Risk-Based Decision Making (RBDM) and Surface Waste Management

Ben Thomas, Ph.D.
Exponent – Health Sciences Group
Houston, Texas

Background

My name is Ben Thomas, and I am here to discuss the value of Risk-Based Decision Making (RBDM) to the regulation of landfarms by the New Mexico Oil Conservation Division (OCD).

I am an expert in the areas of pathology, toxicology, and risk assessment. In addition to my consulting practice at Environ, I also hold an academic appointment at the rank of Professor on the adjunct faculty of the University of Texas Health Science Center at Houston.

During my career, I have completed more than 50 risk assessments for industry, as well as for regulatory agencies. I served as consultant to LDNR concerning amendment of their Rule 29-B dealing with the treatment of Exploration &Production (E&P) wastes in commercial landfarms (Thomas 2000).

The Surface Waste Management Rule

The SWM Rule describes the regulatory processes involved in the permitting, operation, and closure of ...

> Landfarms – for treatment of hydrocarbon-contaminated soils; and
>
> Landfills – for permanent burial of "untreatable" exempt or non-hazardous oilfield wastes

In this regard, Landfarms serve an important regulatory function – they eliminate the toxic hydrocarbons that are present in petroleum, and render the treated soil to a form that poses no threat to public health, fresh water, and the environment. As discussed by Dr. Sublette, once the bioremediation process in the landfarm is complete (i.e., once the "bioremediation endpoint" has been reached), treated soils do not have to be transported to and buried in New Mexico's few permitted Landfills.

OCD has adopted what they call a "Best Demonstrated Available Technology" (BDAT) approach. This is an engineered solution that is usually used to prevent the environmental release of the most dangerous of chemicals. However, as I reviewed the details of the SWM Rule, I came to the conclusion that adopting BDAT for the regulation of petroleum-impacted soils is like using a nuclear warhead to get rid of an ant bed.

Based on my 30+ years of professional experience, I recommend that OCD use a Risk-Based Decision Making (RBDM) process. A RBDM approach will provide a logical and consistent framework from which OCD can best regulate oilfield wastes.

It is instructive to note that the US Environmental Protection Agency (USEPA) and other regulatory authorities (including the New Mexico Environmental Department – NMED), have found BDAT-type approaches to be manpower intensive, expensive to implement, and difficult to enforce. These agencies have adopted RBDM approaches, and reserve BDAT only for those situations where conditions and/or operations require it (USEPA 1998; USDOE 1999; NMED 2005).

What is Risk-Based Decision Making (RBDM)?

In order to explain RBDM, I need to define two terms:

> Hazard – the ability to produce an adverse effect.
>
> Risk – the probability that an adverse effect will occur.

During the mid-1970, the US Occupational Safety & Health Administration (OSHA) proposed to lower their workplace standard for benzene vapor from 10 ppmv to 1 ppmv. The petroleum and chemical industries challenged OSHA's claim that their regulatory mandate to protect workers' health allowed them to establish an occupational standard for a carcinogen at the lowest technically feasible concentration. In 1980, the US Supreme Court ruled in favor of Industry, saying that before OSHA can promulgate a standard, they must a) show that the existing level of exposure poses an unacceptable risk to health, and 2) that the proposed standard reduces that risk. [*Industrial Union Dept. v. American Petroleum Institute,* 448 U.S. 607]

The implications of the Supreme Court's ruling was quickly recognized by the US Environmental Protection Agency (EPA) -- contaminants could no longer be regulated simply based on the hazard associated with a chemical...they had to be regulated based on the risk that chemical poses to public health and the environment. EPA quickly began to develop methods to estimate the levels of risk posed by exposures to toxic chemicals. Those methods are commonly known under the general name of "risk assessment", but evolved to become the conceptual regulatory framework (called RBDM) for complex environmental programs like Superfund (EPA 1989, 1990).

The RBDM process provides a logical and consistent way of thinking through landfarm issues by evaluating who and what need to be protected and why. It evaluates site-specific factors, then determines what are the most effective and appropriate regulatory actions to manage the risks at that site. This systematic, step-by-step RBDM process would give OCD (and the Operator) greater flexibility to manage potential threats to public health, fresh water, and the environment. Of importance, RBDM allows OCD to determine if conditions at a landfarm warrant adoption of BDAT.

Risk-Based Decision Making (RBDM) is a formal process that defines:

- What chemical (or agent) is of regulatory concern;
- Who specifically is the "receptor" being protected from that chemical (present and future);
- What are the most likely pathways and levels of exposure to that chemical;
- What is considered to be an appropriate level of risk (the "target risk level"); and

- Based on the above, RBDM defines the maximum allowable concentration of the chemical in soil or water such that the "target risk level" is not exceeded.

Risk-Based Decision Making (RBDM) recognizes that each SWM facility may be unique in terms of size, mass loading, types of soils, depth to groundwater, etc. It uses a tiered approach for regulation:

> Tier 1 – makes conservative (protective) risk-based assumptions to develop soil screening levels (SSLs) for applicable chemicals of concern. May be applied at any facility.
>
> Tier 2 – allows certain site-specific parameters be used in the Tier 1 regulatory risk equations.
>
> Tier 3 – allows an Operator to propose an alternative risk model that he believes is more appropriate for site conditions.

Landfarming of Petroleum Hydrocarbons

Only certain materials are allowed in Landfarms – specifically soils and soil-like materials that contain...

- Crude Oil
- Natural Gas Liquids (Condensate)
- Possibly Tank Bottoms (a mix of water, sediment, crude oil, and water-soluble hydrocarbons)
- Salt (especially Sodium Chloride)

> [Note: Refinery wastes and hazardous wastes (e.g., wastes like chlorinated solvents, PCBs, etc.) are not allowed by OCD to be placed in an OCD permitted or registered landfarm.]

It is worth briefly considering the chemistry and toxicity of these materials, as well as what compositional changes occur during landfarming.

<u>Crude Oil</u>: Crude oils are extremely complex mixtures, and vary widely (Coleman et al. 1978; TPHCWG 1998b). Constituents not easily separated for identification and quantification (TPHCWG 1998a).

Crude oils have low acute toxicity, chronic toxicity, and carcinogenicity in animals (IPCA 1982; USEPA 1987,1993,1995; TPHCWG 1997a,1999), and low toxicity to plants (deOng et al. 1927; Plice 1948; Currier & Peoples 1954; Baker 1970; Udo & Fayemi 1975; Chaineau et al. 1997; Sample et al. 1998; Saterbak et al. 1999). According to a review of the scientific literature by the International Programme on Chemical Safety (IPCA 1982):

> "Available information indicates that the health risks for the general population from the production of crude oil and the manufacture and use of petroleum products are very low. Under normal circumstances, there is, at the most, a nuisance because of pollution of the air and/or water." --- Section 2.3

Low levels of toxicity should not be interpreted to mean that toxic constituents are not present. Toxic compounds are present in crude oil, but only at small concentrations in the mixture.

The most common surrogate measure for crude oil is called Total Petroleum Hydrocarbon (TPH-Total) in which hydrocarbons are extracted into a solvent, then quantified by various methods. Two of the EPA methods for TPH-Total discussed in the SWM Rule are...

> <u>Method 418.1</u> – Extract into Freon-113; quantify by extent of absorption of infrared light. Method 418.1 is OCD's preferred method for TPH-Total. However, it should be noted that use of Freon has been banned in the United States since the late 1990s, and Method 418.1 is no longer listed as an approved method in EPA SW-846.
>
> Method 8015M – Extract into an appropriate solvent (e.g., hexane) and analyze by GC-FID. This is an appropriate method, approved by EPA.

TPH methods are non-specific…not everything reported as TPH is petroleum. For example, "TPH-Total" content by Method 418.1 was found at high concentration in the following non-petroleum materials:

Grass (TPH-Total = 14,000 mg/kg)
Pine Needles (TPH-Total = 16,000 mg/kg)
Oak Leaves (TPH- Total = 18,000 mg/kg)

It should also be emphasized that TPH estimates by different methods cannot be directly compared, and the methods may give highly disparate results.

Because toxicology / risk data are available for the common distillate fractions of crude oil, TPH-Total is often separated by GC methods (e.g., 8015M) into …

- TPH-GRO (gasoline, C6-C10),
- TPH-DRO (kerosene and diesel fuel, C10-C28), and
- TPH-ORO (lubricating oil, C28-C40).
- Asphalt-range constituents of crude oil (C40+) are not able to be extracted by light aliphatic solvents, and cannot be analyzed directly.

Scientific literature indicates that a concentration of 1%wt (TPH-Total = 10,000 mg/kg) of crude oil in soil does not affect plant growth, or groundwater quality (API 1993; Currier & Peoples 1954; Udo et al. 1975; Baker 1970; deOng et al. 1927; Plice 1948; Chaineau et al. 1997; Saterbak et al. 1999).

The constituents in crude oils of greatest concern from a toxicity and environmental migration perspective are:

- Benzene, Toluene, Ethylbenzene, Xylenes, called BTEX) that exist in the TPH-GRO fraction; and
- Naphthalene that exists in the TPH-DRO fraction.

The BTEX and Naphthalene compounds are volatile, water-soluble, and bioavailable constituents of petroleum. As discussed more fully by Dr. Sublette, they are preferentially degraded by bacteria and other microorganisms in soil and water.

When oil-impacted soils are placed in a Landfarm, the Operator tills, and adds organic matter, water and/or nutrients as needed. Landfarming promotes the growth of microorganisms that preferentially metabolize the smaller hydrocarbon constituents including BTEX (TPH-GRO) and Naphthalene (TPH-DRO).

When the bioremediation process that occurs in a landfarm is complete, the aromatic compounds have been almost completely eliminated from the hydrocarbon mixture and toxicity ceases to be an issue of concern. The Residual TPH-Total hydrocarbons (comprising larger TPH-DRO constituents + TPH-ORO + Asphalt) are:
non-toxic, poorly soluble, and not environmentally mobile. Hence, biotreated oil-contaminated soils cease to be of regulatory concern from a risk perspective.

Because the crude oil has been mixed with the bioremedied soil, the Residual TPH-Total contributes to the organic content of the soil, and does not form asphaltic clumps on the landfarm surface.

Condensate: Condensate (also called "natural gasoline") contains primarily TPH-GRO (C6 - C10), with lesser amounts of TPH-DRO (C10 – C28) hydrocarbons. The chemical composition of fourteen gas condensates was determined by the Petroleum Environmental Research Forum (PERF) and the Gas Research Institute (GRI). These studies were reported by Hawthorne et al. (1998) and Rixey (1999), and confirmed that condensates contain BTEX and Naphthalene. Benzene concentrations range from 0.15 – 3.6 %wt.

Landfarm treatment (including biopiles) of condensate-impacted soils results in volatilization and microbial destruction of BTEX and Naphthalene. As a result, the hydrocarbons remaining after landfarming are:non-toxic; poorly soluble; and not environmentally mobile.

Sodium Chloride: Chloride ion is highly soluble in water, and is used by environmental scientists as an indicator of water migration. The toxicity of chloride salts is related to the positively charged cation (e.g., sodium, calcium, etc.), rather than to the chloride anion. The acute toxicity is low, as indicated by its oral LD50 in man and animals of about 4000 mg/kg.

Dr. Stephens has modeled the vertical migration of chloride from a hypothetical small landfarm that has been sited according to OCD criteria and has shown that vertical migration is extremely slow. Based on his conservative model, soils containing Chloride concentrations of 4,000 to 11,000 mg/kg could be treated in small landfarms without adversely affecting groundwater.

Dr. Sublette has discussed data confirming that bioremediation of petroleum hydrocarbons occurs even at sodium concentrations of 5000 ppm in soil and higher. Phytotoxicity not expected when EC of soil water is < 4 mmhos/cm (or appropriate EC for the site).

Although the data presented by Drs. Stephens and Sublette indicate that higher chloride concentrations could be allowed in a landfarm, the Industry Committee has suggested a 1,000 mg/kg Tier 1 limit for chloride is acceptable for purposes of moving forward the regulatory discussions with OCD.

Based on the discussion above, several conclusions can be reached:

1. Landfarming of crude oil and condensate impacted soils effectively eliminates toxic aromatic hydrocarbons (BTEX and Naphthalene).
2. The hydrocarbons that remain after landfarming are non-toxic, poorly soluble, not environmentally mobile.
3. With regard to hydrocarbons, biotreated soils do not pose a risk to public health, fresh water, or the environment.
4. Chloride is not toxic, but is used as an indicator of water movement.
5. The Industry Committee has agreed to a Tier 1 Chloride criterion of 1,000 mg/kg to move the regulatory discussion forward.
6. However, results from a conservative regulatory water model indicate that substantially higher concentrations in landfarm-treated soils will not adversely affect water quality.

Proposed SWM Rule Leaves Unanswered Questions and Issues

I believe that the lack of a formal regulatory structure like RBDM has caused a number of issues and questions to arise in OCD's proposed SWM Rule. I will not address all of these today, but will focus on a few examples.

1. <u>ISSUE - TPH-Total</u>

   SWM Rule requires Operator to analyze TPH-Total by Method 418.1 or other acceptable method.

   > *<u>Comment</u>: Different TPH methods give widely varying estimates of TPH-Total depending on type of hydrocarbons, extraction solvent, extraction method, separation method, and quantitation method.*
   >
   > *<u>Recommendation</u>: TPH-Total is poorly correlated with risk to health, fresh water, and environment – should not be a required parameter. TPH-GRO and/or TPH-DRO (by 8015M) are the appropriate measures, depending on type of petroleum hydrocarbons present.*

2. <u>Issue - 80% Reduction of TPH-Total</u>

   SWM Rule specifies that TPH-Total must be reduced by at least 80% before bioremediation is considered complete.

   > *<u>Comment</u>: OCD's technical or risk basis for an 80% Total TPH criterion is unclear, but is unrelated to protection of fresh water, public health and environment.*
   >
   > *<u>Comment</u>: It is possible that a hydrocarbon-impacted soil has reached its Bioremediation Endpoint (i.e., no risk to public health, fresh water, or environment), yet have to be excavated and transported to a landfill because TPH-Total has not been reduced 80%.*

Recommendation: As discussed by Dr. Sublette, TPH-GRO and/or TPH-DRO (by 8015M) are appropriate measures of bioremediation effectiveness. TPH-Total is not useful and should not be measured.

3. Design Equivalency

SWM Rule allows Operator to propose alternative to OCD's default landfarm design (BDAT), but it is not clear how Operator is to demonstrate equivalent effectiveness.

Recommendation: Use RBDM approach to identify relevant threats to public health, fresh water, and the environment. Operator's proposed alternate design should address those threats and show that "target risks" are not exceeded.

4. Metals

Commercial and centralized landfarms soil closure standards include Total Arsenic, Total Barium, Total Mercury, and other metals.

Comment: It is only the soluble fraction of a metal that is capable of environmental migration and is potentially toxic.

Comment: Published studies indicate that metals in crude oil- and condensate-impacted soils are present at low levels that do not pose a risk to fresh water, public health, and environment.

Recommendation: Measurement of metals should be based on types of wastes to be managed in a permitted commercial or centralized landfarm.

Recommendation: If analysis of a metal is required, a leachate method should be used and compared to the relevant Tier 1 SSL.

5. DAF1 vs. DAF20

SWM Rule proposes Target Soil Closure Concentrations that are simply the lower of NMED's Residential SSL or NMED's DAF1 SSL for protection of groundwater.

> *Comment: Dr. Stephens discussed the many problems of adopting DAF1 value as the Tier 1 default for New Mexico...not the least of which is that precision of available laboratory methods cannot reliably estimate concentrations as low as the DAF1 SSL for many analytes – it is impossible to demonstrate compliance.*
>
> *Comment: RBDM process identifies appropriate Soil Closure Concentrations for protection of groundwater.*
>
> *Recommendation: OCD's Tier 1 Soil Closure Standards should be 1) Background, 2) the Practical Quantitation Limit (PQL), or 3) the lower of NMED's Residential SSL or DAF20 SSL.*

6. Criteria for 3103 Wastes

SWM Rule proposes Tier 1 Soil Closure Concentrations for 3103 wastes (e.g., chlorinated solvents, PCBs, etc.):

> *Comment: None of the listed 3103 wastes occur as natural constituents of petroleum, and none are permitted to be placed in a Landfarm.*
>
> *Recommendation: Delete non-oilfield wastes from closure criteria.*

Benefits of RBDM; Conclusions

The Risk-Based Decision Making (RBDM) is a formal process that defines:

- What chemical (or agent) is of regulatory concern;

- Who specifically is the "receptor" being protected from that chemical (present and future);
- What are the most likely pathways and levels of exposure to that chemical;
- What is considered to be an appropriate level of risk (the "target risk level"); and
- Based on the above, RBDM defines the maximum allowable concentration of the chemical in soil or water such that the "target risk level" is not exceeded.

RBDM uses a tiered approach for regulation:

Tier 1 – Maximum allowable concentration determined from higher of background, PQL, or either NMED Residential SSLs or NMED DAF 20 SSL; and chloride at 1000 mg/kg.

Tier 2 – allows certain site-specific parameters be used in the Tier 1 regulatory risk equations.

Tier 3 – allows an Operator to propose an alternative risk model that he believes is more appropriate for site conditions.

As discussed above, the RBDM process provides a number of important benefits to the rulemaking process:

1. RBDM provides a logical, consistent, and technically defensible thought process from which the SWM Rule can be structured and understood by all parties.

2. In particular, RBDM clearly defines OCD's reasons for requiring specific design elements, analytical data, plans, and procedures -- states OCD's intent, even if an issue is not specifically addressed in the SWM Rule.

3. The formality of the RBDM process gives OCD and the Industry flexibility to consider site-specific conditions, as well as to reflect future changes in technology and science.

4. RBDM identifies and evaluates the specific issues of concern such that the resulting program protects fresh water, public health, and the environment.

<u>CONCLUSION -- OCD Should Embrace RBDM</u>

References

Altgeit KH & Boduszynski MM, eds. (1994). Composition and Analysis of Heavy Petroleum Fractions (New York: Marcel Dekker).

American Petroleum Institute (1983). 28-Day Dermal Toxicity Study in the Rabbit: Vacuum Residuum (Samples 81-13 and 81-14). API Medical Research Publication 30.

American Petroleum Institute (1993). Evaluation of Limiting Constituents Suggested for Land Disposal of Exploration and Production Wastes, API Publication No. 4527.

American Petroleum Institute (1996). Characterization of Exploration and Production Associated Waste. API Publication Number DR53.

American Petroleum Institute (1997). "Environmental Guidance Document: Waste Management in Exploration and Production Operations", Publication No. API E5, 2nd Edition.

American Petroleum Institute (1999). Decision Support System for Exposure and Risk Assessment (DSS) [Version 2].

American Society for Testing & Materials (1989). Manual on Hydrocarbon Analysis, 4th Ed. (West Conshohocken, PA: Society for Testing and Materials).

American Society for Testing & Materials (1998). Standard Provisional Guide for Risk-Based Corrective Action [PS 104-98].

Baker JM (1970). "The Effects of Oils on Plants," Environ Pollution 1: 27-44.

Bruce LG & Schmidt GW 1994. "Hydrocarbon Fingerprinting for Application in Forensic Geology: A Review With Case Studies," AAPG Bulletin , 78(11):1692-1710.

Canadian Council of Ministers (2000a). Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil.

Canadian Council of Ministers (2000b). Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil — Technical Supplement.

Chaineau CH, Morel JL & Oudot J (1997). "Phytotoxicity and Plant Uptake of Fuel Oil Hydrocarbons." J. Environ. Qual. 26:1478-1483.

Coleman HJ, Shelton EM, Nichols DT &Thompson CJ (1978). "Analysis of 800 Crude Oils from United States Oilfields." Department of Energy Report No. BETC/RI-78/14.

Colorado Bureau of Land Management (1997). Colorado BLM Policy for the On-Site Remediation of RCRA Exempt, Hydrocarbon Based, Oil and Gas Exploration & Production Waste and Terrestrial Spills of Crude Oil.

Colorado Oil and Gas Commission (1995). Rules 907 and 908, Denver, Colorado

Colorado Oil and Gas Commission (1997). Revisions to the 900 Series Rule, Denver, Colorado.

CONCAWE (1997). Petroleum products – first aid, emergency and medical advice. Report 1/97.

Currier HB &Peoples SA (1954). "Phytotoxicity of Hydrocarbons." Hilgardia 23:155-173.

deOng E.R, Knight H & Chamberlin JC (1927). "A Preliminary Study of Petroleum Oil as an Insecticide for Citrus Trees," Hilgardia 2: 353-384.

DeVaull GE & Brost EJ (2000a). "Non-Aqueous Phase Liquid (NAPL) Mobility Limits in Soil." Soil and Groundwater Research, API Bulletin No. 9.

Gas Research Institute (1993). "Sampling and Analysis of Wastes Generated from Natural Gas Industry Operations", Publication No. GRI-93/0208.

Hamilton WA, Sewell HJ & Deeley G (1999). "Technical Basis for Current Soil Management Levels of Total Petroleum Hydrocarbons." Proceedings of the International Petroleum Environmental Conference, Houston, TX, November 16-18.

Harju JA, Nakles DV, DeVaull G & Hopkins H (1999). "Application of Risk-Based Approaches for the Management of E&P Sites", SPE Paper No. 52723, presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, Texas, February 28 - March 3.

Hawthorne SB & Miller DJ (1998). "Hydrocarbon Characterization of Gas Condensates and Impacted Soils," Proceedings of the International Petroleum Environmental Conference, Albuquerque, NM, October 20-23.

International Programme on Chemical Safety (1982). Environmental Health Criteria 20: Selected Petroleum Products (Geneva: World Health Organization, 1982).

Kerr JM, Hamed MM, Melton HR, Magaw RI, McMillen SJ & Naughton G (1999a). "Risk-Based Soil Screening Levels for Crude Oil: The Role of Polyaromatic Hydrocarbons", Paper presented at the International Petroleum Environmental Conference, Houston, Texas, November 16-18.

Kerr JM, Melton HR, McMillen SJ, Magaw RI & Naughton G (1999b). "Polyaromatic Hydrocarbon Content in Crude Oils Around the World", SPE Paper 52724, presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, Texas , February 28 - March 3.

Louisiana Department of Environmental Quality (1998). Proposed Louisiana Department of Environmental Quality Risk Evaluation/Corrective Action Program, April 20.

Magaw RI, McMillen SJ, Gala WR, Trefry JH, Trocine RP (1999b). "A Risk Evaluation of Metals in Crude Oils", SPE Paper No. 52725, presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, Texas, February 28 - March 3.

Magaw RI, S. J. McMillen SJ, Gala WR, Trefry JH & Trocine RP (1999a). "Risk Evaluation of Metals in Crude Oils", Paper presented at the International Petroleum Environmental Conference, Houston, Texas, November 16-18.

McMillen S. Magaw RI, Kerr JM & Edwards DA (1999a). "A Risk-Based Screening Method for Evaluating Total Petroleum Hydrocarbons at Upstream Sites," SPE Paper No. 52722, presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, Texas, February 28 - March 3.

McMillen SJ, Magaw RI, Kerr JM, Sweeney RE, Nakles DV & Geiger SC (1999b). "A New Risk-Based Approach to Establish Cleanup Levels for Total Petroleum

Hydrocarbons," Paper presented at the International Petroleum Environmental Conference, Houston, Texas, November 16-18.

Michigan Department of Environmental Quality, 1997. Supervisor's Letter No. 1997-1, "Total Petroleum Hydrocarbon (TPH) and Aesthetic Cleanup Criteria for Soil at Oil and Gas Facilities", May.

Nakles, D. V., J. W. Lynch, D. A. Edwards, J. G. Tell, T. L. Potter, and R. P. Andes, 1996. "Risk-Based Determination of Soil Clean-up Goals for Diesel-Contaminated Sites in the Railroad Industry", Association of American Railroads, Washington, D.C., September.

New Mexico Environmental Department, Hazardous Waste Bureau and Ground Water Quality Bureau. Technical Background Document for Development of Soil Screening Levels, Revision 3.0 (August 2005).

New Mexico Oil Conservation Division, 1993. "Guidelines for Remediation of Leaks, Spills, and Releases", August.

Newell CJ &Conner JA (1998). "Characteristics of Dissolved Petroleum Hydrocarbon Plumes." Soil and Groundwater Research, API Bulletin No. 8.

Plice MJ (1948). "Some Effects of Crude Petroleum on Soil Fertility," Soil Science Society Proceedings 13:413-416.

Reible DD & Valsaraj KT (1999). TCLP Characterization of Exploration and Production Wastes in Louisiana. Final Report to Louisiana Department of Natural Resources

Rixey WG, McMillen SJ, Magaw RI & Naughton G (1999). "An Evaluation of Benzene Risk at E&P Sites", Paper presented at the International Petroleum Environmental Conference, Houston, Texas, November 16-18.

Sample, B.E, Efroymson RA, Jones DS & Suter GW (1998). "Ecotoxicological Benchmarks for Evaluation of Exposures to Petroleum Materials", Publication No. 4826, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Saterbak A, Toy RJ, Wong DCL, McMain BJ, Williams MP, Dorn PB, Brzuzy LP, Chai EY & Salanitro JP (1999). "Ecotoxicological and Analytical Assessment of Hydrocarbon-Contaminated Soils and Application to Ecological Risk Assessment." Environmental Toxicology and Chemistry 18:1591-1607.

Thomas FB (2000). Phase 3 Report: Risk-Based Evaluation of Exploration & Production Wastes. Report to the Louisiana Department of Natural Resources.

TPHCWG (1997a). "Selection of Representative TPH Fractions Based on Fate and Transport Considerations", Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 3, Amherst Scientific Publishers, Amherst, Massachusetts.

TPHCWG (1997b). "Development of Fraction Specific Reference Doses (RfDs) and Reference Concentrations (RfCs) for Total Petroleum Hydrocarbons", Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 4, Amherst Scientific Publishers, Amherst, Massachusetts.

TPHCWG (1998a). "Analysis of Petroleum Hydrocarbons in Environmental Media", Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 1, Amherst Scientific Publishers, Amherst, Massachusetts.

TPHCWG (1998b). "Composition of Petroleum Mixtures", Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 2, Amherst Scientific Publishers, Amherst, Massachusetts.

TPHCWG (1999). "Human Health Risk-based Evaluation of Petroleum Release Sites: Implementing the Working Group Approach," Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 5, Amherst Scientific Publishers, Amherst, Massachusetts.

Udo EJ & A. A. A. Fayemi AAA (1975). "The Effect of Oil Pollution of Soil on Germination, Growth, and Nutrient Uptake of Corn," J. Environ. Qual. 4: 537-540.

US Department of Energy (1997). Assessment of Short-term and Long-term Risks for Remedy Selection, DOE/EH-413-9708.

US Department of Energy (1999). Guidance for Conducting Risk Assessments and Related Risk Activities for the DOE-ORO Environmental Management Program, BJC/OR-271.

US Environmental Protection Agency (1987). "Report to Congress: Management of Wastes from Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy", NTIS Publication No. PB88-146212.

US Environmental Protection Agency (1988). Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, EPA/540/G-89/004.

US Environmental Protection Agency (1989). Risk Assessment Guidance for Superfund: Volume 1-Human Health Evaluation Manual (Part A), EPA/540/1-89/002.

US Environmental Protection Agency (1990). Guidance for Data Usability in Risk Assessment, EPA/540/G-90/008.

US Environmental Protection Agency (1991a). Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part B, Development of Risk - based Preliminary Remediation Goals), OSWER Directive 9285.7-01B.

US Environmental Protection Agency (1991b). Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives), OSWER Directive 9285.7-01C.

US Environmental Protection Agency (1991c). Standard Default Factors, OSWER Directive 9285.6-03.

US Environmental Protection Agency (1991d). Appendix D of RAGS, Vol. 1, Human Health ("Corrections to RAGS—Part B, Sections 3.3.1 and 3.3.2").

US Environmental Protection Agency (1992). Dermal Exposure Assessment: Principles and Application, Interim Report, EPA/600/8-91/011B.

US Environmental Protection Agency (1993). "Clarification of the Regulatory Determination for Waste from the Exploration and Production of Crude Oil, Natural Gas, and Geothermal Energy," Federal Register 58: 15284-15287.

US Environmental Protection Agency (1993). Guidance on Conducting Non-Time Critical Removal Actions Under CERCLA, EPA/540-R-93-057.

US Environmental Protection Agency (1995). "Crude Oil and Natural Gas Exploration and Production Wastes: Exemption from RCRA Subtitle C Regulation".

US Environmental Protection Agency (1995). Exposure Factors Handbook, EPA/600/8-89/043.

US Environmental Protection Agency (1996a). Supplemental Guidance to RAGS: Region 4 Bulletins, Human Health Risk Assessment (Interim Guidance).

US Environmental Protection Agency (1996b). Soil Screening Guidance: User's Guide, EPA/540/R-96/018.

US Environmental Protection Agency (1998). Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments) Interim, Publication 9285.7-01D.

US Supreme Court (1980). Industrial Union Department, AFL-CIO v. American Petroleum Institute et al. Certiorari to the United States Court of Appeals for the Fifth Circuit [No. 78-911]. Together with No. 78-1036, Marshall, Secretary of Labor v. American Petroleum Institute et al., also on certiorari to the same court. 448 US 607.

Wallcave L, Garcia H, Feldman R, Lijinsky W & Shubik P (1971). Skin tumorigenesis in mice by petroleum asphalts and coal-tar pitches of known polynuclear aromatic hydrocarbon content. Toxicol Appl Pharmacol 18(1): 41-52.

Western States Petroleum Association (1993). Chemical and Physical Characteristics of Crude Oil, Gasoline, and Diesel Fuel: A Comparative Study.