributions of values for each variable within 20 geothermal field sites were analyzed to develop a best-estimate (most common) environmental setting and a conservative (but not worst-case) setting. Table 8 lists the values of the environmental variables for each setting.

Qualitative Risk Assessment Results

Underground Injection of Produced Fluids

There are at least four release pathways whereby underground injection of produced fluids can lead to contamination of near-surface

Table 8 Environmental Settings at Geothermal Energy Facilities

Environmental variable	Values for variables	
	Best estimate	Conservative
Ground-Water Velocity	100 m/yr	1 m/yr 100 m/yr 1,000 m/yr[a]
Aquifer Configuration	Unconfined	Unconfined
Recharge Rate	1 in/yr	20 in/yr
Depth to Ground Water	20 m	5 m
Unsaturated Zone Permeability	10^{-2} cm/sec	10^{-2} cm/sec
Distance to Nearest Downgradient Drinking Water Well	> 2,000 m	200 m
Distance to Surface Water	> 2,000 m	60 m
Average Surface Water Flow Rate	0	40 cfs
Distance to Nearest Downstream Surface Water Intake	10 km[b]	1 km[b]

[a]A range of velocities was examined to analyze the range of risks caused by different chemical constituents in the conservative setting. For some constituents, a slow velocity is conservative (i.e., yields higher risk results), while for other constituents, a fast velocity is conservative.

[b]Because of lack of data, these assumed values were chosen to reflect a reasonable range of distances.

aquifers: (1) release through failure of the well casing; (2) release through failure of grout seals separating injection zones from near-surface aquifers; (3) upward contaminant migration through abandoned wells; and (4) upward contaminant migration through fractures or faults. Because of technical constraints and data limitations, however, only releases through failure of the well casing and releases through failure of grout seals separating injection zones from near-surface aquifers are considered here.

Power Plants

At the majority of existing geothermal power plants (roughly 70 percent), an injection well failure that releases produced fluids into near-surface aquifers would not be expected to pose significant human health risks because few drinking water wells are within 2,000 meters in a downgradient direction. The potential for exposure is much greater, however, at the few facilities estimated to have private drinking water wells within 2,000 meters downgradient.

Injection well failures associated with geothermal power plants could result in cancer risks ranging from zero to approximately 10^{-4}, if the geothermal produced fluids have the same arsenic concentrations estimated for oil and gas industry produced fluids. Injection well failures at a few power plants could also result in sodium concentrations in downgradient drinking water wells that are high enough to cause hypertension in sensitive individuals. Produced fluids from the flash process have significantly higher sodium concentrations than do fluids from the binary process, and therefore pose a greater risk for hypertension.

The relatively high concentrations of chloride, boron, and mobile salts in geothermal produced fluids from power plants, and the relatively high rate at which these fluids are injected, create the potential for injection well failures to damage ground-water resources. It is presently uncertain, however, how far these contaminants could migrate in ground water before dilution would cause the concentration to drop below levels of concern. Results from the oil and gas modeling study suggest that releases of produced fluids from the binary process could result in harmful concentrations up to 60 meters away, while releases of produced fluids from the flash process could result in harmful concentrations at an even greater distance.

Direct Users

When downhole heat exchangers are used by direct users, the need for fluid disposal is eliminated and the potential for adverse health or environmental impacts is very small. At direct-use facilities using surface heat exchange systems, the potential for geothermal fluids to cause adverse health and environmental effects is considered small because they are unlikely to come in contact with people or biota. Available data on the composition of produced fluid disposed of by direct users are presently insufficient, however, to estimate quantitatively the potential for adverse effects. In general, if an injection well failure occurred during direct user operations, the magnitude of resulting impacts is expected to be smaller than that associated with similar releases from power plants. The principal health threats probably would be the potential for cancer and hypertension caused by ingestion of ground water contaminated with arsenic and sodium, respectively. Concentrations of chloride, boron, and mobile salts could also render ground water in the vicinity of releases unsuitable for certain uses.

Onsite Reserve Pits--Solid Drilling Wastes

Because most geothermal power plants do not have private drinking water wells within 2,000 meters, seepage of reserve pit contaminants into surface aquifers at most plant sites would not be expected to pose a significant health risk. Even at those plants where drinking water wells may be within range to be affected, seepage of reserve pit contaminants is expected to cause very low risks of cancer. Results from the oil and gas modeling study indicate that cancer risk caused by the leachate should be zero in most cases, and probably never more than 10^{-7}. Reserve pit seepage appears to present a greater potential for noncarcinogenic risk. For a few of the oil and gas scenarios that reasonably represent conditions that exist at geothermal power plants, sodium concentrations in downgradient drinking water wells were predicted to exceed a threshold that could cause hypertension in sensitive individuals. Reserve pits at geothermal power plants should not cause significant ground-water resource damage. Because concentrations of the main constituents of concern appear to be lower in geothermal reserve pits than in oil and gas reserve pits, ground-water contamination resulting from geothermal reserve pits would probably be even less. (Concentrations of drilling waste contaminants in ground water were predicted to be below levels of concern 60 meters away from most oil and gas reserve pits.)

Conclusions

Because of the lack of reliable data on the composition of geothermal energy waste streams, strong conclusions about the risk associated with these wastes cannot be drawn at this time. Conclusions have been based on comparisons with the oil and gas risk analysis and on the waste management practices and environmental settings expected at geothermal sites.

- Of the 20 or so U.S. geothermal power plants, it was estimated that 13 currently have no drinking water wells within 2,000 meters downgradient. As a result, even if produced fluid or drilling waste contaminants were released to near-surface aquifers at the majority of these power plants, the potential for adverse health effects is small, because it is unlikely that an individual would ingest ground water contaminated by such a release.

- If geothermal produced fluids have an arsenic concentration similar to that estimated for oil and gas produced fluids, releases from failed injection wells at geothermal power plants could cause cancer risk levels greater than 10^{-5} in a few cases. (It is emphasized, however, that arsenic concentrations in geothermal produced fluids are unknown.) Risk levels of concern would be expected primarily at sites having nearby drinking water wells (e.g., within approximately 200 meters) and relatively high ground-water velocities (e.g., 100 to 1,000 meters/year).

- If an injection well failure released geothermal produced fluids into a near-surface aquifer, resulting sodium concentrations in downgradient drinking water wells could exceed levels that may cause hypertension in sensitive individuals. This noncancer risk is greatest for releases of produced fluids from flash process power plants, which appear to have much higher sodium concentrations than geothermal produced fluids from plants using the binary process. Greater noncancer risks would be expected at sites having nearby drinking water wells (e.g., within approximately 200 meters) and relatively slow ground-water velocities (e.g., 1 to 10 meters/year).

- Adverse health and environmental impacts from injection well failures (if they occur) at direct user sites could be similar in nature to those expected from injection well failures at power plants; this is highly unlikely, however, as water quality is generally better in direct use operations. Because direct users dispose of smaller volumes of waste by underground injection, injection well failures at direct user sites would be expected to release smaller quantities of contaminants than do releases from power plants. Although releases from direct users would probably occur closer to drinking water wells, drinking water wells in the vicinity of direct use operations often tap the same aquifer. Therefore, waters having similar qualities are used for domestic use and direct use applications.

- If injection well failure occurred at geothermal power plants or direct user sites, released produced fluids could sufficiently contaminate surrounding ground water to render it unsuitable for certain uses. In particular, chloride concentrations could result in objectionable taste (making it unsuitable for drinking), and resulting concentrations of mobile salts could be harmful to sensitive crops (making it unsuitable for irrigation). In most cases, concentrations of concern are not expected to be exceeded 60 meters downgradient, although there could be instances in which potentially harmful concentrations exist farther away.

- Based on the limited information available on the composition of wastes from geothermal well drilling, seepage of drilling waste contaminants from geothermal reserve pits would be expected to cause only minor (if any) cancer risk, noncancer risk, and ground-water resource damage.

CURRENT REGULATORY PROGRAMS

Federal Regulations

Regulatory Agencies

The Geothermal Steam Act of 1970, as amended (U.S.C. 1001-1025), authorizes the U.S. Department of the Interior to issue leases for the development and use of geothermal resources. The implementing regulations (43 CFR, Part 3200) are now administered almost exclusively by the Bureau of Land Management (BLM). The BLM may issue leases on Federal lands under its jurisdiction and on lands administered by the U.S. Forest Service, with the consent of the latter. In addition, the BLM evaluates and classifies geothermal resources on Federal land and supervises all pre- and post-leasing operations, including exploration, development, and production.

Geothermal Resources Operational Orders

Geothermal Resources Operational (GRO) Orders are formal, enforceable orders, originally issued by the U.S. Geological Survey, to supplement the general regulations found in 43 CFR, Part 3200. They detail the procedures that lessees must follow in a given area or region. Geothermal Resources Order No. 1 outlines the BLM requirements for conducting exploratory operations on Federal lands. Standards for drilling, completion, and spacing of wells are set forth in GRO Order No. 2. Geothermal Resources Order No. 3 regulates plugging and abandonment procedures. GRO Order No. 4 requires the lessee to comply with all applicable Federal and State standards with respect to the control of air, land, water, and noise pollution, including the control of erosion and the disposal of liquid, solid, and gaseous wastes. The lessee is required by GRO Order No. 4 to provide and use pits and sumps to retain all wastes generated during drilling, production, and other operations, unless other specifications are made by the Authorized Officer.

Underground Injection Control Program

The Safe Drinking Water Act of 1974, as amended, requires EPA to establish a national program to ensure that underground injection of wastes will not endanger underground sources of drinking water. EPA implemented this mandate by enacting the Underground Injection Control (UIC) Program for Federal, Indian, State, and private lands. EPA has primary enforcement authority and responsibility for the program for all States, except for those that have approved UIC programs. Geothermal injection wells are considered Class V under the UIC classification system; this class includes electric power industry injection wells, direct heat user injection wells, heat pump and air conditioning return flow wells, and ground-water aquaculture return flow wells. The BLM defers to EPA or the primacy State the task of determining whether underground freshwater sources are safe from the effects of these operations.

Summary of State Requirements

Regulatory Requirements

State rules and regulations obtained from 35 States have been examined for their applicability to geothermal energy exploration and development. Thirteen State legislatures have passed laws mandating the implementation of geothermal rules and regulations. Typically, these regulations are very comprehensive and, in general, address permitting, solid and liquid waste disposal, well design, well plugging, and restoration of surface. The requirements of the 13 States that have specific geothermal regulations are summarized in Chapter VII. The geothermal regulations of California are presented in greater detail because they are considered "model regulations" for geothermal operations and because of the extensive use of geothermal resources in California.

CONCLUSIONS

- There is no record of significant damages, danger, or risks to human health and the environment resulting from the exploration, development, and production of geothermal energy.
- Geothermal operations are regional by nature, with the bulk of activities confined to California.
- Existing regulations appear to be effective in protecting human health and the environment.
- There is no indication that additional Federal regulations are necessary.

RECOMMENDATIONS

EPA recommends that Subtitle C regulations not be applied to geothermal wastes. Further, at present, the Agency sees no need for additional regulations under Subtitle D.