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RISK ASSESSMENT FOR PRODUCED WATER DISCHARGES TO LOUISIANA OPEN BAYS

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1. INTRODUCTION

Potential human health and environmental impacts from discharge of produced water to the Gulf of Mexico concern regulators at the State and Federal levels, environmental interest groups, industry and the public. Current regulations in the United States require or propose a zero discharge limit for coastal facilities based primarily on studies performed in low energy, poorly flushed environments. Produced water discharges in coastal Louisiana, however, include a number located in open bays, where potential and impacts are likely to be larger than the minimal impacts associated with offshore discharges, but smaller than those demonstrated in low-energy canal environments.

This paper summarizes results of a conservative screening-level health and ecological assessment for contaminants discharged in produced water to open bays in Louisiana, and reports results of a probabilistic human health risk assessment for radium and lead. The initial human health and ecological risk assessments consisted of conservative screening analyses that identified potentially important contaminants and excluded others from further consideration. A more quantitative probabilistic risk assessment was completed for the human health effects of the two contaminants identified in this screen: radium and lead. This work is part of a series of studies on the health and ecological risks from discharges of produced water to the Gulf of Mexico, supported by the United States Department of Energy (USDOE).

2. RISK ASSESSMENT

Risk assessment can be defined as a process of estimating magnitudes and probabilities of potential adverse effects on human health or the environment. Risk assessments provide risk managers with the scientific information needed to balance the degree of risk permitted, against competing risks and the costs of risk reduction.

A human health risk assessment for a pollutant describes its discharge, transport and fate in the environment, and the resulting human exposure. Human-health risks are then calculated using data and models that relate exposures to health effects.

The United States Environmental Protection Agency (USEPA) considers excess individual lifetime cancer mortality risks less than 1×10^{-4} (one in ten thousand) to 1×10^{-6} (one in one million) to be acceptable (Federal Register, 1991). No similar standard "acceptable risk" value is available for toxic effects -- intakes are usually compared to a chemical-specific reference dose to determine if toxic effects are expected.

With some modifications and the addition of important uncertainties, the paradigm developed for assessment of human health risks is being applied to estimation of risks to the environment. The receptors or values of concern in an ecological risk assessment may range from individual organisms to entire ecosystems and fundamental ecological processes. Ecological risk assessments may be more qualitative than human health assessments because of the many sources of uncertainty in assessing risks to ecological values (USEPA, 1992).

A tiered approach to human health and ecological risk assessment is logical and cost-effective. In a tiered approach the initial analysis is a conservative (i.e. worst case) screening step, designed to screen out contaminants and pathways that are not of concern. If conservative models and assumptions yield small estimated risks no further analyses are needed. If a conservative analysis suggests that risks may be high, a more detailed and realistic assessment is performed. The state-of-the-science now involves use of a probabilistic approach that explicitly considers uncertainties.

Monte Carlo analysis, a commonly used tool in probabilistic risk assessment, was used here (Crystal Ball®, Decisioneering, Inc., Denver, Colorado). In a Monte Carlo analysis, a sample from the distribution of an input parameter is placed into a simulation to interact in a model with samples from other input parameters.

3. RECEPTORS AND EXPOSURE PATHWAYS

Important receptors for radium discharged in produced water are recreational fishermen and their families. Recreational fishermen may fish close to a platform, return often to the same fishing spot, and derive a large percentage of their diet from fish caught near a platform. Ingestion of contaminated fish is expected to be the most important exposure route for people. Children of recreational fishermen fishing near produced water platforms were considered the subpopulation at risk for exposure to lead.

In the screening assessment, potential ecological receptors included recreationally and commercially important finfish and shellfish species living close to platforms. Screening assessments for other potential receptors will be reported elsewhere. The exposure pathway addressed was direct exposure of biota to contaminants in water.

The State of Louisiana has identified a standard acute toxicity mixing zone of 50 feet and a standard chronic and human health zone of 200 feet from produced water discharges. In the risk assessment reported here, these distances were used because they imply a risk management decision about the "acceptable" location for potential impacts.

DISCLAIMER

4. CONTINUING OPEN BAY DISCHARGES

4.1 Characterization

Louisiana regulations (Title 33, March 20, 1991) required the termination of all produced water discharges to natural or man-made water bodies located in intermediate, brackish or saline marsh areas after January 1, 1995, unless the discharge(s) were authorized in an approved schedule for elimination or effluent limitation compliance. A variance through January, 1997 was granted (12/16/94) for permitted discharges located in open waters, and at least 1 mile from any shoreline, in Chandeleur Sound, Breton Sound, Barataria Bay, Caminada Bay, Timbalier Bay, Terrebonne Bay, East Cote Blanche Bay, West Cote Blanche Bay or Vermillion Bay.

The Louisiana Department of Environmental Quality (LDEQ) identified produced water discharges in open bay areas that may qualify for this variance. In August, 1994, a telephone survey of these operators was conducted to determine if they would take advantage of an extension of the phase-out rule for coastal Louisiana produced water discharges. Most operators indicated that they would continue to discharge through 1997, if allowed. Figure 1 shows the locations of the 72 assumed continuing discharges in open Louisiana bays. Table 1 summarizes data describing platform depths and discharge rates abstracted from LDEQ permit files.

4.2 Dilution

The USEPA surface water transport model CORMIX (Cornell Mixing Zone Expert System Model; Doneker and Jirka, 1990) was used to estimate the dilution expected at 200 feet (61 m) from open bay discharges. A depth of 8 feet (2.4 m) and a range of discharge rates (100 - 37,500 bbl/day) was modeled.

Because of the shallow depth, the model was run using an unstratified scenario with a surface and bottom water density of 1005 kg/m^3. These values were derived from temperature and salinity data published in literature reviewed by USEPA (USEPA, 1995a). A produced water discharge density of 1020 kg/m^3 was derived from USEPA's review of produced water effluent density estimates, and an ambient velocity of 0.05 m/s was used (USEPA, 1995a).

CORMIX forces a submerged single port discharge to be in the bottom 1/3 of the water column. This is unrealistic for produced water discharges, normally discharged on or close to the surface. The model can be adjusted to make the projections more accurate by creating a mirror image using a stratified water column and inverting the ambient densities (Avanti Corporation, 1993). Sensitivity analyses using this approach did not produce significantly different results.

Model results are presented in terms of the expected dilution factor at 200 feet, where the dilution factor (DF) is the concentration of the discharge (100 %) divided by the concentration of effluent in the water at 200 feet. A relationship between discharge rate and dilution factor was derived from model results (Figure 2):

Eq. 1. $\text{DILUTION FACTOR} = 7315.6 * (\text{DISCHARGE})^{-0.6473}$ (R=0.95)

This relationship fits well at high discharge rates, but tends to underestimate dilution at lower discharge rates (Figure 2). The derived relationship was applied to the distribution of discharge rates to produce a distribution of dilution factors (Table 1).

5 SCREENING ASSESSMENT

5.1 Human Health Risk

A conservative screening human health risk assessment was done for metals, organic compounds and radionuclides in continuing open bay discharges using the USEPA Superfund approach(USEPA, 1989).

Worst-case water concentrations were estimated, using the highest recorded (in LDEQ permit files) concentration of a contaminant for any of the assumed continuing discharges at any time, and assuming a DF of 20. Concentrations in fish were estimated using the bioaccumulation factor method (USEPA, 1989; Strenge and Peterson, 1989). Exposures were assumed to continue over a lifetime (70 years), and the intake rate used was the USEPA (1990) 95th percentile value of 132 g/day. Hazard quotients and individual lifetime fatal cancer risks were calculated (USEPA, 1989). Hazard quotients less than one and risk estimates less than 1×10^{-4} suggest that a contaminant is not of concern in terms of human health risk. The details of this screening analysis will be reported elsewhere.

This conservative screening analysis served to eliminate contaminants that do not warrant further time and attention. Contaminants eliminated from further consideration were arsenic, chromium, copper, silver, naphthalene, phenol, toluene and xylenes.

Contaminants of concern included antimony, cadmium, lead, mercury, nickel, zinc, benzene and radium. Because of the conservative nature of this screening analysis, no important effect on human health can be assumed. Screening hazard quotients for antimony, cadmium, nickel and zinc exceeded one by less than an order of magnitude. The cancer risk estimate for benzene exceeded 1×10^{-4} by less than an order of magnitude (6.4×10^{-4}). A more realistic and quantitative assessment using effluent concentration distributions and predicted dilutions for the entire range of discharges is expected to predict few hazard quotients greater than one, and a median risk for benzene of less than 1×10^{-4}. This analysis is being done.

Risk from ingestion of radium in fish exceeded 1×10^{-4} by more than an order of magnitude (7.8×10^{-3}). Contaminants that exceeded hazard quotients by more than an order of magnitude were lead and mercury. Comparison of the few mercury concentrations in effluent reported above the detection limit suggested that mercury in the continuing discharges was similar to that expected in the Gulf of Mexico. Mercury was not analyzed further. Radium and lead were analyzed quantitatively in a probabilistic risk assessment.

5.2 Ecological Risk

5.2.1 Radium

Radium concentrations reported in LDEQ permit files were used to assess potential ecological effects. Worst-case water concentrations were estimated for the highest reported concentrations in open bay discharges, using a conservative DF of 20. Predicted water concentrations were compared to screening dose-rate factors (IAEA, 1988) that relate radiation exposure of an organism to a unit concentration of the radionuclide in the water in which the organism lives. Estimated doses were compared to published reference dose rates (NCRP, 1991).

No estimated doses exceeded the National Council on Radiation Protection and Measurements (NCRP) reference limit of 10 mGy/day. Several estimated doses exceeded the NCRP suggested screening level for detailed assessment (2.4 mGy/day). Additional quantitative assessments could be performed to assess the extent to which the NCRP screening level of 2.4 mGy/day is likely to be exceeded. Because of the conservative nature of this analysis, it can be concluded that no effects are expected on aquatic organisms from radium discharged in produced water to open bays in Louisiana.

5.2.2 Individual Contaminants

Worst-case water column concentrations of measured contaminants in continuing open bay effluents (Section 5.1) were compared to USEPA and Louisiana water quality criteria. This conservative analysis served to eliminate contaminants that do not warrant further time and attention.

Contaminants eliminated from further consideration included arsenic, chromium, benzene, naphthalene and toluene. Worst-case water concentrations exceeded acute water quality standards for copper, lead, nickel, silver and zinc. Chronic water quality criteria were exceeded for antimony, cadmium, copper, lead, mercury, nickel, silver, zinc and phenol. No important effect on aquatic biota can be assumed because of the conservative nature of the screening analysis. Water quality standards were exceeded by less than an order of magnitude for cadmium, silver, zinc, and phenol. A more realistic and quantitative assessment using predicted dilutions for the entire range of discharges and effluent concentration distributions is expected to predict few exceedances for these contaminants and is being done.

Water quality standards for copper, lead, mercury, and nickel were exceeded by more than an order of magnitude. These contaminants are being assessed in a quantitative risk assessment that includes estimated distributions for: DFs, effluent concentration, and dose-response relationships.

6. PROBABILISTIC RISK ASSESSMENT: RADIUM AND LEAD CONCENTRATIONS IN WATER AND FISH

6.1 Concentration in Water

Measured concentrations of radium and lead in open bay produced water discharges, reported in LDEQ permit files, are summarized in Table 2. The largest lead concentration reported in permit files (800,000 µg/l) was several orders of magnitude larger than maximum values reported in other studies (Stephenson, 1992; Middleditch, 1984) and was not included in the data set for the risk assessment. Many of the lead concentrations in produced water were reported as "less than (<)" the detection limit. The detection limit for lead ranged from 50 to 125 µg/l. These values were replaced by one-half the value of the reported detection limit.

To estimate ambient water concentrations, the distribution of radium and lead concentrations reported for open bay discharges was modified by the distribution of DFs. All radium, and 38% of lead was assumed to remain in solution based on calculations performed by LDEQ (USEPA, 1995). Table 2 gives estimated lead and radium concentrations in the water column at 200 feet.

6.2 Concentration in Fish

6.2.1 Fish Near Platforms

Radium and lead concentrations in fish near produced water discharges were estimated using the bioaccumulation factor (BAF) method:

Eq. 2. $C_{fish} = BAF \times C_{water} / 1000\ (g/l)$

where:
C_{fish} = contaminant concentration in fish (pCi/g; µg/g)
BAF = bioaccumulation factor
C_{water} = contaminant concentration in water (pCi/l; µg/l))

A radium BAF distribution, derived from data collected in coastal Louisiana (Meinhold and Hamilton, 1992), was used to estimate concentrations in fish. This distribution is lognormal, has a range of 2 to 100, a mean of 30.4 and a standard deviation of 28. Table 2 gives the estimated distributions for radium concentrations in fish.

A distribution for a lead BAF was developed from published estimates. In a report prepared for USEPA, Avanti Corporation (1993) cited a range of 10 to 100 for bioaccumulation of lead. IAEA (1982) presented a default BAF of 300 for lead in seawater. A triangular distribution for BAF of lead ranging from 10 to 300, with a most likely value of 100 was used in this analysis.

6.2.2 Fish Away From Platforms

For comparison, concentrations of radium and lead in fish caught in the Gulf of Mexico away from platforms (and associated health risks) were estimated. Radium concentrations in fish not associated with platforms were assumed to be uniformly distributed, with a range of 0 to 0.01 pCi/g (Meinhold et al., 1995).

Distributions of lead in fish not associated with platforms were derived from measured concentrations of lead in whole fishes at two Environmental Monitoring and Assessment Program (EMAP) sites on the coast of Louisiana (USEPA, 1995b). These measurements may under- or overestimate background concentrations because the samples were of whole fish rather than edible fillets. Background concentrations were assumed to be lognormally distributed with an arithmetic mean value of 0.05 μg/g (standard deviation: 0.06; range: 0.01 - 0.28). Although the data used in deriving this distribution have been funded wholly or in part by the USEPA through its EMAP-Estuaries Program, it has not been subjected to Agency review, and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

7. PROBABILISTIC RISK ASSESSMENT: FISH INGESTION RATES

Ingestion rates were derived from reported data on meals per week for recreational fishermen in Louisiana, collected in a survey of recreational and commercial fishermen (Steimle & Associates, Inc., in preparation). The ingestion rate distribution for recreational fishermen and their families was derived as follows:

Eq. 3. $$FI = \frac{M \times MS}{7d \times week^{1}}$$

where:
FI = derived ingestion rate (g/day)
M = meals per week (assumed lognormal distribution: arithmetic mean 1.8; sd 1.3; range 0-15; derived from Steimle & Associates Inc., in preparation)
MS = meal size (150 g/meal; USEPA, 1989b).

This distribution (Table 3) was used to estimate exposures of recreational fishermen and their families to radium in recreationally caught fish.

The populations with highest susceptibility to adverse health effects from lead intakes are infants and young children. USEPA (1990) reported data for intake rates of seafood by the population consuming seafood, obtained in a survey conducted over a period of one year (1973-1974). For juveniles (0-9 years of age) the rate of ingestion of seafood was approximately 43% that of the general population. The intake rate distribution derived for recreational fishermen and their families was multiplied by a factor of 0.43 to estimate the rate of juvenile ingestion of fish (Table 3). This intake rate distribution was used in the risk assessment for lead.

8. PROBABILISTIC RISK ASSESSMENT FOR RADIUM

8.1 Exposure Period

Exposure periods (i.e., number of years fishermen catch and eat fish close to an offshore produced water discharge) may vary from several years to a large part of a lifetime. The exposure period for recreational fishermen was assumed to be a triangular distribution, ranging from 5 to 65 years, with the most frequent value set at 20 years.

8.2 Intake

Daily ^{226}Ra and ^{228}Ra ingestion rates during the exposure period were calculated as:

Eq. 4. $RI = FI \times [Ra]_{fishes}$

where:
RI = radium intake (pCi/day)
FI = intake of fish (g/day) for recreational fishermen and their families
$[Ra]_{fishes}$ = concentration of radium in fishes (pCi/g)

8.3 Dose-response Assessment

Current practice in radiation protection assumes there is a cancer risk associated with even small doses of radiation. Risk factors, derived from epidemiological data are extrapolated down to low doses to describe the cancer risk associated with small exposures. Risk factor distributions were derived from USEPA values (Federal Register, 1991) by assuming that the USEPA values represent the upper 90% upper confidence limit of a lognormal distribution (Meinhold et al., 1995). Table 4 shows the distribution of risk factors used.

The risk factor was modified for each exposure period by adding 10 years for radium retention (Meinhold et al., 1995).

Eq. 5. $RF(EP) = \dfrac{[EP + 10]}{70 \text{ years}} \times URF(70)$

where:
RF(EP) = risk factor as a function of exposure period EP (lifetime risk per pCi/day)
EP = exposure period (years)
URF(70) = USEPA unit risk factor for lifetime exposure (lifetime risk per pCi/day)

8.4 Risk Characterization and Results

Individual lifetime fatal cancer risks were calculated as:

Eq. 6. $ILR = RI \times RF(EP)$

where:
ILR = individual lifetime fatal cancer risk
RI = daily radium intake during the exposure period (pCi/day)
RF(EP) = risk factor modified by exposure period (lifetime risk per pCi/day)

Individual lifetime risks were calculated separately for ^{226}Ra and ^{228}Ra and then summed. Results are presented in Table 5. Median individual lifetime fatal cancer risks were 9.8×10^{-6}, and 95th percentile risks were 5.4×10^{-5}. Median risks from ingestion of fish caught away from open bay discharges were 3.8×10^{-7}, and 95th percentile risks were 1.3×10^{-6}.

9. PROBABILISTIC RISK ASSESSMENT FOR LEAD

9.1 Intake

9.1.1 Background Intake

Lead is ubiquitous in the environment, and children, in particular are exposed to lead through a number of pathways. Important sources of lead exposure to children include food, drinking water, air, soil and dust. Exposures from specific sources are added to background exposures experienced by children and increase the probability of exceeding blood lead levels of concern identified by USEPA (Section 9.3). This analysis used the assumed age-specific background intakes for children ages one-half to 7 years described in USEPA (1994).

9.1.2 Recreational Fishing

Lead intake was estimated for children eating fish caught near platforms, and away from platforms. Distributions of lead intake in recreationally caught fish were calculated as:

Eq. 7. $PbI = FI \times [Pb]_{fishes}$

where:
PbI = lead intake (μg/day)
FI = intake of fish (g/day) for children of recreational fishermen
$[Pb]_{fishes}$ = concentration of lead in fish (μg/g)

Intake estimates were divided into groups (27 groups for fish caught near platforms, 13 groups for fish caught away from platforms) and the midpoint of the intake range for each group was used to represent the intake of lead ingested in recreationally caught fish. Daily lead ingestion rates in food were calculated for each year of life to age 7 by adding the background intake for that age (USEPA, 1994) to the estimated intake from recreationally caught fish. This approach slightly overestimates lead intake in food because recreationally caught fish would actually replace a small amount of lead in fish and meat obtained from other sources.

9.2 Dose-response assessment

Lead exposure can affect a number of systems, including the brain, hematopoietic system, cardiovascular system and the developing fetus (Derosa *et al.*, 1991). Extensive data are available to link low-level lead exposure of young children to deficits in neurobehavioral-cognitive performance (Rosen, 1995). Federal agencies and advisory groups including USEPA (USEPA, 1986, 1990a), have defined a level of concern for children as a blood lead level ≥10 μg/dl (Rosen, 1995; USEPA, 1994). USEPA has developed a biokinetic/uptake model for lead (UBK Model; USEPA, 1994) that relates intake in food, air, water and soil to the probability of exceeding a blood lead level of 10 μg/dl (BL>10). This analysis used this probability as the metric for risk from ingestion of lead in fish.

9.3 Risk Characterization

The UBK model (USEPA, 1994) was used to estimate the blood lead concentration and the probability of BL>10 for each level of intake of recreationally caught fish. All other UBK model parameters reflected USEPA (1994) estimates of average background intakes.

Blood lead levels were estimated for two age groups: age 1-2 years when they are at their maximum level for a given intake; and averaged over age 0 to 7 years. Figure 3 shows the relationship between the intake of lead in recreationally caught fish and the probability of BL>10. For comparison, background intakes of lead are associated with a probability of BL>10 of 1.56% for age 0-7 years and of 4.42% for age 1-2 years.

The total risk (that is, the probability of BL>10 across all predicted intake rates) was calculated as:

Eq. 8. $$TP = \Sigma\ P(PbI) * P(BL>10 \mid PbI)$$

where:
TP = total probability (%) of exceeding a blood lead level of 10 μg/dl
P (PbI) = probability (%) of a given lead intake in recreationally caught fish
P(BL>10 | PbI) = probability (%) of exceeding a blood lead level of 10 μg/dl for a given intake of lead in fish

9.4 Results

The frequency distribution for the probability of BL>10 is given in Figure 4 for fish caught near platforms and fish caught away from platforms. Risks for most intake rates in the distribution for fish caught near platforms only slightly exceeded the background risks of 1.6% and 4.4 % for 0-7 years and 1-2 years, respectively. Fifty-two percent of the predicted intake rates at platform sites had risks of BL>10 less than 2.7% and 6.4% for age 0-7 and 1-2 years, respectively. Seventy-four percent of the predicted intake rates at platform sites had risks of BL>10 less than 5% and 10.6% for age 0-7 and 1-2 years, respectively. Figure 5 shows the cumulative frequency distribution of the risks for ingestion of fish caught near platforms.

Table 6 shows the total probability of BL>10 for fish caught near platforms, fish caught away from platforms and background intakes. Risk from ingestion of fish caught away from platforms only slightly exceeded risks from background intake of lead. The total probability of BL>10 from intake of lead in fish caught near platforms was approximately 3-5 times higher than risks from background intakes of lead.

10 UNCERTAINTIES

Uncertainties associated with this analysis include: uncertainty in modeling of radium and lead discharge concentrations, dilution and bioaccumulation; uncertainty in ingestion rate distribution; and uncertainty in dose-response functions. These uncertainties were included in the probabilistic risk assessments by describing each of the relevant variables as a distribution in the Monte Carlo analysis. Because of a lack of knowledge and data, a number of major conservative assumptions remain. Because risks from radium ingestion in fish are predicted to be small (less than 1×10^{-4} individual lifetime fatal cancer risk), these remaining conservatisms are not of concern for interpretation of the results for radium. Based on the analysis presented for lead, however, risks for children ingesting a large amount of fish caught near some produced water platforms may be of concern.

Two major conservative assumptions that remain in the analysis were investigated in a sensitivity analysis:

1. Discharge concentrations of lead were based on a very limited data set (15 values), with 8 values reported as "less than" the detection limit. The detection limit varied from 50 to 125 μg/l. A standard approach of using 1/2 the reported detection limit was used in the analysis. The true concentration in the effluent is unknown and may be much lower than suggested by the reported detection limits.

2. The transport model used to predict lead concentrations in water underestimates dilution at low discharge rates.

A sensitivity analysis was performed to assess the importance of these assumptions to the estimates of risk from lead in ingested fish. Additional analyses were done by either replacing "less than" values with a high estimate of background lead in sea water (1.0

µg/l); or assuming that the water concentrations of lead were overestimated by a factor of 10. The results of the sensitivity analyses are summarized in Table 7.

Results of the sensitivity analysis suggest that the two major conservatisms remaining in the assessment have an important effect on the estimate of total risk from lead ingestion in fish. Replacing "less than, <" values with an estimate of background lead concentrations reduced the total risk by a factor of approximately 1.2. Total risks were reduced by a factor of 3-4 (similar to background risks) when lead water concentrations were assumed to be overestimated by a factor of 10.

11 SUMMARY AND CONCLUSIONS

The tiered approach to risk assessment is a cost-effective way to provide risk managers with information needed to make decisions. A screening assessment for human health risks eliminated a number of contaminants from further consideration. Quantitative assessments were performed for two contaminants of concern identified using this screen: radium and lead.

An ecological screening assessment concluded that radium discharged to open bays in produced water is not expected to affect aquatic fish or shellfish. Contaminants of concern identified by the screening ecological risk analysis were copper, lead, mercury, and nickel. These contaminants are being assessed in a quantitative risk assessment.

Median individual lifetime fatal cancer risks for continuing open bay discharges of radium were 2.2×10^{-7}, and 95th percentile risks were 1.9×10^{-5}. These results suggest that ingestion of radium in fish caught near open bay produced water platforms does not present an important risk to human health.

Risks from ingestion of lead in fish caught near platforms exceed background risks and risks from ingestion of lead in fish caught away from platforms. Most predicted intake rates are associated with risks that only slightly exceed the risk from background intakes. Because of the conservatisms embedded in the analysis (assumptions concerning "less than" effluent concentrations, underestimate of dilution at low discharges rates) the risk from ingestion of lead discharged from open bay discharges in Louisiana appears to be small, although exposures to children eating a large amount of fish caught near the few platforms discharging measurable amounts of lead may be of concern.

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Table 1. Platform depths, discharge rates and dilution factors.

	Depth (feet)[1]	Discharge[2] (bbl/day)	Dilution Factor[3]
arithmetic mean	9.1	4,500	62
standard deviation	2.3	7,200	52
minimum	4.0	1	8
maximum	18.0	37,000	750

[1]29 data points available

[2] 62 data points available

[3] Modeled dilution factor at 200 feet.

Table 2. Radium and lead concentrations in open bay produced water discharges, and estimated concentrations in water and fish at 200 feet.

	Effluent[1]			Ambient Water[2]			Fish[3]		
	^{226}Ra	^{228}Ra	Lead	^{226}Ra	^{228}Ra	Lead	^{226}Ra	^{228}Ra	Lead
arithmetic mean	191.4	250.0	284.6	5.5	6.9	3.6	0.2	0.2	0.5
sd deviation	122.4	163.6	616.2	5.5	6.7	5.6	0.2	0.27	0.8
minimum	0.0	0.0	25.0	0.0	0.0	0.03	0.0	0.0	0.0
maximum	592.0	560.0	2,280.0	51.2	65.1	78.0	2.6	3.5	12.8

[1]Measured in effluent: pCi/l radium, μg/l lead.

[2]Modeled concentrations in water: pCi/l radium, μg/l lead.

[3]Modeled concentrations in fish: pCi/g radium, μg/g lead.

Table 3. Derived intake distributions for fish caught near open bay platforms.

	Intake (g/day)	
	Recreational Fishermen and Families	Children
arithmetic mean	38.4	16.6
median	31.5	13.6
standard deviation	26.4	11.6
minimum	3.3	1.3
maximum	228.6	115.7
95th percentile	89.5	38.5

Table 4. Risk factor distribution for ^{226}Ra and ^{228}Ra (lognormal distributions).

	Individual lifetime fatal cancer risk per pCi/day	
	^{226}Ra	**^{228}Ra**
arithmetic mean	1.5×10^{-6}	1.0×10^{-6}
lower 90% confidence limit	9.4×10^{-7}	4.7×10^{-7}
upper 90% confidence limit	2.2×10^{-6}	1.9×10^{-6}

Table 5. Risk for ingestion of radium in fishes.

	Individual Lifetime Fatal Cancer Risk	
	Fish Near Platforms	Fish Away From Platforms
mean	1.7×10^{-5}	5.0×10^{-7}
median	9.8×10^{-6}	3.8×10^{-7}
standard deviation	2.3×10^{-5}	4.4×10^{-7}
5th percentile	1.8×10^{-6}	8.1×10^{-8}
95th percentile	5.4×10^{-5}	1.3×10^{-6}

Table 6. Total probability (%) of exceeding a blood lead level of 10 μg/dl.

	0-7 years	**1-2 years**
Fish Near Platforms	7.8	14.3
Fish Away From Platforms	2.0	5.2
Background	1.6	4.4

Table 7. Sensitivity analysis: importance of "less than" values and overestimation of lead concentrations in water on estimating the total probability (%) of exceeding a blood lead level of 10 μg/dl for ingestion of fish caught near platforms.

Scenario	**Probability blood lead > 10μg/dl**	
	0-7 years	**1-2 years**
base case[1]	7.8	14.3
replace "less than, < " values with 1 μg/l	6.7	11.7
lead concentrations in water divided by 10	2.1	5.2

[1] base case is the risk assessment reported in the text, "less than, <" value replaced by 1/2 their value and water concentrations estimated using the model described in the text

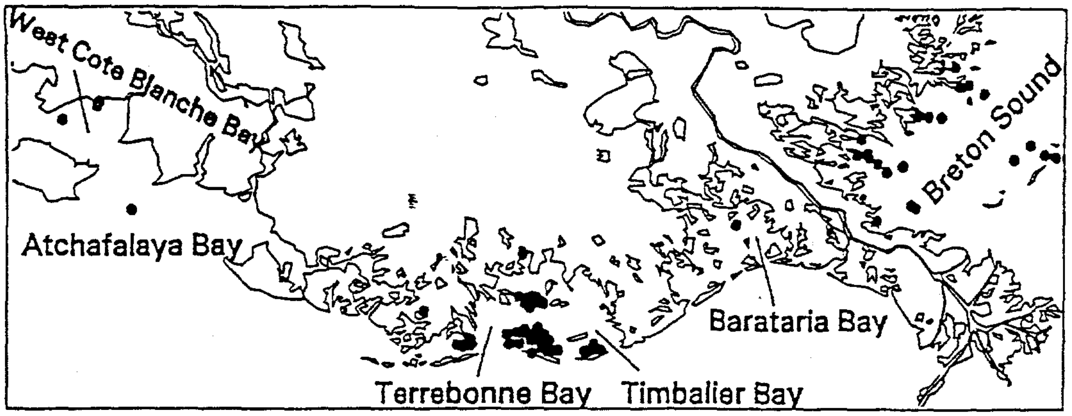
Figure 1. Assumed continuing discharges in open Louisiana bays.

Figure 2. Relationship between discharge rate and modeled dilution factor at 200 feet from discharge.

Figure 3. Relationship between intake of lead in recreationally caught fish and probability of exceeding 10 μg/dl blood lead for two age groups.

Figure 4. Frequency distribution of the probability of exceeding 10 μg/dl blood lead from ingesting fish caught near platforms and away from platforms. (□ = 0 to 7 years; o = 1-2 years; note differences in x axes).

Figure 5. Cumulative frequency distribution of the probability of exceeding 10 μg/dl blood lead from ingesting fish caught near platforms (□ = 0 to 7 years; o = 1-2 years; 70-80% of values represented, up to 10% probability).


West Cote Blanche Bay
Atchafalaya Bay
Breton Sound
Barataria Bay
Terrebonne Bay
Timbalier Bay

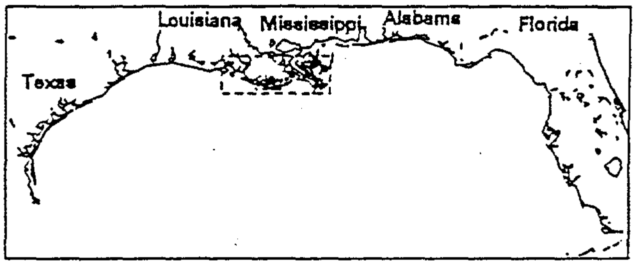

Louisiana
Mississippi
Alabama
Florida
Texas

Figure 1.

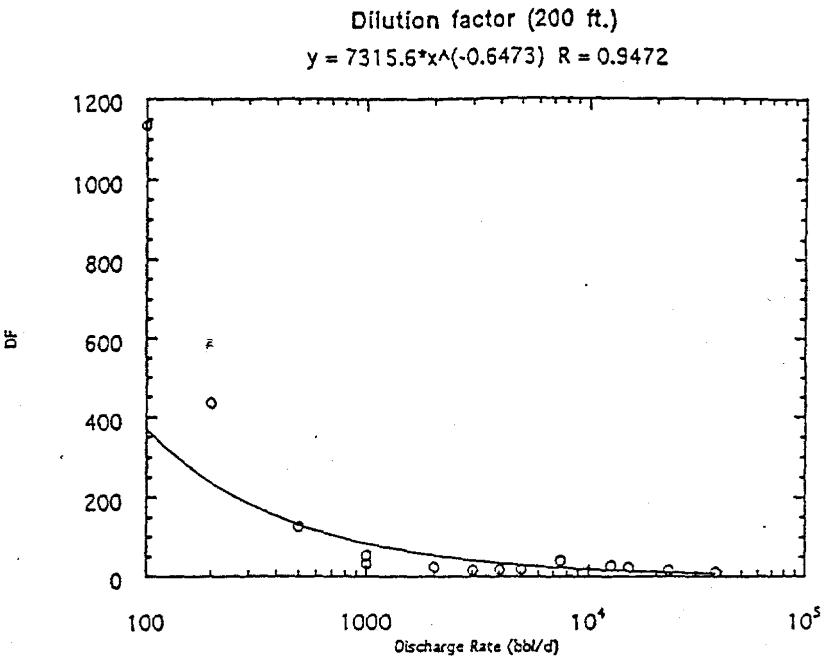
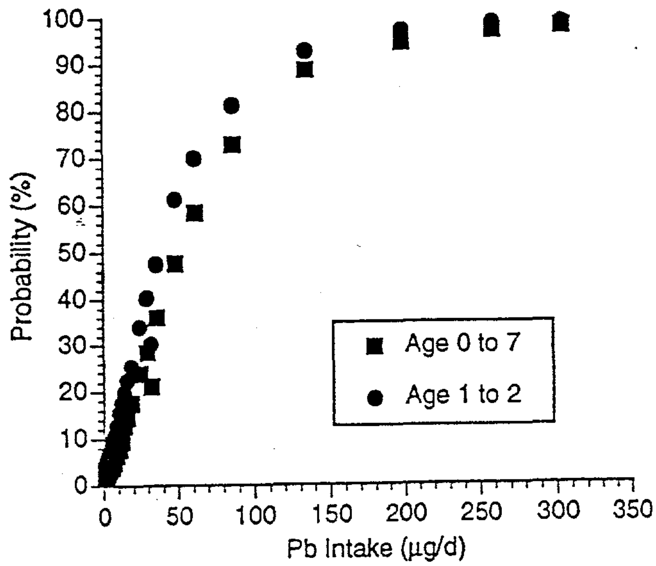

Dilution factor (200 ft.)
y = 7315.6*x^(-0.6473) R = 0.9472
1200
1000
800
600
400
200
0
DF
100
1000
10⁴
10⁵
Discharge Rate (bbl/d)

Figure 2



100
90
80
70
60
50
40
30
20
10
0
Probability (%)
0
50
100
150
200
250
300
350
Pb Intake (µg/d)
Age 0 to 7
Age 1 to 2

Figure 3

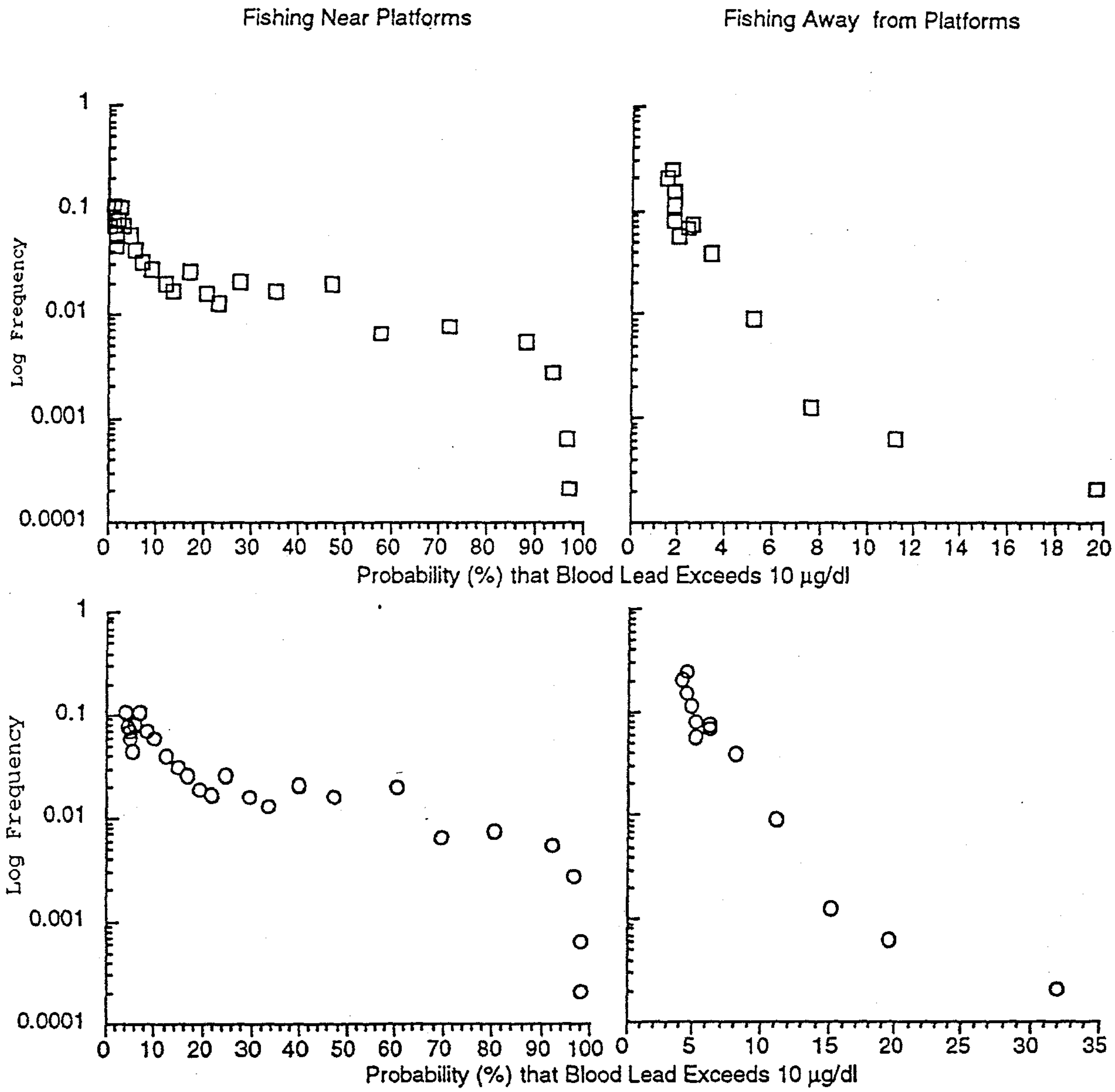

Fishing Near Platforms
Fishing Away from Platforms
Log Frequency
1
0.1
0.01
0.001
0.0001
0 10 20 30 40 50 60 70 80 90 100
0 2 4 6 8 10 12 14 16 18 20
Probability (%) that Blood Lead Exceeds 10 µg/dl
Log Frequency
1
0.1
0.01
0.001
0.0001
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35
Probability (%) that Blood Lead Exceeds 10 µg/dl

Figure 4.

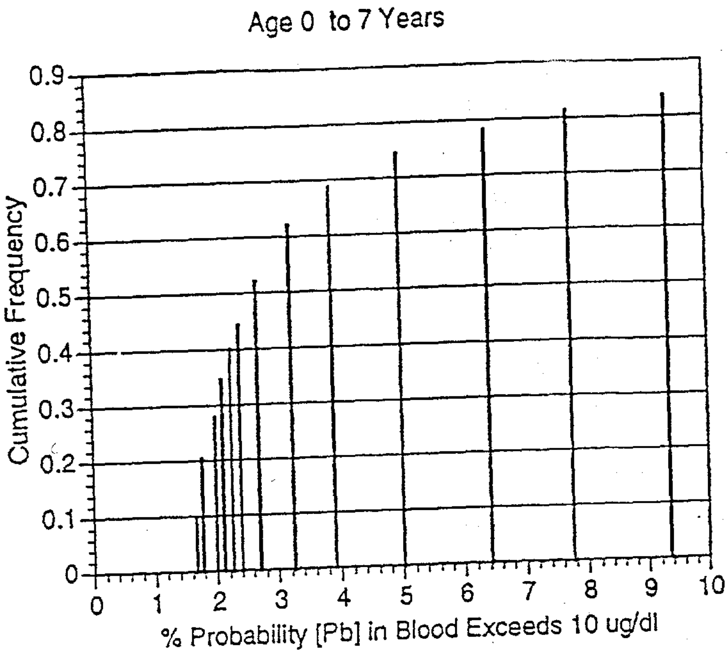


Figure 5

DISCLAIMER