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ABSTRACT

There is an unsurpassed lack of scientific data with respect to the concentrations and isotopic compositions of uranium, thorium, and radium in the produced formation fluids (brine), precipitates, and sludges generated with the operation of oil and gas wells in Mississippi. These radioactive elements when contained in the formation fluids have been given the term NORM, which is an acronym for naturally occurring radioactive materials. When they are technologically enhanced during oil and gas production activities resulting in the formation of scale (precipitates) and sludges they are termed TENORM (technologically enhanced naturally occurring radioactive materials). As a result of this lack of data no scientifically sound theses may be developed concerning the presence of these radionuclides in the fluid (brine), precipitate (scale), or sludge phases. Also there is little or no published information on the relative amounts or isotopic compositions of NORM in Mississippi. In relation to this lack of information, Mississippi oil and gas production produces vast amounts of formation water. Over the period of just one year, 1997 for example, Mississippi produced over 39,372,963,584 liters (10,402,368,186 gallons or 247,675,433 barrels) of formation water associated with hydrocarbon production from 41 oil and gas producing counties across the state.

Published studies have indicated that the main contributor to NORM in oil and gas production is radium and its daughters. Further, assumptions have been made concerning this issue especially with respect to the isotopic composition of the radium, i.e. ^{228}Ra versus ^{226}Ra, found in NORM. ^{228}Ra is a product in the decay chain of thorium (^{232}Th) and ^{226}Ra is the daughter product of the naturally occurring uranium (^{238}U) decay series. Few studies have been made concerning the isotopic composition of naturally occurring radium. It has been assumed that ^{228}Ra and ^{226}Ra are present in equal amounts. This assumption has not been supported or refuted in the literature. The underlying significance is that ^{226}Ra, which has a half-life of approximately 1,620 years, undergoes radioactive decay by emitting an alpha particle and a gamma ray; and ^{228}Ra, which has a half-life of approximately 5.76 years, undergoes radioactive decay by beta particle emission. Of these three radiation emissions, gamma emissions have been documented to be the most worrisome because of their capability to travel through steel, iron, etc.; they have a “whole body” penetrating ability because they can travel a considerable distance in body tissue. The following describes each of the radioactive decays which are of concern in NORM.

Alpha (α) decay **-** during alpha decay literally a portion of the nucleus is ejected, which is comprised of 2 neutrons and 2 protons bound together with no orbital electrons. This is equivalent to the nucleus of a helium atom, less its electrons. This gives it an atomic mass number of four (4) and a net electrical charge of +2e.

Beta (β) decay **-** beta decay occurs when there is a radioactive transformation of a nuclide in which the atomic number decreases or increases by unity and there is no change in mass number. During beta decay the nucleus ejects a high-energy electron (not from the electron shells that surround the nucleus). The mass of the beta particle

is 1/1836 that of a proton or neutron and the same as that of an electron. A beta particle is typically a single, negatively charged particle. Less commonly beta particles may also have a positive charge; these are termed positrons and are the anti-matter equivalent of an electron. Note that beta particles do not exist independently inside the nucleus, but are created during the instant of emission.

Gamma (γ) decay - gamma decay or radiation is excess energy which is released from the nucleus of an atom and has no mass or electrical charge. Because of the lack of mass and charge gamma rays may pass through a large number of atoms without any interaction taking place. Gamma radiation or gamma rays is a form of electromagnetic radiation and consists of photons, which are small packets of energy. As a result gamma rays exhibit properties of both waves and massless particles, traveling at the speed of light. Occasionally they will interact with an atomic electron or nucleus. Of the several interactions possible the following are of importance:

> Photoelectric Effect: In this interaction the energy of the gamma ray is completely transferred to an atomic electron which is ejected from its atom. The gamma ray ceases to exist after the collision.
>
> Compton Effect: The gamma ray loses only part of its energy in its interaction with an atomic electron. The electron is ejected from its atom along with a gamma ray of reduced energy.
>
> Pair Production: Gamma rays with an energy greater than about 1.2 MeV may interact with an atomic nucleus to form an electron-positron pair. The gamma ray energy is completely converted into the mass and kinetic energy of the electron and positron with only a very small amount going to the nucleus in order to conserve momentum.

All three of the preceding reactions result in the production of either energetic electrons or electrons and positrons.

The intent of this study, however, is not to assess radiation risk associated with NORM or TENORM but to contribute primary, unbiased data which will provide the knowledge base from which rational, informed, social, economic, and environmentally sound decisions may be made. The NORM/TENORM database that will be developed during the course of this study will be extremely useful in any epidemiological studies and inferences concerning the issue.

It is anticipated that this database development will include identification of relevant references in the geological literature, acquisition of necessary petrophysical well logs, identification of oil and gas pools from these logs, and provision of guidance as to implications of rock type and petrogenesis as to the occurrence of NORM in Mississippi. This information and the database that will be developed may also be usefully applied

to other areas of the United States as well as on a global basis where NORM is an issue of consideration and importance.

Where indicated and available, well sample cuttings and/or core chips of producing reservoirs with high NORM concentrations will be examined. Additional studies where warranted on these sample cuttings and/or core chips may include thin sections, electron microscopy, and/or X-ray diffractograms.

TABLE OF CONTENTS

PAGE

Disclaimer i

Abstract ii

Table of Contents v

Executive Summary 1

Introduction 3

Field Collection Procedures 5

Disposition of Samples 6

Standard Method for Analysis of Radium 6

A. Sample processing 6

B. Analysis of radium 7

C. Summary of preliminary chemical and isotopic data 8

Conclusion 9

References 10

List of Acronyms, Abbreviations, and Definitions 12

FIGURES

Figure 1. NORM sample index map 13

Figure 2. Collection of brine sample at wellhead 14

Figure 3. Transfer of collected sample into sample container 14

Figure 4. Laboratory setting - NORM sample preparation at RIPS 15

EXECUTIVE SUMMARY

As reported in previous semi-annual reports, during the initial “start-up” period, the background infrastructure for the project was developed for the major work required in the later phases of the investigation. A significant portion of the work involved consultations with the investigators of each respective agency, i.e. the Mississippi Office of Geology, the Mississippi Mineral Resources Institute (MMRI) and the Research Institute of Pharmacological Science (RIPS). As a result of these discussions there is currently in place a standard procedure for sample collection, labeling, and handling that is both unambiguous and straightforward. An equally important aspect of the sample collection procedure is the maintenance of custody records which can accurately document the handling of the sample(s) from the field collection site(s) to the final laboratory analysis(es). The important aspect of this task was not only to create a workable system, but to assure that all three organizations intimately understand how it will work so as to minimize the potential of errors during sample handling.

To date a total of approximately 1,500 liters of oil field brines has been collected from 182 wells from several different producing horizons and fields in Mississippi. As noted in the first semi-annual report, approximately 150 liters of oil field brines were initially collected from 16 wells completed in several different producing horizons in Baxterville Field, located in Lamar County, Mississippi. Baxterville Field ranks as the most prolific oil producing field in the state and is ranked as the third largest field in cumulative production. Baxterville has been continuously producing hydrocarbons since its discovery in November, 1944. Along with the brines which were collected from the operational oil wells completed in the Lower Tuscaloosa "stringer" sands and the Lower Tuscaloosa Massive Sand (Mesozoic Erathem, Cretaceous System, Upper Cretaceous Series, Tuscaloosa Group), 8 liters of produced formation brine were also obtained from an Eagleford gas pool at Baxterville (Upper Cretaceous Series, Lower Eutaw Group). Baxterville Field ranks third in the state in cumulative gas production. Formation brine samples were also collected at South Smithdale Field, located in Amite County, Mississippi, a Sparta gas field (Cenozoic Erathem, Tertiary System, Middle Eocene Series, Claiborne Group). Previous sampling during a pilot, pre-grant phase recovered brines from a Rodessa oil pool at Traxler Field, located in Smith County (Cretaceous System, Lower Cretaceous Series, Trinity Group, Glen Rose Sub-group), and at several Wilcox fields (Cenozoic Erathem, Tertiary System, Eocene Series, Wilcox Group), located in the southwestern portion of the state.

To date, during the sampling conducted under this grant, brines have been recovered from producing horizons ranging in age from the Upper Jurassic through the Upper Cretaceous at the following 32 fields located in the Mississippi Interior Salt Basin: Quitman, Davis, and Frances Creek (Clarke County); Brownsville Dome, Bolton, and Edwards (Hinds County); West Paulding, Verba, East Heidelberg, and West Heidelberg (Jasper County); Pool Creek, Reedy Creek, Sandersville, Summerland, and Laurel (Jones County); Baxterville (Lamar County); East Flora and Flora (Madison County); East Apollo (Perry County); Puckett (Rankin County); Boykin Church and Mize (Smith

County); North Clara, West Yellow Creek, Cypress Creek, Diamond, Eucutta, East Eucutta, and South Thompson Creek (Wayne County); Satartia and Tinsley (Yazoo County); and SoSo (Jasper, Smith, and Jones counties).

In addition to these samples, brine samples have also been collected at the following four (4) fields: Buttahatchie, Maple Branch, and McKinley Creek fields (Monroe County), and Corinne Field (Monroe, Clay, and Lowndes counties), all of which are located and productive from the Paleozoic-age Black Warrior Basin (Mississippian System, Chesterian Series). Figure 1 depicts the areas within the state, on a county basis, where brine samples have been collected.

Complete analysis of 89 brine samples from 20 fields have been performed and partial analyses have been performed on 39 additional samples and 9 additional fields. Brine pH values have ranged from 3.66 to 7.74 with an average of 5.69. It has been observed that the pH values can change by as much as 0.5 pH units upon storage. This is most probably due to uptake of CO_2 from the atmosphere. Dissolved solutes have ranged from 0.2 g/l to 315.8 g/l with an average of 155.44 g/l. The low dissolved solute of 0.2 g/l came from a sample collected at Maple Branch Field in the Black Warrior Basin. This sample as well as others collected from Black Warrior Basin wells all had low solute concentrations. This may be the result of maintenance work which had been performed at these facilities which involved the introduction of fresh water into the salt water storage tanks. If one does not consider the values of the Black Warrior samples or other anomalous samples, the range of dissolved solute is from 114.4 g/l to 315.8 g/l. ^{226}Ra concentration levels range from 0.142 to 22.66 pM/l with an average of 7.14 pM/l. ^{228}Ra levels have ranged from 0 to 3.41 fM/l with an average of 0.66 fM/l. The ratio of molar concentrations of ^{226}Ra to ^{228}Ra ranges from 1,106 to 67,660 and averages 11,125.

INTRODUCTION

There is an unsurpassed lack of scientific data with respect to the concentrations and isotopic compositions of uranium, thorium, and radium in the produced formation fluids (brine), precipitates, and sludges generated with the operation of oil and gas wells in Mississippi. These radioactive elements when contained in the formation fluids have been given the term NORM, which is an acronym for naturally occurring radioactive materials. When they are technologically enhanced during oil and gas production activities resulting in the formation of scale (precipitates) and sludges they are termed TENORM (technologically enhanced naturally occurring radioactive materials). As used in this document, NORM and TENORM will be considered equivalent terms and the occurrence of NORM in the oilfield will be considered the result of production operations. As a result of the lack of data no scientifically sound theses may be developed concerning the presence of these radionuclides in the fluid (brine), precipitate (scale), or sludge phases. Over the period of just one year, 1997 for example, Mississippi produced over 39,372,963,584 liters (10,402,368,186 gallons or 247,675,433 barrels) of formation water associated with hydrocarbon production from 41 counties across the state.

Published studies have indicated that the main contributor to NORM in oil and gas production is radium. Further, assumptions have been made concerning the isotopic composition of the radium, i.e. ^{228}Ra versus ^{226}Ra, found in NORM. ^{228}Ra is a product in the decay chain of ^{232}Th and ^{226}Ra is the daughter product of the naturally occurring ^{238}U decay series. Few studies have been made concerning the isotopic composition of naturally occurring radium. It has been assumed that ^{228}Ra and ^{226}Ra are present in equal amounts. This assumption has yet to be supported or refuted in the literature. This study is exploring that issue, i.e. determination of the ^{226}Ra and ^{228}Ra abundances and resulting ratios. The underlying significance is that ^{226}Ra, which has a half-life of approximately 1,620 years, undergoes radioactive decay by emitting an alpha (α) particle and a gamma (γ) ray; and ^{228}Ra, which has a half-life of approximately 5.76 years, undergoes radioactive decay by beta (β) particle emission. Of these three radiation emissions, gamma emissions have been documented to be the most worrisome because of their capability to travel through steel, iron, etc.; they have a “whole body” penetrating ability because they can travel a considerable distance in body tissue.

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The intent of this study, however, is not to assess radiation risk associated with NORM or TENORM nor to assess its effects on biologic tissue. The purpose of the study is to contribute primary, unbiased data which will provide the knowledge base from which rational, informed, social, economic, and environmentally sound decisions may be made. The NORM/TENORM database that will be developed during the course of this study will be extremely useful in any epidemiological studies and inferences concerning the issue.

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Overall, during the course of the present study, sampling has recovered brines from producing horizons ranging in age from the Upper Jurassic through the Upper Cretaceous at the following 32 fields located in the Mississippi Interior Salt Basin: Quitman, Davis, and Frances Creek (Clarke County); Brownsville Dome, Bolton, and Edwards (Hinds County); West Paulding, Verba, East Heidelberg, and West Heidelberg (Jasper County); Pool Creek, Reedy Creek, Sandersville, Summerland, and Laurel (Jones County); Baxterville (Lamar County); East Flora and Flora (Madison County); East Apollo (Perry County); Puckett (Rankin County); Boykin Church and Mize (Smith County); North Clara, West Yellow Creek, Cypress Creek, Diamond, Eucutta, East Eucutta, and South Thompson Creek (Wayne County); Satartia and Tinsley (Yazoo County); and SoSo (Jasper, Smith, and Jones counties).

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Located at the end of this report is a list of acronyms, abbreviations, and definitions. Please refer to page 12 for this information.

FIELD COLLECTION PROCEDURES

As a result of the emulsified nature of the produced fluid at the wellhead with respect to oil content, on-site sampling procedures had to be devised to help minimize the amount of oil included in the collected, produced fluids. To minimize the amount of oil, the fluid being produced at the wellhead was first collected in a 20 liter sampling container

equipped with an on/off valve located at its base. After the container was filled approximately two-thirds to three-quarters full, the collected fluid was allowed to sit briefly, which allowed a partial separation of the produced oil and water. Because of its lesser density the oil was the upper layer. The produced brine, which was the lower, more dense layer, was then transferred to a 4-liter sample container by simply opening the valve at the base of the collection container, which allowed the water phase to be removed without introduction of large amounts of oil with the brine.

Figures 2 and 3 illustrate this sample collection process. During the course of sampling the preferred source was at the wellhead. However, this was not always possible generally as a result of emulsions which would not break into water/oil phases, because there were no valves to remove fluid at the wellhead, or because the gravity of the oil was so low it could not physically be poured into the sample containers. When a sample could not be collected at the wellhead, other sample collection sources were, in order of preference: 1) flow lines to separators, heater treaters, or salt water storage tanks, 2) separators, 3) heater treaters, and 4) salt water storage tanks.

DISPOSITION OF SAMPLES

At each sample collection point approximately 8 liters of produced formation fluid is being collected. During the current chemical analysis procedure, approximately 4 liters of each sample is utilized; a portion of this (500 ml) is being acidified and stored for potential future reference. The remaining 4 liters of fluid are being stored for any additional chemical analyses which may be required or desired.

STANDARD METHOD FOR ANALYSIS OF RADIUM

The standard method that has been developed for analysis of radium in produced waters from hydrocarbon production is as follows. This method corrects for the following: 1) high and variable solute concentrations and compositions encountered in produced formation waters; and 2) radium that might become insoluble during storage of the samples. The developed method also determines the ratios of ^{226}Ra and ^{228}Ra present in the samples.

A. Sample processing

Approximately 30 ml of each 4-liter brine sample is passed through a Whatman #1 paper filter to remove suspended oil. 10 ml of this is placed into a pre-weighed flask, weighed, dried, and re-weighed to determine the density and the dissolved solute content. The pH is taken on the remainder of this aliquot.

The volume of the remainder of the 4-liter sample is measured, 100 ml of concentrated

HCl is added per liter and most of this is returned to the original container and allowed to sit until all of the precipitated material has been dissolved off of the container walls. The entire sample is then recombined and filtered through two layers of Whatman #1 filter paper to remove suspended oil. Eleven ml of the filtrate is placed in a pre-weighed vial, dried and weighed. Next 1.1 liter is taken for analysis of radium content, and the remainder is placed in a clean container for storage. Each sample is analyzed for radium content a minimum of two (2) times by taking additional 1.1 liter aliquots with at least a 1 week interval between replicate analyses.

B. Analysis of radium

The 1.1 liter acidified brine sample is divided into two 550 ml aliquots. One aliquot is spiked with 25 nCi of ^{226}Ra by adding 50 μl of 0.5 μCi/ml $^{226}RaCl$. Then 25g of powdered anhydrous Na_2CO_3 is added gradually to each 550 ml brine sample and stirred until completely dissolved. Then 32% w/v Na_2CO_3 in water is added slowly, dropwise, under the control of a peristaltic pump, with stirring until the solution color changes from bright yellow to dark amber. An additional 100 ml of 32% w/v Na_2CO_3 is added dropwise, and the mixture is stirred for 15 minutes and filtered through Whatman #1 filter paper. The filtrate receives another 100 ml addition of sodium carbonate solution as before, followed by filtering. This step is repeated until no further precipitate forms with added sodium carbonate. This procedure results in quantitative precipitation of the radium from the brine solution and it separates the radium from the monovalent cations, which are the major sources of interference with radium binding to the 3-M Company Radium Rad Disks. The precipitates are combined and redissolved to a resultant 1 liter volume with 2 N nitric acid. This solution is prefiltered through Whatman 0.45μm cellulose nitrate membrane filters and then filtered through Radium Rad Disks. Depending upon the amount and composition of the salts from the brine, 40 to 100% of the radium from the sample is captured on the Rad Disk by this procedure. Because of the large variability in recovery from one brine to another it is necessary to run a spiked sample as an internal standard to determine recovery for each brine sample.

The Rad Disk is then <u>immediately</u> counted for 30 minutes in a gamma counter to quantify the 186 KeV gamma emission of ^{226}Ra. If the Rad Disks are allowed to age, daughter isotopes grow in and interfere with the quantification. The Rad Disks from the unspiked samples are then placed in a desiccator jar under vacuum with $CaSO_4$ desiccant and activated charcoal and aged for 2 weeks. This allows ^{228}Ac, a daughter of ^{228}Ra, to grow in and equilibrate. Storage with desiccant and activated charcoal under vacuum helps to pull off and adsorb volatile ^{222}Rn, the first daughter of ^{226}Ra. This minimizes possible interference with quantification of ^{228}Ac. The aged Rad Disks are then counted for 30 minutes in a gamma counter to quantify the 911 and 969 KeV emissions of ^{228}Ac. The content of ^{228}Ra is determined from this by calculation. Similarly, the amounts of ^{238}U and ^{232}Th that were, theoretically, in equilibrium with the brines in the substratum are calculated.

Each brine is analyzed through two complete replicates of spiked and unspiked aliquots with at least one week between replicate analyses. When the two spiked replicates are within 10% of one another the analysis is considered accurate. If the two spiked replicates are greater than 10% different, then a third replicate analysis of both spiked and unspiked is performed. Occasionally, when there are several brine samples from a single field, and they all have similar pH and solute concentrations, and the radium recoveries are within 10% of one another from at least half of the brines from that field, then only one spiked replicate is run for the remaining brines. The analysis is considered complete if the single analysis falls within 10% of the average for the field. Samples containing less than 25 g/l of dissolved solutes are not analyzed beyond the solute and pH measurements since the amounts of ^{226}Ra and ^{228}Ra likely to be contained therein would be less than experimental error for the measurement.

C. Summary of preliminary chemical and isotopic data

To date complete analyses of 89 brine samples from 20 fields and partial analyses of 39 additional samples from 9 additional fields have been performed. Brine pH values have ranged from 3.66 to 7.74 with an average of 5.69. It has been observed that the pH values can change by as much as 0.5 pH units upon storage. This is most probably due to uptake of CO_2 from the atmosphere. Dissolved solutes have ranged from 0.2 g/l to 315.8 g/l with an average of 155.44 g/l. The low dissolved solute of 0.2 g/l came from a sample collected at Maple Branch Field in the Black Warrior Basin. This sample as well as others collected from Black Warrior Basin wells all had low solute concentrations. This may be the result of maintenance work which had been performed at these facilities which involved the introduction of fresh water into the salt water storage tanks. If one does not consider the values of the Black Warrior samples or other anomalous samples, the range of dissolved solute is from 114.4 g/l to 315.8 g/l. ^{226}Ra concentration levels range from 0.142 to 22.66 pM/l with an average of 7.14 pM/l. ^{228}Ra levels have ranged from 0 to 3.41 fM/l with an average of 0.66 fM/l. The ratio of molar concentrations of ^{226}Ra to ^{228}Ra ranges from 1,106 to 67,660 and averages 11,125.

Figure 4 is a photograph of the laboratory where the chemical and isotope geochemistry is being performed. Please refer to each figure for additional descriptive information.

Recent studies have indicated a correlation between total chlorinity and radium content (e.g., Fisher, 1998). This current study has been modified to analyze samples for total chlorinity to evaluate the correlation. Current data neither confirm nor deny the correlation which has been noted.

Of the fields analyzed to date, Brownsville and Reedy Creek have produced the highest concentrations of radium. However, even these highest concentrations are still very low.

CONCLUSION

As noted, the data presented herein are preliminary. The complete isotopic and concentration analyses for radium, thorium, and uranium will be presented with the final report of this study.

Since the radium chloride has been received, spiked samples have been run, the methodology has been perfected, and analyses have been utilizing the methodology as presented herein. Sample analysis has been proceeding on a relatively uniform schedule. As noted, the analyses of 89 brine samples from 20 fields have been completed and partial analyses of 39 samples from 9 additional fields have been performed.

As reported in previous semi-annual reports we placed thermoluminescent dosimeters out in the field in an area which had elevated background NORM. These dosimeters, which were designed to be sensitive to gamma rays, were placed to determine the variation in gamma radiation emitted versus distance from the apparent emitting source of NORM. One dosimeter was placed on the wall of an apparent gamma radiating source one (1) meter above ground level and another was placed at a distance of one (1) meter, at a height of one (1) meter. The dosimeters were left in the field for approximately one month and then collected and sent in for analysis. The result of the field test was that the thermoluminescent dosimeter which was placed on the wall of the emitting source received the equivalent of 1.08 rem/year. On a monthly basis this would be approximately equivalent to 90 mrem/month or 3 mrem/24 hour day. The dosimeter which was located one (1) meter away at a one (1) meter height from the apparent emitter did not receive any gamma radiation greater than background as compared to dosimeters which were at an ambient, non-NORM site.

Also noted in previous semi-annual reports we have also been collecting soil samples from areas of oil and gas operations and other areas which have elevated NORM readings. A portion of these samples are currently being exposed to simulated rain/acid-rain conditions. The purpose of this experiment is to ascertain the potential for mobilizing the NORM contained therein. From the results of these experiments it is anticipated that a better understanding of radium and its potential pathways of movement in the environment may be developed. We are also looking into the effects, if any, which may result from the interactions of scale and sludge with soil and soil microorganisms and the effects that these may have on mobilization of the radium contained therein.

Oil and gas operators in Mississippi continue to provide us with virtually unlimited access to producing properties and it appears that the goals of the brine sampling phase of this investigation will be accomplished. It is anticipated that additional samples will be collected from the Black Warrior Basin and Mississippi Interior Salt Basin fields, as well as producing areas in the Wilcox Trend, located in the southwestern portion of the state, over the next six (6) months.

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List of Acronyms, Abbreviations, and Definitions:

1,000 electron volts . . . . . KeV
alpha . . . . . α
barrel(s) . . . . . 42 gallons = 168 quarts = 158.97 liters = bbl(s)
beta . . . . . β
bbl(s) . . . . . barrel(s)
Ci . . . curie = 3.7 X 10^{10} disintegrations per second (dps) = 2.22 X 10^{12} disintegrations per minute (dpm)
counts per minute . . . . . cpm ≈ disintegrations per minute
cpm . . . . . counts per minute
curie . . . Ci = 3.7 X 10^{10} disintegrations per second (dps) = 2.22 X 10^{12} disintegrations per minute (dpm)
eV . . . . . electron volt
electron volt . . . . . eV
fM . . . . . femtomole = 1 X 10^{-15} mole
femtomole(s) . . . . . fM = 1 X 10^{-15} mole(s)
g . . . . . gram
gamma . . . . . γ
gram . . . . . g
KeV . . . . . 1,000 electron volts
L or l . . . . . liter
liter l
M . . . . . molar
μM . . . . . micromole = 1 X 10^{-6} mole
micromole(s) . . . . . μM = 1 X 10^{-6} mole(s)
milliliter . . . . . ml
Mississippi Mineral Resources Institute . . . . . MMRI
ml . . . . . milliliter
MMRI . . . . . Mississippi Mineral Resources Institute
molar . . . . . M
N . . . . . Normal
nanocurie(s) . . . . . nCi = 1 X 10^{-9} curie(s)
Naturally Occurring Radioactive Materials . . . . . NORM
nCi . . . . . 1 X 10^{-9} curie
NORM . . . . . Naturally Occurring Radioactive Materials
Normal . . . . . N
pCi . . . . . picocurie = 1 X 10^{-12} curie
picocurie(s) . . . . . pCi = 1 X 10^{-12} curie(s)
picomole(s) . . . . . pM = 1 X 10^{-12} mole(s)
pM . . . . . picomole = 1 X 10^{-12} mole
Research Institute of Pharmaceutical Science . . . . . RIPS
RIPS . . . . . Research Institute of Pharmaceutical Science
Technologically Enhanced Naturally Occurring Radioactive Materials . . . . . TENORM
TENORM . . . . . Technologically Enhanced Naturally Occurring Radioactive Materials
w/v . . . . . weight per volume
weight per volume . . . . . w/v

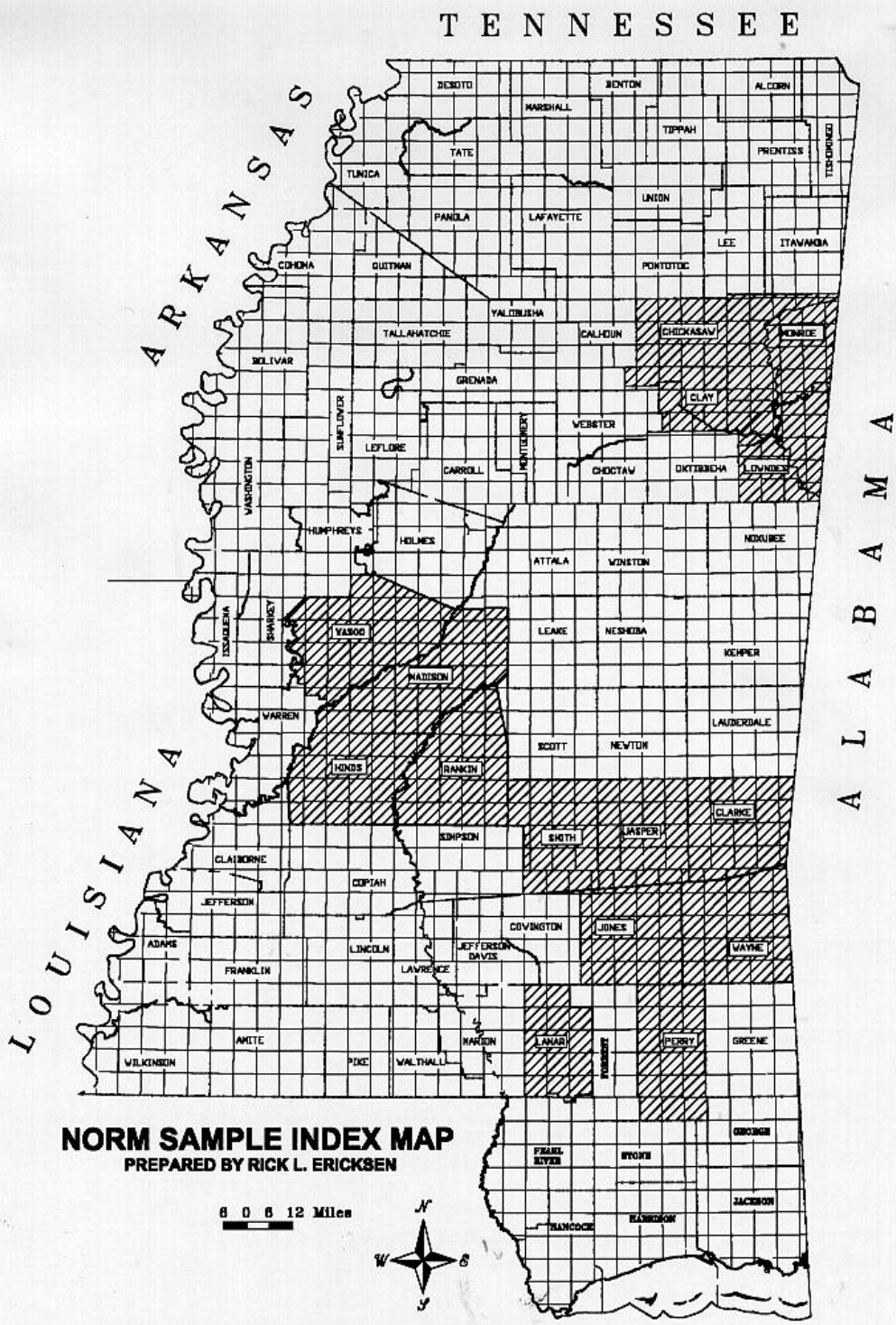

Figure 1. NORM sample collection areas, county-wide basis.

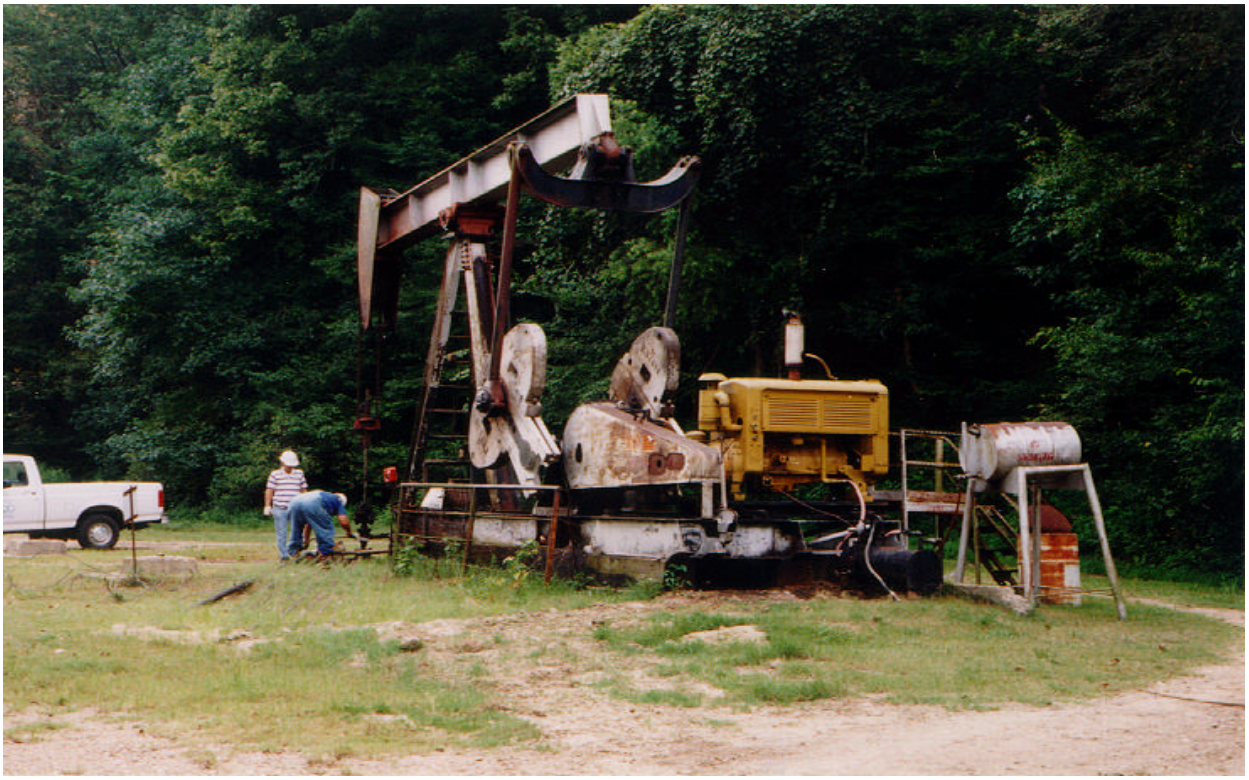

Figure 2. Collection of brine sample at well head.

Figure 3. Transfer of collected sample into sample container.

Figure 4. Laboratory setting - NORM sample preparation at the Research Institute of Pharmacological Science, University, Mississippi.