OCCUPATIONAL EXPOSURES TO RADIOACTIVE SCALE AND SLUDGE

Coleman *et al* v. H.C. Price Co. *et al*

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Report Prepared by

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1.0 Introduction

Radioactive Waste Management Associates has been retained by the Smith Stag law firm to evaluate the radiation and toxic exposures of the 33 plaintiffs involved in the case Coleman et al v. H.C. Price Co. et al.

The aforementioned plaintiffs worked in pipe yards and on onshore and offshore oil production rigs for various companies in Louisiana[1]. During these times, the workers were regularly exposed, without their knowledge, to naturally occurring radioactive material (NORM) in the course of oil field pipe cleaning and refurbishing operations at the pipe yards and oil production rigs. Workers were exposed to radiation through inhalation of the radioactive scale dust, incidental ingestion of radioactive scale dust and radioactive sludge, and to external radiation from the scale and sludge in the oil production pipes, radiographic inspections and from the scale and sludge deposited on their clothing and the ground of their work areas.

The plaintiffs were diagnosed with cancer, which we determined to be a consequence of their occupational exposures to radiation. Two of the thirty-three plaintiffs were diagnosed with diseases that often precede a cancer diagnosis. The remaining thirty-one plaintiffs involved in the case Coleman et al v. H.C. Price Co. et al. have been diagnosed with cancer, which we determined to be a consequence of their occupational exposures to radiation.

There were no radiation protection programs at the pipe yards and on the oil production rigs on which the workers worked and therefore no radiation measurements were made at the time the work was performed. Thus, the true radiation doses received by these workers will never be exactly known. In this report, a range of likely radiation doses is employed based on the technical literature. It is very likely that workers received doses well in excess of applicable limits to nuclear industry workers. This conclusion is evident even when modest values for exposure factors are used (scale and sludge activities, breathing rates, dust loadings, and so on). The radiation doses received by the workers greatly increased the workers' risk of developing cancer.

To prepare this report we reviewed court petitions, exhibits, deposition transcripts, previous work in similar cases, and the plaintiffs' medical and social security records. Interviews with the plaintiffs or the plaintiffs' family members were also conducted as well as several articles and reference documents which are listed at the end of this report. We performed spreadsheet calculations using standard dosimetry methodology for exposure to radiological contaminants, which are summarized in the tables at the end of the text. As additional information becomes available, we reserve the right to supplement this report.

2.0 Naturally Occurring Radioactive Materials (NORM)

As discussed earlier, the workers were exposed to naturally occurring radioactive materials (NORM) in scale and sludge though a variety of different pathways, including inhalation of scale dust, incidental ingestion of scale dust and sludge, and external direct gamma radiation emanating from radiographic inspections and scale and sludge deposited on the workers' clothing, work equipment, and on the floor of their work areas. Radiation exposure is assumed to have occurred from radium-226 (Ra-226) and

[1] See Section 5 for detailed descriptions of the plaintiffs' work histories.

radium-228 (Ra-228) and their radioactive decay products (all of which are assumed to be in secular equilibrium).

The following sections describe the presence of Ra-226 and Ra-228 in oil production piping. A more detailed discussion of the activities of scale and sludge used in this report can be found in Appendix A.

2.1 Radioactivity in Scale

Louisiana contains elevated naturally occurring radioactive materials (NORM) concentrations in its oil and natural gas production equipment[2]. When oil and natural gas are pumped from an underground formation, water contained within the formation is also extracted with the oil and gas. This water, known as produced water, contains dissolved mineral salts, which are radioactive. Uranium and thorium compounds are fairly insoluble and remain in the formation, but Ra-226 and Ra-228, progeny of uranium and thorium, are more soluble in water and become mobilized in the reservoir liquid.

As the natural pressure and temperature within the bearing formation falls, the dissolved solids in produced water precipitate out of solution and deposit as scale within the oil production piping. Scale, a hard residue, consists of salts that are composed of mainly barium, calcium, and strontium compounds. Because radium (Ra-226 and Ra-228 combined) shares similar chemical properties with these three elements, it also precipitates to form complex sulfate and carbonate salts in scale. Higher salinity in produced water results in higher radium concentrations, although the presence of high salinity does not necessarily mean that the water contains radium.

Scale is typically found in piping and tubing (oil flow and water lines), injection and production well tubing, manifold piping, and small diameter valves, meters, screens, and filters. According to the American Petroleum Institute (API), radium concentrations in scale tend to be highest in wellhead piping and in production piping near the wellhead, with concentrations as high as tens of thousands pCi/g. The largest volumes of scale have been found in water lines associated with separators, heater treaters, and gas dehydrators.

Scale in an oil production well increases over time, i.e. the scale buildup will be thickest in pipes that have been in the ground the longest. The thickness of scale build up in production piping and equipment may vary from a few millimeters to more than an inch. At times the scale may build up in production equipment to completely block the flow in 4-inch diameter pipes.

It is not clear that the contaminated piping with which the plaintiffs worked was screened for radioactivity before being handled by the plaintiffs. Because direct measurements are not available, we estimate the radioactivity in scale using reported measurements by the U.S. Environmental Protection Agency (US EPA)[3], Chevron[4] and Reed et al.[5].

[2] US EPA, 1993b
[3] US EPA, 1987
[4] NORM Study Team, 1990
[5] Reed, G, B Holland, and A McArthur, 1991

A study performed by the Chevron NORM Study Team reported an average Ra-226 content of 5,500 pCi/g for pipe scale[6]. The maximum readings observed in this study were much higher than this value. In addition, an earlier analysis by Chevron found a similar average of 5,960 pCi/g Ra-226 in pipe scale[7]. The report by Reed, *et al*. lists Ra-226 concentrations in pipe scale up to 6,027 pCi/g. Based on these studies, in this report we assume an average Ra-226 concentration of 6,000 pCi/g in pipe scale.

The ratio of Ra-226 to Ra-228 activity concentrations in fresh pipe scale is reported to be approximately 3:1[8,9]. Based on these findings, in this report we use a concentration of 6,000 pCi/g for Ra-226 and 2,000 pCi/g for Ra-228 in pipe scale. We assume secular equilibrium between Ra-226 and Ra-228 and their respective progeny, i.e. we apply the same activity in scale (in pCi/g) for the daughter nuclides as their parents.

Used, offshore oilfield production pipes contaminated with radioactive scale were handled onsite by many of the workers who worked on onshore and offshore production rigs and were also sent off-site to various pipe yards where workers cleaned and refurbished the contaminated pipes. Most often, used, contaminated pipes were cleaned by reaming out the scale using a rattler or sandblaster. In addition, pipes were also often cut and refurbished using acetylene torches. The scale removed from the cleaned pipes was generally left on the ground of the pipe yards after cleaning activities.

2.2 Radioactivity in Sludge

Like scale, sludge also deposits within oil production equipment. Sludges tend to accumulate on the oil and water side of the separation process, especially in areas where there are changes in pressure and temperature. The concentrations of radionuclides in sludge depend on the chemistry of the geologic formation and characteristics of the production process. Like scale, the quantity and concentration of sludge changes over time as the quantities of gas, oil, and water in the geologic formation change, with sludge increasing as the well ages and gas and oil are depleted.

Sludge deposits usually contain silica and are oily and loose, while dried sludge is more granular and has a consistency similar to that of soil. Some sludge remains oily even when dried.

Sludge deposited in oil production equipment during the extraction process is further removed from extraction fluids in the separator, a piece of oilfield production equipment that divides oil, gas and water into separate fluid streams based on their different densities. Thus, the extracted sludge tends to accumulate in the separator. The American Petroleum Institute (API) has determined that the greatest volumes of sludge settle and remain in the oil stock and water storage tanks. Like in scale, it appears that the activity of Ra-226 in sludge is approximately three times greater than that of Ra-228[10].

Since we do not have measurements of sludge concentrations present in production pipes of the oil rigs on which the plaintiffs worked, we use a range of sludge concentrations provided by the International

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[6] NORM Study Team, 1990
[7] Scott, LM, 1986
[8] US EPA, 1993a
[9] Wilson, AJ, and LM Scott, 1992
[10] US EPA, 1993a

Atomic Energy Agency (IAEA)[11]. These concentrations were measured in various locations within the United States and we believe them to be a representative range of the concentrations to which the plaintiffs were most likely exposed. Table 3 lists the range of activities of Ra-226 and Ra-228 and some of their progeny in oil production sludge. For the sludge calculations, we assume secular equilibrium between Ra-226 and Ra-228 and their respective progeny, i.e. we apply the same activity in sludge (pCi/g) for the daughter nuclides as their parent.

2.3 Regulation of NORM in Louisiana Pipe Yards

NORM regulations on contaminated oil production equipment in pipe yards were not enforced in Louisiana until 1989. Long before regulations specific to NORM were promulgated, the oil and gas industry was aware that radioactivity was present in oil production tubulars. Radioactivity in oil and brine was reported as early as the 1930's[12], the USGS reported radioactivity in Kansas oil fields[13] in the 1950's, and the American Petroleum Institute (API) issued a report in 1982 that analyzed the potential impact of the inclusion of radionuclides into the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[14] process of the petroleum industry. The report described in detail where specific radionuclides were prevalent: Uranium in crude oil, radium in brine, and radon in both oil and brine[15]. The report concluded, "*the regulation of radionuclides could impose a severe burden on API member companies*".

The first rules in Louisiana that specifically addressed NORM in relation to oil field equipment and pipe yards were promulgated by a "Declaration of Emergency" in February 1989. In September 1989, the Division of Radiation Control issued the State's current regulations regarding radioactive materials associated with oil and gas producing operations through the Department of Environmental Quality (DEQ) under Title 33 Part XV, Radiation Protection. The regulations state that individual pieces of incoming pipe yard shipments cannot exceed a dose rate limit of 50 µR/hr. Workers who are to handle equipment that exceeds the 50 µR/hr-limit require an appropriate license. Workers without an appropriate license could not work. These regulations are discussed in greater detail in section 7.0 of this report.

It is unclear to us when, or if at all, the pipe yards in which the plaintiffs worked began scanning their incoming shipments of used, contaminated oil production piping. In this report, we assume that all companies for which the plaintiffs worked abided by all regulations beginning in 1990, even though the regulations were repealed and repromulgated in 1992. In our calculations, we assume no pipes entering the pipe yard facilities after 1990 exceeded the limit of 50 µR/hr. If the pipe yards did not actually begin to scan their shipments in 1990, the actual radiation dose received by the plaintiffs will be greater than the doses calculated in this report.

[11] IAEA, 2003
[12] Komlev, LV, 1933
[13] Armbrust, BF, and PK Kuroda, 1956
[14] Also commonly known as the Superfund Act. This law created a tax on the chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment.
[15] API, 1982

In order to determine the concentrations of Ra-226 and Ra-228 that correspond to a dose rate of 50 µR/hr, we employed the program MicroShield Version 8.02[16], by Grove Software, Incorporated. MicroShield is a program used to estimate dose rates due to a specific external radiation source.

A linear relationship exists between radiation concentrations and their corresponding external dose rates. Therefore, we first used MicroShield to obtain the dose rate that corresponds to the total radium (Ra-226 + Ra-228) concentration in scale used in this report. We then extrapolated these results to determine the radium concentration that corresponds with a dose rate of 50 µR/hr.

As inputs to MicroShield, we assume an outer pipe diameter of 2 7/8 inches (7.3025 cm), a scale thickness of 0.2 cm, and a pipe wall thickness of 0.551 cm, as suggested by the US EPA[17]. We assume that each contaminated pipe is 30 feet long, and that radiation measurements would have been taken at the center of the pipe, on contact with the outer pipe wall. From MicroShield, we obtain a Ra-226 concentration in scale of 1,313.5 pCi/g, and a Ra-228 concentration in scale of 437.8 pCi/g that correspond with a dose rate of 50 µR/h.

Since Louisiana's NORM regulations apply only to oil production equipment entering pipe yards, we do not adjust the radioactivity of the scale and sludge the plaintiffs were exposed to on onshore and offshore oil production rigs after the year 1990.

A more detailed discussion on the activities of scale used in this report can be found in Appendix A. The following section describes the health effects caused by exposure to radioactive materials.

3.0 Radiation Exposure Pathways

Workers were occupationally exposed to radiation while working at various pipe cleaning yards and onshore and offshore oil production rigs. For the time workers spent working in these locations, they were primarily exposed to radiation via inhalation of radioactive scale dust, incidental ingestion of radioactive scale dust and sludge, and direct gamma radiation.

We calculate the radiation dose rate due to inhalation and ingestion of radioactive scale and sludge by first calculating the amount of radioactivity that a person inhaled or ingested per unit time, and then by employing standard dose conversion factors (DCFs) recommended by the International Commission on Radiological Protection (ICRP). These DCFs convert an amount of a specific inhaled or ingested radionuclide into the resulting inhalation or ingestion dose. Age-dependent DCFs from ICRP 68[18] (specific for workers) were also used to calculate doses from the inhalation and ingestion of radioactive materials. These age-dependent DCFs have been compiled into a database and put on the CD-ROM, ICRPDOSE2[19]. For this report, the appropriate DCFs were extracted from the database and used in our dose calculations.

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[16] Grove Software Incorporated, 2008
[17] US EPA, 1993b
[18] ICRP, 1995
[19] ICRP, 2001

In addition to being age-dependent, ICRP 68 DCFs are specific to effected organ and/or tissue types (i.e., if a worker was diagnosed with bladder cancer, ICRP 68 DCFs specific to the bladder were used). In our calculations, we use the appropriate target organ recommended for each of the plaintiffs' cancer types by the National Institute of Occupational Safety and Health (NIOSH)[20].

The ICRP 68 DCFs were scaled in one-year increments of the commitment period to which each of the pipe yard workers were exposed to radiation. A commitment period is the time period between when a person is diagnosed with cancer and the time he was first exposed to radioactive materials. For example, if a pipe yard worker began working in 1973 and he was diagnosed with cancer in 1987, in 1973 he had a commitment period of 15 years, in 1974 a commitment period of 14 years, in 1975 a commitment period of 13 years, and so on and so forth.

For direct gamma radiation exposure, we employ the program MicroShield, version 8.02[21], developed by Grove Software, Incorporated. MicroShield 8.02 is a program used to estimate external dose rates due to specific radiation source geometries. The program allows its user to choose from sixteen different source geometries (such as a cylinder, sphere, disk, or rectangle) and up to ten different radiation shields. The program does not allow the use of multiple source geometries at a single time.

MicroShield users may also choose custom source and shield materials from the MicroShield database, or design their own source and shield materials with the option of over thirty different constituents. When designing a source or shield material, MicroShield calculates the attenuation and build up factors of all constituents.

MicroShield simultaneously calculates un-collided and build up results for 19 different organs by employing ICRP 74 dose conversion factors. ICRP 74[22] dose conversion factors link the operational quantities defined by International Commission of Radiation Units (ICRU) with the dosimetric and protection quantities defined by the International Commission on Radiological Protection (ICRP). We use MicroShield to calculate external radiation doses to the appropriate target organ for each of the plaintiffs' specific cancer type, as recommended by NIOSH[23].

3.1 Dose Due to Inhalation of Radioactive Particulates

We calculate the radiation dose rate due to inhalation of radioactive particulates by first calculating the amount of radioactivity that a worker inhaled per unit time, and then employing standard dose conversion factors (DCF) recommended by the International Commission on Radiological Protection (ICRP)[24]. These DCFs convert an amount of a specific inhaled radionuclide into the resulting inhalation dose. The inhalation dose rate can therefore be calculated using the following equation:

$$DR_{inh} = C * A * V * DCF_{inh}$$

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[20] NIOSH, 2006a & 2006b
[21] Grove Software Incorporated, 2008
[22] ICRP, 1997
[23] NIOSH, 2006a & 2006b
[24] ICRP, 2001

Where:

DR_{inh}	Inhalation dose rate (mrem/time)
C	Air particulate concentration (mg/m^3)
A	Activity of Ra-226 and Ra-228 in scale (pCi/g)
V	Ventilation, or breathing rate (m^3/time)
DCF_{inh}	Dose conversion factor for inhalation for Ra-226 and Ra-228 decay chains (mrem/pCi)

The concentration of radioactive particulates in the air of the plaintiffs' work environment depended on the type of equipment used to clean and refurbish the used, NORM contaminated oil production pipe the plaintiffs handled. Pipes were cleaned using a rattler or a sandblasting machine, and particulate matter would also enter the air due to the cutting of used pipe with an acetylene torch.

A rattler, or reamer, is a rotating metal device attached to an air gun that spins at high speeds inside of the contaminated pipe. During this process, the rattler grinds and pulverizes the scale attached to the pipe wall and large amounts of particles and dust are blown out of the pipe with the air that powers the rattler. At the same time, scale is brushed off the outside of the pipe. The outside scale is sucked into a dust collector where the larger particles fall into a compartment known as a catcher and the smaller particles are blown directly into the air. Depending on the degree of contamination within each pipe, the cleaning process removes about 0.5 to 2 pounds of scale from the inside of 30-foot pipe joints[25].

At some pipe yards, sandblasters were also employed to clean the inner and walls of used, NORM contaminated pipe. Each sandblasting machine contains a large pot that carries sand or other abrasive blasting materials. A hose connected to the pot is inserted inside of a contaminated pipe and the tip of the nozzle sprays sand radially against the walls of the pipe, removing scale deposited on the pipe walls[26]. Many of the workers who operated the sandblasting machines recall that this process produced a great deal of dust in the air and on the ground of the pipe yards.

In addition to cleaning the inner and outer walls of pipes, workers often utilized an acetylene torch to cut used pipe. Acetylene torches were used to cut damaged pipe into smaller 3- to 4-foot segments so that it could be more easily disposed of, and workers also used the torches to cut the ends off of old oil production pipe before beveling new pipe threads at the ends of the pipes. The workers who used an acetylene torch to cut pipes wore a standard welding face shield. Many of the workers who used an acetylene torch recall that dust, sometimes as thick as cigarette smoke, was generated while they cut pipes.

As stated previously, there are no exact measurements of air particulate concentrations at the pipe yards and oil production rigs at which the plaintiffs worked. However, isolated measurements of particulate air concentration have been made at various Louisiana pipe yards, such as the Intracoastal Tubular Services (ITCO) pipe yard, and we employ these measurements in our calculations. Particulate

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[25] Testimony of Mike Bulot in Grefer Case, p. 26.
[26] Garverick, L, 1994

air concentrations were measured as 11 mg/m^3 in the ITCO yard[27] and 53 mg/m^3 at another Louisiana pipe yard[28]. Both measurements were taken while pipe was being cleaned, but presumably at different distances from the cleaning machine. We assume these air concentrations resulted from the use of a rattler, since pipe cleaning was carried out using rattlers at the ITCO pipe yard.

Respirable particulate air concentrations resulting from sandblasting and other abrasive blasting activities have been measured and well documented. In one study[29], the abrasive blasting of a ship hull was found to generate respirable dust concentrations in air of 55 mg/m^3. A study by Samimi, et al,[30] measured dust concentrations due to abrasive blasting activities in a steel fabrication yard to be 37 mg/m^3. Additionally, the air concentrations of respirable dust in other abrasive blasting workplaces have been found to be greater than 100 mg/m^3.[31]

According to a 1987 report by GJ Newton[32] the measured concentration of aerosols in air from using an oxygen acetylene torch was 15 ± 11 mg/m^3, meaning that the concentration could be as high as 26 mg/m^3. The worker breathing zone is about 1.5 to 2 feet from the flame or saw. In a 1994 report by J.T. Karlsen et al[33], exposure to workers from aerosols was greater, but Karlsen only measures particulates that are 0.8 microns or larger. The Newton paper, on the other hand, measured particulates, ranging in size from a gas to 10 microns, with an average size of 0.3 microns in the breathing zone.
Due to a lack of specific measurements, we employ an air particulate concentration range, as opposed to a single value in our calculations. We expect that this range includes the "true" average air particulate concentration to which the plaintiffs were exposed while cleaning and cutting pipe. In the vicinity of the pipe cleaning and cutting processes, we use a respirable dust concentration of C = 10 mg/m^3 as a lower bound and a concentration of C = 30 mg/m^3 as an upper bound. This range includes the air particulate concentration measured at the ITCO pipe yard and from using an oxygen acetylene torch, but it is below the measurement obtained at the additional pipe yard and for the sandblasting processes.

Several of the plaintiffs wore protective hoods and respirators when operating the sandblasters in order to help protect them from inhaling a great deal of scale dust. Different types of protective hoods and respirators have different protective capabilities which are measured in units of workplace protection factors, or WPF. WPF represent the ratio between the air concentration of a specific contaminant outside of the hood and the concentration of this contaminant inside of the protective hood. Therefore, the higher the WPF, the greater protection provided by the hood or respirator.

WPF for specific types of hoods and respirators are regulated by the American National Standards Institute (ANSI). ANSI WPF have been agreed upon and adopted by the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA).

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[27] ITCOEX 925
[28] Radiation Technical Services of Baton Rouge, 1993
[29] Greskevitch, MF, 1996
[30] Samimi, B, et al., 1975
[31] State of Queensland, 1999
[32] Newton, G, et al., 1987
[33] Karlsen, J, T Torgimsen, and S Langård, 1994

In 1969, ANSI released Respiratory Protection Standard Z88.2, "Practices for Respiratory Protection." This standard set the first respirator protection standard for workplace hoods and respirators. Z88.2-1969 did not yet assign exact workplace protection factors for hoods and respirators, but instead recommended that "due consideration be given to potential inward leakage in selecting [respirator] devices." In addition, it contained a list of the expected air leakages into the face piece of various respirators and hoods.[34] In 1971, the OSHA standard for workplace respiratory protection[35] was largely adopted from the 1969 ANSI Z88.2 standard.

In August 1975, the joint NIOSH-OSHA Standards Completion Program published the "Respirator Decision Logic" which listed protection factors thought to be provided by several respirators and hoods. A WPF of 1,000-2,000 was given for supplied air-line hoods and respirators[36]. This meant that only 0.05% to 0.1% of the concentration of a contaminant outside of the hood would be able to leak to the inside of the hood.

In 1980, ANSI revised the Z88.2 standard, based on advances in research and technology that were made in the ensuing years. Z88.2-1980 established assigned protection factors for multiple types and families of respirators and hoods so that respirator selection, fit, and use were standardized. The Z88.2-1980 standard included a table of assigned protection factors.

In 1987, NIOSH revised its "Respirator Decision Logic" and reduced the WPF of supplied air-line hoods and helmets to 25, indicating that supplied air-line hoods actually offered less protection than was previously thought.[37] In 1992, ANSI revised its Z88.2 Respiratory Protection Standard mandating that air-supply hoods and respirators provide a WPF of 1,000.

For the plaintiffs who wore protective hoods and respirators before 1992, we employ a WPF of 25 when calculating the workers' inhalation doses. This is equivalent to a scale dust air concentration of 0.4 mg/m^3 to 1.20 mg/m^3. For the year 1992 and thereafter, we employ a WPF of 1,000, which is equivalent to a scale dust air concentration of 0.01 mg/m^3 to 0.03 mg/m^3.

For locations away from the direct vicinity of the pipe cleaning and cutting areas, but still within the pipe yard, we use a concentration range directly due to pipe cleaning and cutting operations that is ten times smaller, i.e. of 1 – 3 mg/m^3. To this, we add resuspension of scale particulates in the yard due to activities that mechanically moved scale. Such activities include movement of trucks and forklifts, road building, rack building and shoveling scale from ground into potholes. Workers walking around, as well as wind activity, would further re-suspend particulates. We estimate that particulate concentration due to resuspension is the same as particulate concentration at a construction site[38], 0.6 mg/m^3. The air particulate concentration in the pipe yards and oil production rigs away from the pipe cleaning and cutting operations therefore ranges from 1.6 - 3.6 mg/m^3. Workers did not wear protective hoods or

[34] ANSI, 1969
[35] Federal Register, 2008
[36] US DHHS, 1987
[37] *Ibid*
[38] US DOE, 1983

respirators when working at a distance from pipe cleaning or cutting machines. A detailed discussion of our calculations and estimates of the concentration range of respirable particulates is presented in App. A.

To calculate the radioactivity (A) in the dust, we use a scale activity of A = 6,000 pCi/g for Ra-226, and of A = 2,000 pCi/g for Ra-228. As discussed in Section 2.1 of this report, these estimates are based on measurements taken by the US EPA[39], Chevron[40, 41] and Reed[42]. We assume secular equilibrium between Ra-226 and Ra-228 and their respective progeny, i.e. we apply the same activity in scale (in pCi/g) for the daughter nuclides as for their parents. For the years after 1989, when Louisiana NORM regulations first came into affect in pipe yards, we use a reduced scale activity of A = 1,313.5 pCi/g for Ra-226 and of A = 473.8 pCi/g for Ra-228 for the times workers performed pipe cleaning and cutting operations in Louisiana pipe yards. These reduced scale activities correlate with an external dose rate of 50 µR/hr. We do not apply the reduced scale activities for the times workers performed pipe cleaning or cutting activities on onshore or offshore oil production rigs, as it was not required by Louisiana law that NORM contaminated equipment be monitored at these locations.

The amount of inhaled radioactive material not only depends on the amount of this material in the air, but also on the rate at with which the particles are inhaled. For adult male workers, we use the ventilation rate (or breathing rate) for moderate exercise recommended by ICRP 66[43] of V = 1.5 m^3/h for the times the workers worked in the pipe yards and on oil production rigs. When performing less strenuous work, such as office work or work inside an auxiliary building, we apply a reduced ventilation rate of 0.925 m^3/h[44].

Different DCFs exist for different exposure assumptions and depend on the solubility and diameter of the inhaled compound. For example, smaller particles will lodge deeper within the lungs and will be retained for a longer period of time[45]. For our calculations, we assume that the respirable scale dust is relatively insoluble and that the radioactive particles are absorbed by the body at a relatively slow rate.

For our calculations, we assume and that the particles generated by pipe cleaning operations involving the use of a rattler have aerodynamic median activity diameter (AMAD) of 1 µm. The diameter of particles released during sandblasting and other abrasive blasting processes has been well documented. A 1991 study performed by CJ Tung and CC Yu[46] found that radionuclide aerosols dispersed as a result of sandblasting steam turbines at the Chin Shan Nuclear Power Station in Taiwan had an AMAD of 3 to 4 microns (µm). An additional study by C Papstefanou[47] found that the average particle size released as a result of sandblasting had an AMAD of 3.1 µm. ICRP-68 states that field measurements taken from most abrasive blasting (sandblasting) situations result in an airborne blasting dust consisting of particles with

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39 US EPA, 1987
40 NORM Study Team, 1990
41 Scott, LM, 1986
42 Reed, G, B Holland, and A McArthur, 1991
43 ICRP, 1994
44 Yu, C, et al., 1993
45 Cember, H, 1996
46 Tung, CJ, and C-C Yu, 1991
47 Papastefanou, C, 2008

an AMAD of 1 µm. In this report, we assume that the particles inhaled by the workers who utilized sandblasters have an AMAD of 1 µm. In addition, we estimate that the respirable scale dust particles due to pipe cutting with an oxyacetylene torch have an AMAD of 0.3 microns[48]. Metal oxide fumes created by welding typically have a particle size between 0.2 and 1 micron.[49]

Using information about the workers' employment histories, we then calculate the total inhalation doses the workers received by multiplying their inhalation dose rates with their total exposure times:

$Dose_{inh} = DR_{inh} * \text{exposure time}$

Where:

$Dose_{inh}$	Total inhalation dose (mrem)
DR_{inh}	Inhalation dose rate (mrem/time)
Exposure time	Total time worker was occupationally exposed to radioactive material.

We utilized the workers' social security records as well as information they or their family members shared during telephone interviews to best estimate the total amount of time each worker was occupationally exposed to radioactive material. Total annual radiation doses were calculated specifically for each year the plaintiffs worked. If a plaintiff was exposed to radioactive materials for only a portion of a specific year, we multiplied the calculated dose for that year by the fraction of time the worker was exposed. The total annual radiation doses were then added together to derive the total dose each plaintiff received over the entire time of his employment.

According to the Committee Examining Radiation Risks of Internal Emitters (CERRIE), the risk due to exposure by alpha-emitting radionuclides taken internally may be as much as 10 times higher than calculated. This is because radiation risks are predominantly determined by epidemiological studies, particularly the study of Japanese bomb survivors 50. Japanese atomic bomb survivors were exposed primarily to an instant of external gamma and neutron radiation, and many researchers have extrapolated the bomb survivor results to radionuclides taken in internally. However, radionuclides that emit beta and alpha short range radiation over long periods of time present several issues that have not been studied in detail. The uncertainties associated with internal emitting radioactive materials, according to CERRIE, might be as much as ten times greater. A more detailed discussion on the uncertainties of exposures to internal emitting radionuclides can be found in Section 6.2.3 of this report.

While working, the plaintiffs were exposed to alpha-emitting radionuclides taken internally via inhalation of scale particulates. Therefore, we multiply the upper bounding inhalation radiation dose calculated for each of the plaintiffs by a factor of 10, to account for the uncertainty in dose rate due to internal alpha emitters, following CERRIE's findings.

3.2 Dose Due to Incidental Ingestion of Scale and Sludge

[48] Newton, G, et al., 1987
[49] NIOSH, 1988
[50] Preston, DL, et al., 2003

The incidental ingestion dose rate is calculated in a manner similar to the inhalation dose rate. We first calculate the ingested amount of radioactive material, followed by the application of a DCF for ingestion to obtain the ingestion dose rate:

$DR_{ing.} = IR * A * DCF_{ing.}$

Where:

DR_{ing}	Ingestion dose rate (mrem/time)
IR	Ingestion rate (g/time)
A	Activity of Ra-226 and Ra-228 in scale or sludge (pCi/g)
$DCF_{ing.}$	Dose conversion factors for ingestion for Ra-226 and Ra-228 decay chains (mrem/pCi).

According to the US EPA's Exposure Factor Handbook Volume I, a study showed that while doing yard work or other physical outdoor activity, adults ingest outdoor soil at 480 mg/day, while the value of 200 mg/day is also used for adults. This estimate is based on the assumption that a 50 μm thick layer of soil is ingested from the inside surfaces of the thumb and fingers of one hand, as most incidental soil ingestion occurs when soil is transferred from a person's hands to their mouth[51]. The incidental soil ingestion rate for outdoor yard work does not take into account eating in dusty work places and licking dust off lips; it is entirely due to accidentally ingesting material from one's hand while working. Eating food in a dusty environment would lead to much greater ingestion rates. We utilize the ingestion rate of (480 mg/day / 24 hr/day) 20 mg/hr, as the work the plaintiffs performed was in a dusty or dirty environment.

We assume 100% of the incidentally ingested material to be scale or sludge for the times the plaintiffs operated rattlers or acetylene torches to clean and cut pipes and when working in contact with sludge on oil production rigs. However, we assume only 50% of the incidentally ingested material to be scale for the times the plaintiffs operated sandblasters, as the other half of the ingested material would be sand or other abrasive material used during the sandblasting process.

As in our inhalation dose calculations, we apply scale activities of 6,000 pCi/g and 2,000 pCi/g for Ra-226 and Ra-228, respectively. For our sludge calculations, we utilize a range of activity for Ra-226 and Ra-228 and some of their progeny: 1.35 pCi/g to 21,600 pCi/g for Ra-226; 13.5 pCi/g to 1,350 pCi/g for Ra-228; 2.7 pCi/g to 35,100 pCi/g for Pb-210; and 0.108 pCi/g to 4,320 pCi/g for Po-210. Again, we assume secular equilibrium between the parent and daughter nuclides. For the years after 1989, when Louisiana NORM regulations first came into affect in pipe yards, we use a reduced scale activity of 1,313.5 pCi/g for Ra-226 and of 473.8 pCi/g for Ra-228 for the times workers performed pipe cleaning and cutting operations in Louisiana pipe yards. We do not apply the reduced scale or sludge activities for the times workers performed pipe cleaning or cutting activities on onshore or offshore oil production rigs, as it was not required by Louisiana law that NORM contaminated equipment be monitored at these locations.

[51] Ibid

Using information about the workers' employment histories, we then calculate the total ingestion dose the workers received by multiplying their ingestion dose rates with their total exposure times:

$Dose_{ing} = DR_{ing}$ * exposure time

Where:

$Dose_{ing}$	Total ingestion dose (mrem)
DR_{ing}	Ingestion dose rate (mrem/time)
Exposure time	Amount of time worker was occupationally exposed to radioactive material

Like our inhalation radiation dose calculations, we utilized the workers' social security records as well as information they or their family members shared during telephone interviews to best estimate the total amount of time each worker was occupationally exposed to radioactive material. Total annual radiation doses were calculated specifically for each year the plaintiffs worked. If a plaintiff was exposed to radioactive materials for only a portion of a specific year, we multiplied the calculated dose for that year by the fraction of time the worker was exposed. The total annual radiation doses were then added together to derive the total dose each plaintiff received over the entire time of his employment. While working, the plaintiffs were exposed to alpha-emitting radionuclides taken internally via incidental ingestion of scale and sludge. Therefore, we multiply the upper bounding ingestion radiation dose calculated for each of the plaintiffs by a factor of 10, to account for the uncertainty in dose rate due to internal alpha emitters, following CERRIE's findings.

3.3 Doses Due to External Radiation

While working in pipe yards and on onshore and offshore oil production rigs, the plaintiffs were further exposed to radiation from the scale and sludge deposited on their clothing the ground of their work areas and from NORM contaminated pipes. External radiation is directly incurred as a radiation dose, as opposed to ingestion and inhalation, for which we first calculate the uptake of radionuclides by a person. The external radiation dose rate to the whole body due to scale and sludge contamination is based on the thickness of this layer and the radioactivity in the contaminated layer.

NORM contaminated sludge splattered all over the workers' clothing as they worked over oil production wells or handled used production pipes that were recently pulled from production wells. In our calculations, we assigned a thickness of 1 millimeter for the layers of sludge deposited on the workers' clothing as they worked. For the layer of sludge that accumulated on the ground of the oil production rig platforms, we assigned a thickness of 1 centimeter. This is an underestimate as many of the workers described that sludge deposited on the floor of the rigs was thick enough to cover the top of their boots.

Scale dust would also settle on the ground of the pipe yards and oil production rigs on which the plaintiffs worked if pipe cleaning and cutting operations were performed. For the layer of scale deposited on the ground of pipe yards and production rigs, we employ a thickness range of 1 centimeter to 5 centimeters. We apply this range because many of the plaintiffs recall that their work areas were never swept clean and therefore scale dust deposited on the ground would accumulate over time. In addition, many Louisiana pipe yards often used scale dust deposited on the ground to fill potholes and other hazardous obstacles in the ground. It is also likely that the depth of scale to which the workers were exposed would vary, slightly, over time, and we believe this range to include the true depth of scale dust to which the plaintiffs were exposed while working.

The plaintiffs who worked in pipe yards also received an external radiation dose from scale built up on the inner walls of used contaminated pipes stored in their direct vicinity while working. Pipes were often stored in large racks in pipe yards, many of which were as wide as 10 pipes across and reached eight to ten feet in height. For each of the pipes contained in the racks, we assume an outer pipe diameter of 2 7/8 inches (7.3025 cm), a scale thickness of 0.2 cm, and a pipe wall thickness of 0.551 cm. These dimensions are based on physical parameters suggested by the US EPA[52]. Because most of the radiation emitted from the contaminated pipes within the racks would be shielded by the steel walls of the pipes in front of them, we assume the workers only received a radiation dose from the first row of contaminated pipes closest to their bodies. This is an underestimate. Since the contaminated pipes are cylindrical in shape, we assume the thickness of the scale in the first row of pipes to be (0.2 cm * 2) 0.4 cm, shielded by a 0.551 cm wall of steel.

To calculate the external radiation dose that the workers received directly from pipe (as opposed to scale deposited on the ground or a vertical wall of pipes), we employed Microshield. As inputs to MicroShield, we assumed a standard production pipe: an outer pipe diameter of 2 7/8 inches (7.3025 cm), a scale thickness of 0.2 cm, and a pipe wall thickness of 0.551 cm. Each contaminated pipe is 30 feet long, and radiation measurements were taken at the center of the pipe, on contact with the outer pipe wall.

Truck drivers who transported pipe were exposed to external radiation in a different way. For this pipe configuration, we assume that the pipe joints were stacked on top of each other, which results in an actual “wall” of pipe endings behind the driver’s back. This situation can be approximated with an external radiation dose from a contaminated layer of infinite depth. To calculate the radioactivity of the load, we multiply the scale activity with the volume fraction of scale in the truckload of 0.02 (the other 98 % of the volume is steel and air). This dose rate includes shielding from the truck cab. We apply this dose rate for drivers only while they are actually driving NORM-contaminated pipes, but not while loading and unloading, which is better represented by the line source calculation described above.

Some plaintiffs were also exposed to gamma radiation from radiographic pipe inspections. Gamma radiation from Ir-192 tested the pipes for leaks after pipes were cleaned. Only **eight** of the plaintiffs were present during radiographic inspections; often, welders were in the proximity of radiographic inspections while they were being performed. Radiographic inspections exposed workers to high levels of radiation and radiographers rarely used any protective equipment. This lack of protection allowed radiographers and workers in the presence of radiographic inspections to be exposed to gamma radiation. In our calculations we include a range in the distance (15 to 30 feet) between pipe welders and the radiographic inspections. It is likely that the welders were actually closer to the inspections and this is therefore an underestimate. As inputs to Microshield we assumed an outer pipe diameter of 2 7/8

[52] US EPA, 1993b

inches (7.3025 cm), and a pipe wall thickness of 0.551 cm. For the source material we used 120 Curies of Iridium-192.

In addition, the workers who cleaned pipes with rattlers were exposed to a single layer of NORM contaminated pipes as they operated the pipe cleaning equipment. With these machines, 10 to 15 NORM contaminated pipes were stored in a single row on a pipe rack located near the pipe cleaning machine. The workers stood between the single row of used pipes and the pipe cleaning machine in order to easily and efficiently roll the dirty pipes onto the machine. The row of pipes located next to the pipe cleaning machine was approximately the same height as the workers' waists.

As with our inhalation and ingestion radiation dose calculations, we utilize an activity of 6,000 pCi/g for Ra-226 and 2,000 pCi/g for Ra-228 in scale. For our sludge calculations, we utilize a range of activity of 1.35 pCi/g to 21,600 pCi/g for Ra-226, 13.5 pCi/g to 1,350 pCi/g for Ra-228, 2.7 pCi/g to 35,100 pCi/g for Pb-210, and 0.108 pCi/g to 4,320 pCi/g for Po-210. We assume all progeny to be in secular equilibrium with their parent radionuclides. In our external radiation dose calculations, we reduce the activities of Ra-226 and Ra-228 in scale for the times the plaintiffs worked in pipe yards after 1989. However, as mentioned before, many of the workers recalled that the dust on the ground of the pipe yards was never swept; only larger pieces of trash and debris were picked up off of the ground. This means that the scale dust on the ground of the pipe yard accumulated and remained on the ground over several years, and therefore the scale dust on the ground after 1989 would not be reduced in activity. Thus, our calculations for scale deposited on the ground of the pipe yard are an underestimate.
We employ the program MicroShield Version 8.02 to calculate the external radiation dose rates the workers received due to scale and sludge deposited on their clothing, in oil production pipes, and on the ground of their work areas. Scale and sludge are not included in the twelve custom source materials contained in the MicroShield database, and so we designed our own source materials to represent the radioactive scale and sludge to which the plaintiffs were occupationally exposed. Radium (Ra-226 and Ra-228 combined) in produced water has been found to co-precipitate with calcium sulfate and calcium and barium carbonates, but most often with barium sulfate[53]. Thus, we designed the constituents of the scale and sludge to which the workers were exposed after the chemical composition of barium sulfate ($BaSO_4$); one part barium, one part sulfur, and four parts oxygen. All scale dust was assumed to have a density of 2.6 grams per cubic centimeter, whereas all sludge was assumed to have a density of 1.6 grams per cubic centimeter[54].

MicroShield allows its user to select one of 16 different source geometries (such as a cylinder, sphere, disk, etc.) when performing external radiation dose rate calculations. For our calculations for sludge deposited on the workers' clothing, we selected the source geometry of an infinite slab to best represent the workers' clothing that surrounded their entire bodies as they worked. We also selected the same source geometry for our calculations for scale and sludge deposited on the ground of the plaintiffs' work areas, since many of the pipe yards and oil rigs at which the workers worked were as large as 6 acres in area. Since the workers almost always stood upright while working and gamma radiation from scale and sludge deposited on the workers' clothing and on the ground of their work area

[53] US EPA, 1993a
[54] *Ibid*

constantly emanated from all directions around the workers, we take the average of the radiation dose rates calculated for the isotropic and rotational geometries for these types of exposure.

We employ a different source geometry for the times workers were exposed to racks of used, NORM contaminated pipes while working in pipe yards and on oil production rigs. Since we cannot simultaneously use multiple source geometries in MicroShield, we assume that the vertical contaminated racks of pipes are best represented as rectangular volumes bounded by the same dimensions. Since each pipe is approximately 30 feet in length and the pipe racks would be stacked to heights that ranged between 8 to 10 feet, we assume the racks of contaminated pipes surrounding the workers to be best represented as rectangular walls that are 30 feet wide and 8 feet tall. As mentioned earlier, we assume the workers received a radiation dose from only the first row of pipes closest to their bodies and the thickness of scale within that first row is 1 cm radius and therefore 2 cm shielded by a steel pipe wall with a thickness of 0.551 cm.

Based on information shared by the workers during their personal interviews, we assume the average distance between the workers and the pipe racks was approximately 10 feet. In our calculations, we assume the pipe yard workers had one rack of contaminated pipe within their work area at all times, whereas in reality, they may have had many more racks of pipes in their direct vicinity. Since the workers stood upright and continuously moved in all directions while working, we take the average of the radiation dose rates calculated for the isotropic and rotational geometries for this type of exposure.

For the times the workers cleaned pipes using rattlers, we use the annular cylinder geometry to best represent a single, NORM contaminated pipe. We assume the single row of pipes located next to the workers as they operated the rattlers contained 15 NORM contaminated pipes and the workers stood on contact with the first pipe in the row. We assume each pipe in the row has a length of 30 feet (914.4 cm), an outer diameter of 2 7/8 inches (7.3025 cm), a scale thickness of 1 cm, and a pipe wall thickness of 0.551 cm.

We assume that the workers who cleaned pipes using a rattler were exposed to this row of pipes from only one side of their bodies and that the contaminated pipes laid perpendicular to their bodies. If we assume that all pipes in the row are touching side to side, i.e. there is no space in between adjacent pipes, we calculate the view factor of each cylindrical pipe to be 0.18[55]. This means that 18% of the entire radiation from all pipes besides the one closest to the workers is absorbed by the pipe in front of it and does not strike the worker.

Since the row of NORM contaminated pipes next to the workers who used rattlers to clean pipe is only a single layer deep, the workers received a radiation dose from all of the 15 pipes in the row. In order to calculate the total radiation dose rate received by the workers from this row of pipes, we had to account for two individual factors using the MicroShield program; 1. the distance of each pipe from the worker and 2. the amount of radiation from each pipe that was capable of penetrating through the pipe walls in front of it.

[55] Avallone, EA, and T Baumeister, 1999

The radiation emanating from a pipe decreases as the distance between the worker and the pipe increases. To account for a decrease in radiation with distance, we use MicroShield to calculate the dose the workers received from each of the 15 pipes in the single row of pipe. That is to say, we calculated the dose rate to a worker received from the center of the first pipe located 2 inches from the worker, from the center of the second pipe located 6 inches from the worker, from the center of the third pipe located 10 inches from the worker, and so on and so forth. We then multiplied each of these dose rates by 0.82, assuming that 18% of the radiation emanating from each pipe is absorbed by the pipe directly in front of it.

To calculate the amount of radiation from each of the 15 pipes that was capable of penetrating through the pipe walls in front of it, we again employed the MicroShield program. To do this, we calculated the dose rate received by the worker from the center of each pipe accounting for both distance and shielding from the pipes located in front of it. For example, when calculating the dose to a worker from the second pipe in the row, we assumed the center of the second pipe was **6.35 centimeters** away from the worker and was shielded by a **1.102** cm thick wall of steel (accounting for the **two**-**0.551** cm thick outer pipe walls of the first pipe in front of it) and a **2** cm thick wall of scale (accounting for the **two 1** cm thick layers of scale on the inner walls of the first pipe in front of it). Similarly, the dose to a worker from the third pipe in the row was calculated assuming the center of the third pipe was located **13.66 centimeters** away from the worker and the pipe was shielded by a **2.204** cm thick wall of steel (accounting for the **four-0.551** cm thick outer pipe walls of the first and second pipes in front of it) and **4** cm thick wall of scale (accounting for the **four-1** cm thick layers of scale on the inner walls of the first and second pipes in front of it). [*Note by author: This paragraph is being rewritten to reflect actual calculation.]

Because the workers stood upright as they cleaned pipes with a rattler and because they constantly changed the direction of their bodies which faced the single row of contaminated pipes as they worked, we average the dose rates calculated for the antero-posterior and postero-anterior geometries. The dose rates calculated for all 15 pipes from both pathways are then added together to obtain the total dose rate received by the workers from the row of pipes.

The MicroShield program calculates radiation dose rates for 19 different organ types using ICRP 74 DCFs. For each of the plaintiffs exposed to direct gamma radiation, we select the dose rate calculated for the target organ appropriate to their specific cancer type, as recommended by the National Institute of Occupational Safety and Health (NIOSH)[56]. If MicroShield does not calculate the dose rate to a specific organ type, we use the calculated effective dose rate. In addition, we model the height of each plaintiffs' affected organ based on the average height of an American, adult male, 5 feet and 10.4 inches (178.9 cm)[57].

Using information about the workers' employment histories, we then calculate the total external radiation dose the workers received by multiplying their external radiation dose rates with their total exposure times:

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[56] NIOSH 2006a & 2006b
[57] McDowell, MA, et al., 2008

$Dose_{\gamma} = DR_{\gamma} * \text{exposure time}$

Where:

$Dose_{\gamma}$	Total external radiation dose (mrem)
DR_{γ}	External radiation dose rate (mrem/time)
Exposure time	Amount of time worker was occupationally exposed to radioactive material

Like our inhalation and ingestion radiation dose calculations, we utilized the workers' social security records as well as information they or their family members shared during telephone interviews to best estimate the total amount of time each worker was occupationally exposed to radioactive material. Total annual radiation doses were calculated specifically for each year the plaintiffs worked. If a plaintiff was exposed to radioactive materials for only a portion of a specific year, we multiplied the calculated dose for that year by the fraction of time the worker was exposed. The total annual radiation doses were then added together to derive the total dose each plaintiff received over the entire time of his employment.

3.4 Total Combined Dose from All Exposure Pathways

The radiation doses to the workers from inhalation, ingestion, and external radiation pathways were summed to derive a total radiation dose for each plaintiff over the entire time they were occupationally exposed to radiation. In Tables 1a and 1b, the TEDE dose rates are listed for each work category are shown, for pipe yard and rig workers, respectively. See Section 4 for details. In Table 2a and 2b, the exposure type, time as each exposure type, total doses received and risks are displayed for each plaintiff for pipe yard and rig workers, respectively.

3.5 Underestimates in the Exposure Assessment

The following pathways were either underestimated or not accounted for in the radiation dose calculations. If these pathways were considered, the total radiation doses received by the plaintiffs would be higher.

Eating lunch in an environment with high levels of radioactive dust (not included in the incidental soil ingestion rate).

Drinking water from coolers located near cleaning machines.

Chewing tobacco while at work.

Sitting under pipe racks in the summer to get shade from the sun. We ignored the external radiation dose from the pipe above and direct contact with the ground below.

Elevated external radiation from potholes filled with scale.

Indoor radon in workers' offices or inside of auxiliary buildings.

Indoor radon at workers' homes, emanating from contaminated work clothes and shoes.

Washing of contaminated vehicles (by workers, done at home).

Workers may have worked overtime or longer hours than accounted for in our calculations.

Ra-226 to Ra-228 ratio could be higher than 3:1, which would result in significantly higher doses.

The pipe yards in which the plaintiffs worked may not have begun screening incoming shipments for pieces of equipment greater than 50 µR/hr. This would result in significantly higher doses as the activity of scale to which the plaintiffs were exposed would not have been reduced beginning in 1990.

More than just the first row of contaminated pipes stacked in a pipe rack would have contributed to the plaintiffs' external radiation doses.

Scale buildup on the inner walls of the used oil production pipes to which the plaintiffs were exposed could have been thicker than 0.2 cm. This would greatly increase the plaintiffs' external radiation doses.

Scale deposited on the ground of the pipe yards may have accumulated over several years and would therefore not be reduced in Ra-226 and Ra-228 activities after 1989.

3.6 Likelihood that Cancers Were Caused Solely by Radiation

We use NIOSH's Interactive RadioEpidemiological Program (IREP), version 5.6[58] to calculate the likelihood that the plaintiffs' cancers were caused by radiation, rather than by something else. This program was developed by NIOSH to apply the National Cancer Institute's (NCI) risk models directly to data about exposure for a specific employee. IREP is based upon radioepidemiological tables developed by the National Institutes of Health (NIH) in 1985 and more recently updated with Japanese atomic bomb survivor data. These tables act as a reference tool to provide the probability of causation estimates for individuals with cancer that were exposed to ionizing radiation. The purpose of this program is to calculate the probability of causation that occupational radiation exposure received while working at a DOE facility or elsewhere within the nuclear weapons industry caused a specific type of cancer[59].

IREP is primarily based upon risk coefficients for cancer incidence gathered from the Japanese atomic bomb survivor studies. The risk coefficients have been adjusted to account for random and systemic errors in the atomic bomb survivor dosimetry as well as for the low dose and low dose-rate situations that are more common to American workers exposed while on the job. The probability of causation, or assigned share, for this risk is calculated as "the cancer risk attributable to radiation exposure divided by the sum of the baseline cancer risk (the risk to the general public) plus the cancer risk attributable to the radiation exposure". That is this is the fraction of cancers observed in a large heterogeneous group with similar exposure histories that would not have occurred in the absence of exposure. The assigned share

[58] NIOSH and SENES Oak Ridge Inc., 2009a
[59] NIOSH and SENES Oak Ridge Inc., 2009b

is estimated with uncertainty in IREP and is expressed as a probability distribution of results. The statistical uncertainty of the risk model is accounted for with a Monte Carlo simulation where repeated samples (typically 2,000) are taken from probability distribution functions and the probability of causation is calculated for each set of samples. The upper 99-percent confidence level from the resulting probability distribution is compared to the probability causation of 50-percent to determine eligibility for compensation of Manhattan Project workers. If cancer is determined to be "at least as likely as not" caused by radiation doses received while working, i.e., with a probability of 50-percent or greater at the 99-percent confidence level, than the worker is deemed eligible for compensation. The upper 99-percent confidence level is used to minimize the possibility of denying compensation to employees with cancer likely caused by occupational radiation exposure. The following equation is utilized in IREP to determine the probability of causation or assigned share:[60, 61]

$$PC = \frac{ERR}{RR} \times 100\%$$

Where:

ERR	Excess Relative Risk - Proportion of relative risk due solely to radiation exposure
PC	Probability of Causation
RR	Relative Risk - Ratio of the total risk from exposure divided by risk due to background alone

In the event of multiple primary cancers, a probability of causation for multiple primary cancers model is used. This is calculated from the following equation provided in IREP, using skin cancer and kidney cancer as examples of two multiple primary cancers:

$$PC_{Total} = 1 - \left[\left(1 - PC_{Skin}\right) \times \left(1 - PC_{kidney}\right)\right]$$

Where:

PC_{Total}	Total probability of causation
PC_{Skin}	Probability of causation for skin cancer
PC_{Kidney}	Probability of causation for kidney cancer

The probability of causation calculated by IREP specific to each workers' cancer type were used in the equation. Doses from external and internal exposure were entered together in the model.

Calculated doses from internal exposure using ICRP 68 derived DCFs and from external exposure using ICRP 74 derived DCFs (inherent to the MicroShield program) were entered into IREP. To enter the doses that resulted from internal radiation exposures, we employed a uniform distribution, using the low and high radiation doses the plaintiffs received during the times they worked at pipe yards and/or on oil production rigs. For external radiation doses, we use a uniform distribution, using the low and high radiation doses the workers received during their time of employment at pipe yards and/or on oil

60 *Ibid*
61 Federal Register, 2002

production rigs. In IREP, the appropriate cancer models were selected, along with the plaintiffs' years of birth and years of diagnoses.

The IREP results for each of the plaintiffs diagnosed with cancer can be found in Table 2a and 2b of this report.

3.6.1 Radiation Exposure Compensation Act

The Radiation Exposure Compensation Act (Public Law 101-426) established the groundwork for compensating individuals involved in the Manhattan Project, the program to develop the atomic bomb.[62] RECA provided for compensation for persons who had contracted cancer of the lung, esophagus, and pharynx. Under the amended RECA (yr 2000), the Energy Employees Occupational Illness Compensation Program (EEOICPA), a former Manhattan Project worker would receive compensation "based on the radiation dose received by the employee at the Manhattan Project facility and the upper 99-percent interval of the probability of causation at 0.5 in the radioepidemiological tables published under section 7(b) of the Orphan Drug Act, as such tables may be updated under section 7(b)(3) from time to time." In 2003, the National Cancer Institute and the Centers for Disease Control produced an updated set of radioepidemiological tables that estimate the probability of causation, into the software IREP. A user must input a person's dose to a specific organ, initial year of exposure, sex, and year at diagnosis. These tables were incorporated into the software program NIOSH-IREP, and were updated with the latest radiological risk data. NIOSH-IREP is the software we employ to assess the radiological risk to the plaintiffs under the same conditions, to determine that radiation was, more likely than not, responsible for the development of their cancer at the 99th percentile.

Since NIOSH-IREP only utilizes the Japanese bomb survivor data, it underestimates the causal connection between radiation and cancer since other more recent studies are not included. Specifically, the study by Cardis et al., that combines data of nuclear workers in 15 countries, shows a significant increase in cancers for fairly low average total doses.[63]

4.0 Specific Dosimetry

The plaintiffs held several different positions and were responsible for a variety of duties while working at the pipe yards and on onshore and offshore oil production rigs. Many workers carried out similar jobs and to simplify our exposure assessment, we group the workers exposure situations into **3** categories, which combined describe the individual exposures for the workers included in this report. Based on a personal interviews and/or plaintiff depositions, we then assign each worker the corresponding amount of exposure time for each type of exposure. We differentiate the workers' exposure into the following exposure types:

Type I: Work in Various Pipe Yards

A.) Physical work in pipe yard near pipe cleaning and cutting processes
B.) Physical work in pipe yard away from pipe cleaning and cutting processes
C.) Work inside of auxiliary buildings (office buildings, warehouses, etc.) adjacent to pipe yard

Type II: Work on Onshore and Offshore Oil Production Rigs

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[62] US Department of Justice, 2009
[63] Cardis E, et al., 2005

A.) Physical work as a Roustabout
B.) Physical work as a Roughneck
C.) Physical work as a Derrickman

Some workers were exposed to the same type of exposure during their entire work history, whereas others were exposed to two or more types of exposure. It should be noted that many of the plaintiffs alternated between working in both pipe yards and on oil production rigs, and they sometimes carried out work that was mainly performed in pipe yards (such as cutting or cleaning pipes) on oil production rigs.

In addition, it should be noted that some of the plaintiffs' occupational radiation exposures varied slightly from those of other plaintiffs who carried out similar work duties. The work descriptions listed below are meant to be used as general descriptions of the types of radiation exposures the workers received while performing different types of work, but the specific details of each plaintiff's individual work histories have been accounted for in their individual radiation dose calculations.

4.1 Pipe Yards

The following sections describe the work duties and subsequent occupational radiation exposures of the plaintiffs who worked in various Louisiana pipe yards.

4.1.1 Physical Work Near the Pipe Cleaning and Cutting Processes

While performing physical work in pipe yards near the pipe cleaning and cutting process (using a rattler, sandblasting machine, or acetylene torch), workers were exposed to radiation via inhalation of radioactive scale dust, incidental ingestion of radioactive scale dust, and direct gamma radiation emanating from scale deposited on the ground of the pipe yards and built up on the inner walls of used oil production pipes.

Near the pipe cleaning and cutting machines, workers were exposed to a concentration of 10 – 30 mg/m^3 of scale dust in the air. We apply a ventilation rate of 1.5 m^3/hr for physical work near the pipe cleaning machines as workers constantly lifted and carried heavy oil production pipe and additional equipment while working. When operating rattlers, we assume 100% of the particulate material in the air to be scale, whereas we assume only 50% of the particulate matter in the air to be scale when the sandblasting machines were utilized, as sandblasting machines released both scale dust and sand or other abrasive material into the air.

We apply an ingestion rate of 0.2 g/hr for scale dust that was incidentally ingested by the workers due to hand-to-mouth contact while working.

Workers were exposed to a layer of scale deposited on the ground ranging between 1 centimeter and 5 centimeters while operating the pipe cleaning machines. Scale dust would build up in thick layers directly around the pipe cleaning machines. We apply a range for the layer of scale deposited on the ground near the pipe cleaning machines as it is likely that the depth of the layer of scale would vary, slightly, throughout the entire time the plaintiffs worked at the pipe yards.

If workers operated a rattler to clean NORM contaminated pipes, they were additionally exposed to a single row of contaminated pipes. Workers received a radiation dose from approximately 15 pipes laid out in a single row located directly next to their bodies as they worked.

We apply activities of 6,000 pCi/g of Ra-226 and 2,000 pCi/g of Ra-228 in scale for all exposures that occurred near the pipe cleaning machines before 1990. From 1990 and thereafter, we apply reduced activities of 1,313.5 pCi/g of Ra-226 and 437.8 pCi/g of Ra-228 in scale which correlate to a dose rate of 50 µR/hr, due to Louisiana regulations requiring that all incoming pipe yard shipments be scanned for NORM contamination greater than 50 µR/hr. We assume that all progeny are in secular equilibrium with the parent radionuclides.

4.1.2 Physical Work at a Distance from the Pipe Cleaning and Cutting Processes

The air of the pipe yards in which the plaintiffs worked was very dusty even at a distance from the pipe cleaning and cutting areas. However, the air at a distance from the pipe cleaning and cutting operations was much less concentrated with dust, and we therefore apply a reduced air concentration. In addition, yard activities at a distance from the pipe cleaning machines led to the resuspension of scale dust in the air, resulting in a total dust air concentration that ranged between 1.6 and 3.6 mg/m^3. Since workers were performing physical work in the pipe yards, such as loading and unloading NORM contaminated pipes, we apply a breathing rate of 1.5 m^3/hr.

Radiation exposure assumptions for incidental ingestion of scale and for external exposure to scale deposited on the ground of the pipe yards at a distance from the pipe cleaning and cutting process remained the same as those for workers near the pipe cleaning and cutting process. In addition, while working at a distance from the pipe cleaning and cutting operations, many of the workers received an external radiation dose from NORM contaminated pipes stored in racks throughout the pipe yards. The plaintiffs worked an average of 10 feet from at least one pipe rack, which was approximately 30 feet long, 8 feet tall, and 10 pipe diameters wide.

We apply activities of 6,000 pCi/g of Ra-226 and 2,000 pCi/g of Ra-228 in scale for all exposures that occurred at a distance from the pipe cleaning and cutting operations. As was assumed for exposures near the pipe cleaning and cutting operations, the activities of Ra-226 and Ra-228 in scale decreased for the years after 1989 due to Louisiana NORM regulations in pipe yards. We assume that all progeny are in secular equilibrium with the parent radionuclides.

4.1.3 Work Inside Pipe Yard Auxiliary Buildings

Inside of plant buildings that were not used for the cleaning, repair of inspection of pipe, workers were not exposed to external radiation. Also, the amount of incidentally ingested material would decrease, because the conditions were less dusty, and the ingested dust would not necessarily be scale dust. For the exposure in such auxiliary buildings, we therefore only take into account inhalation of particulates. Since the distance to the pipe cleaning machine would be relatively large, we only take into account the particulate concentration that is due to resuspension of deposited scale by the movement of heavy equipment. This air particulate concentration is the same as found at a construction site, of 0.6 mg/m^3.

Because work in auxiliary buildings is usually not very physical, we apply a reduced ventilation of 0.925 m^3/hr.

As with all of our other pipe yard calculations, we apply scale activities of 6,000 pCi/g for Ra-226 and 2,000 pCi/g for Ra-228 and assume these activities were reduced to 1,313.5 pCi/g for Ra-226 and 437.8 pCi/g for Ra-228 for all years after 1989 due to NORM regulations in Louisiana pipe yards. We assume that all progeny are in secular equilibrium with the parent radionuclides.

4.2 Oil Production Rigs

The following sections describe the work duties and subsequent occupational radiation exposures of the plaintiffs who worked on various onshore and offshore oil production rigs in Louisiana.

4.2.1 Physical Work as a Roustabout

Roustabout is the term used to represent a manual laborer on an oil production rig. Roustabouts are entry level workers and are responsible for carrying out peripheral rig tasks so that higher ranking members of the rig crew are not distracted while performing well workovers[64]. Roustabouts usually work hard, long hours and are responsible for a plethora of tasks while working on the rigs. These tasks may include cleaning the rig floor, cleaning and maintaining rig equipment and tools, aiding in well workovers, and transporting pipe throughout the rig.

Sludge built up on in the inner walls of the production pipe would spray all over the Roustabouts' clothing and any exposed skin as they worked. In addition, sludge would also cover the equipment rig floor for which they were responsible of maintaining. Many of the plaintiffs who worked as Roustabouts wore gloves, but their work was often so messy that they wore through two or more pairs of gloves per day.

In our calculations, we assume that Roustabouts were exposed to sludge on their clothing and the rig equipment and floor 75% of the total time they worked. During this time, they received a radiation dose due to incidental ingestion of sludge via hand-to-mouth contact and external radiation from a layer of sludge deposited on their clothing and the rig floor. We assume they were not exposed to sludge 25% of the time they worked on the rigs, as some of their tasks were performed at a distance from the production well and did not require them to work directly with NORM contaminated equipment or on the sludge-covered rig floor.

We apply a range of sludge activities for the radionuclides contained in sludge: 1.35 pCi/g to 21,600 pCi/g for Ra-226, 13.5 pCi/g to 1,350 pCi/g for Ra-228, 2.7 pCi/g to 35,100 pCi/g for Pb-210, and 0.108 pCi/g to 4,320 pCi/g for Po-210. We assume all progeny to be in secular equilibrium with their parent radionuclides. We do not reduce the activities of Ra-226 and Ra-228 in scale and sludge for the times the plaintiffs worked on onshore and offshore oil production rigs after 1989, as Louisiana regulations did not require that equipment be monitored for NORM contamination at these locations.

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[64] A well worker is the process of performing maintenance or remedial work on an oil or gas production well. This work requires removing and replacing the pipe string from the production well.

4.2.2 Physical Work as a Roughneck

Roughnecks are members of the rig crew that rank directly above Roustabouts. These workers perform many of the same tasks as Roustabouts but are more involved in the well workover process. When performing well workovers, roughnecks spend the majority of their time on the production rig floor pulling used, NORM contaminated pipes from the well hole and replacing the pipes with new or refurbished ones. During a workover, sludge contained in the used production pipe sprays all over the workers clothing and exposed skin, as well as on the rig equipment and floor.

In our calculations, we assume that Roughnecks were exposed to sludge on their clothing and the rig floor and equipment 75% of the total time they worked. During this time, they received a radiation dose due to incidental ingestion of sludge via hand-to-mouth contact and external radiation from a layer of sludge deposited on their clothing and the rig floor as well as stacks of NORM contaminated pipe. We assume they were not exposed to sludge and contaminated pipe 25% of the time they worked on the rigs, as some of their work tasks were performed at a distance from the well hole and/or did not require them to work directly in contact with the NORM contaminated equipment or rig floor.

We apply a range of sludge activities for the radionuclides contained in sludge: 1.35 pCi/g to 21,600 pCi/g for Ra-226, 13.5 pCi/g to 1,350 pCi/g for Ra-228, 2.7 pCi/g to 35,100 pCi/g for Pb-210, and 0.108 pCi/g to 4,320 pCi/g for Po-210. We assume all progeny to be in secular equilibrium with their parent radionuclides. We do not reduce the activities of Ra-226 and Ra-228 in scale and sludge for the times the plaintiffs worked on onshore and offshore oil production rigs after 1989, as Louisiana regulations did not require that equipment be monitored for NORM contamination at these locations.

4.2.3 Physical Work as a Derrickman

Derrickmen are members of the rig crew that rank directly above Roughnecks. Derrickmen hold a unique position in that they work not on the production rig floor but from an elevated platform, known as a monkeyboard, suspended approximately 90 feet above the rig floor. When performing well workovers, derrickmen are responsible for running production piping in and out of the well hole. They work from an elevated platform located above the rig floor in order to manage the top of the pipe strings entering and exiting the production wells while other workers, such as roughnecks and roustabouts, manage the bottom of the pipe strings from the rig floor. The monkeyboards from which derrickmen work are located at a height of approximately 90 feet above the rig floor because, during a workover, most used production pipes are pulled from a well 3 pipes at a time. Since each pipe is approximately 30 feet in length, a string of 3 pipes is approximately 90 feet long.

The job of a derrickman is very physically demanding. In order to reach the tops of the pipe strings pulled from the production well during a workover, derrickmen must secure themselves to the monkeyboard with a harness and lunge off of the platform to lasso in the pipe string. Once a derrickman successfully grips the pipe string, he pulls it in to the platform and stores it in the platform's fingerboard. A fingerboard consists of several steel pipes, or "fingers", that extend outward to keep the pulled production pipe in place.

NORM contaminated sludge contained within the pulled production pipes covered the derrickmen's clothing and work area as they worked from the monkeyboard. In our calculations, we assume that derrickmen were exposed to sludge on their clothing and the monkeyboard floor 100% of the total time they worked. During this time, they received a radiation dose due to incidental ingestion of sludge via hand-to-mouth contact and external radiation from a layer of sludge deposited on their clothing and the platform floor as well as stacks of used pipes near the monkeyboard.

We apply a range of sludge activities for the radionuclides contained in sludge: 1.35 pCi/g to 21,600 pCi/g for Ra-226, 13.5 pCi/g to 1,350 pCi/g for Ra-228, 2.7 pCi/g to 35,100 pCi/g for Pb-210, and 0.108 pCi/g to 4,320 pCi/g for Po-210. We assume all progeny to be in secular equilibrium with their parent radionuclides. We do not reduce the activities of Ra-226 and Ra-228 in scale and sludge for the times the plaintiffs worked on onshore and offshore oil production rigs after 1989, as Louisiana regulations did not require that equipment be monitored for NORM contamination at these locations.

5.0 Plaintiff Profiles and Radiation Dose Calculations

The specific exposure types to which each worker was exposed are discussed in greater detail in Section 5 of this report.

For each of the exposure types, we calculate a total organ-specific radiation dose in mrem, using the methodology described in the previous section. Detailed calculations are presented in Appendices A (inhalation and ingestion of particulates) and B (direct gamma radiation). Table 2a, 2b, and 2c gives a detailed listing of the plaintiffs name, what he was diagnosed with, the range of rems he was exposed to and his assigned IREP share. The plaintiffs were assigned a table based on their occupation: pipeyard worker (Table 2a), rig worker (Table 2b) and other occupation (truck driver, tank cleaner etc) (Table 2c).

5.1 Worker 1

Worker 1 was born January 4, 1933 and was diagnosed with multiple myeloma during 2006. Worker 1 stated that he was also later diagnosed with lung cancer but the timing of the diagnosis is not clear from his medical records. During his career, Worker 1 primarily worked for HBI Incorporated as a pipeline welder from 1962-1998. Several other companies are also listed on Worker 1's Social Security Records but he stated that he performed the same type of work under similar circumstances regardless of the employer. While employed as a pipeline welder, Worker 1 was responsible for welding oil and gas pipelines during their construction and frequently worked 12-16 hour shifts. All material used during the construction of these pipelines was new, making it unlikely that Worker 1 was exposed to NORM during these times. However, Worker 1 was frequently in the vicinity of radiographic inspections of newly completed welds. Inspections occurred more or less constantly and Worker 1 stated that he was typically one pipe joint away (~30 feet) during this time. Worker 1 was not completely certain as to what methods were used for inspection of the pipe, though he described a device that was put around each weld prior to inspection and mentioned that he specifically remembered gamma ray devices were used on occasion.

Over the course of his career, Worker 1 was exposed to direct gamma radiation from the radiographic inspection of pipeline welds. His calculated low dose is 17.15 rem while his high dose is calculated as 102.89 rem. These values are due in large part to the fact that Worker 1 was approximately 30 feet away from radiographic inspections. Worker 1's IREP share is 26.83 %, indicating that work experience was a substantial and contributing factor to his cancer.

5.2 Worker 2

Worker 2 was born March 21, 1964 and was diagnosed with chronic granulocytic leukemia in April of 1994. Worker 2 passed away on August 26, 1994, just four months after his initial diagnosis from his battle with cancer.

Worker 2 worked for a variety of companies throughout his career in several pipe yards. His performed tasks include cleaning pipes in his earlier years and later moving on to pipe inspection towards the end of his working years. Worker 2 performed these duties when he was employed between the years of 1984 and 1994 for companies such as AD Surratt Pipe Inspection Company, Tuboscope Vetco International, and Acuren Inspection, Inc. Worker 2 frequently worked between 40 and 50 hours a week, Monday through Friday. In speaking with his widow, she recalled that he frequently came home from work covered in a thick layer of black filth (scale), and that his clothes, boots and skin were soaked with materials from the pipe yard. She also stated that he would often complain that his hands/skin hurt and burned at the days end from being covered in materials throughout the day of work. It is unclear exactly how Worker 2 was inspecting pipes at the pipeyard and whether or not he was receiving an additional gamma dose of radiation during this process. He also received a dose of radiation directly from the dirty pipes within the pipe yard, and this calculation was not included. Therefore, it should be noted that the values for Worker 2's exposure to radioactive materials may actually be slightly higher than what is represented below.

Worker 2's work in the pipeyard industry between 1984 and 1994 has resulted in exposure to NORM via the ingestion and inhalation of scale and direct gamma radiation from scale groundshine and while cleaning pipes. The calculated low dose for all of Worker 2's exposures is 118.65 rems while his high dose is calculated as 1868.78 rems. His IREP share is 99.73% indicating it is more likely than not that Worker 2's leukemia was caused by his exposure to radioactive materials on the job.

5.3 Worker 3

Worker 3 was born March 24, 1964 and was diagnosed with acute promyelocytic leukemia in January of 2008. Worker 3 has had chemotherapy, and is currently struggling to find and maintain employment due to pain and complications from his cancer.

Worker 3 performed a variety of tasks during his career throughout many employment opportunities with oil and pipeyard companies. His performed tasks include working as a truck driver for oil-filled trucks, as a pipe cleaner in a pipeyard, and later as a truck mechanic who worked on trucks that were hauling sludge/oil from the oil fields. Worker 3 performed these duties when he was employed between the years of 1990 and 2008, until he was diagnosed with cancer, for companies such as Ambar Incorporated, Quail Tools, BR Welding Supplies and Swift Transportation Company. Worker 3 frequently worked many hours in a week, ranging from 50 to 80 hours depending on his current employer. He recalls being dirty at the end of each work day from scale/sludge debris at each job. While cleaning pipes for Quail Tool, he would handle dirty pipes with no gloves and would often cough throughout the day from the inhalation of airborne materials being cleaned from the pipes. He also recalls being even dirtier at times when working as a truck driver/mechanic of large trucks hauling oil field sludge, as he would get himself into tight spaces around and under the truck and near the hatch that closed to contain all of the materials inside. He specifically noted that his boots were often completely soaked in sludge materials from the truck throughout the entire day, and recalled that his feet would sometimes burn at night time when he returned home from work. Calculations were not included for the additional gamma dose that Worker 3 obtained from his dirty clothes in the workplace. Therefore, it should be noted that Worker 3's numbers for exposure to radioactive materials on the job are actually slightly higher than what is presented below.

Worker 3's work in the oil and pipeyard industry between 1990 and 2008 has resulted in exposure to NORM via the ingestion and inhalation of scale, the ingestion of sludge and direct gamma radiation from scale, sludge and cleaning pipes. The calculated low dose for all of Worker 3's exposures is 12.34 rems while his high dose is calculated as 455.65 rems. His IREP share is 97.49% indicating it is more likely than not that Worker 3's leukemia was caused by his exposure to radioactive materials on the job.

5.4 Worker 4

Worker 4 was born July 3, 1960 and died April 29, 2011. Worker 4 was diagnosed with lung cancer with malignant plural effusion during 2008. It should be noted that Worker 4 smoked approximately 1-1.5 packs of cigarettes per day for much of his life.

Worker 4 worked for a variety of companies near the Harvey Canal but always had the title of "pipe welder" or "pipefitter" regardless of employer. From 1977-2009, Worker 4 worked in a variety of shops helping to fabricate a variety of structures from new and used pipe (including used oilfield tubulars). Worker 4 also worked reconditioning used tubulars by welding new box and pin sections onto pipe joints. As a regular part of his job, Worker 4 would frequently cut NORM contaminated tubulars with an oxy/acetylene torch and would only wear a paper dust mask and face shield or shaded goggles for eye protection. Although Worker 4 was not a radiographer, as a welder he was frequently in the vicinity of radiographic inspections. Worker 4's son (who frequently worked along side his father) recalled that inspections typically involved panoramic radiography of welds, whereby an isotopic source is placed into the bore of a tubular. During these inspections, Worker 4 and other workers would be required to stand a minimum of 20' from the source although workers would sometimes inadvertently get closer. During the course of the day, Worker 4 would get covered with dust and his son recalls that he would frequently work in the vicinity of a variety of operations including cutting, welding and cleaning of NORM contaminated tubulars

During the course of his career, Worker 4 was exposed to alpha radiation via the inhalation of scale as well as direct gamma radiation pipe radiography and while welding NORM contaminated pipes. Worker 4's calculated low dose is 927.57 rems while his high calculated dose is 32933.65 rems. His IREP share is calculated to be 99.63% indicating that it is more likely than not that Worker 4's cancer was caused by on the job exposure to radioactive materials.

5.5 Worker 5

Worker 5 was born March 5, 1952 and was diagnosed with colon cancer around 2000. Worker 5's medical records are not entirely clear as to the precise timing of his diagnosis, however he underwent a colon resection in 2000, a procedure that likely would have followed shortly after a cancer diagnosis.

Worker 5 began his career in the oil and gas industry in 1969 working for various subcontractors. He recalled that the exact nature of his work was highly varied and that at different times he worked as a pipe cleaner in dedicated pipeyards, a pipefitter/welder in pipeyards and refineries and later as an independent fabricator/welder. Early in his career, Worker 5 was primarily involved in descaling NORM contaminated tubulars. He recalled that he worked for a variety of employers helping to clean tubulars in a dedicated pipeyard. Pipeyard locations varied, however Worker 5 recalled that the environment was always dusty and required using an automated pipe rattler. At the time, he specifically remembers that he did not wear a respirator or other protective equipment. Worker 5 gradually took on other responsibilities and eventually started work as a welder but continued to descale tubulars. As a welder, Worker 5 performed a variety of tasks with new and used tubulars, including welding and cutting them with an oxy-acetylene torch. Worker 5 also occasionally performed work in oil and gas refineries, helping with general pipefitting tasks. Near the end of his career, Worker 5 began contracting for pipefitting/welding jobs and was self employed. The tasks he performed were similar to those from earlier in his career with the exception that he not descale any NORM contaminated tubulars. Worker 5 has been on disability since 1989 and has not worked in the oil or gas industry since.

Worker 5 was subject to the inhalation and incidental ingestion of scale dust as well as direct gamma radiation from scale built up on the ground and in NORM contaminated tubulars. The calculated low dose for Worker 5 is 97.9 rems while the high dose is calculated as 268 rems. Worker 5's IREP share is 88.52 %, indicating it is more likely than not that his colon cancer was caused by exposure to radioactive materials on the job.

5.6 Worker 6

Worker 6 was born April 17, 1941 and was diagnosed with colon cancer during September 2004. This cancer soon metastasized to his brain and Worker 6 succumbed to his illness on April 13, 2005.

According to Worker 6's eldest daughter, he worked primarily as a pipe cleaner between 1968 and 2001. Although his Social Security records show a variety of employers listed during this period, Worker 6 worked for a single company that underwent frequent changes in ownership. Worker 6's daughter occasionally visited him on the job and remembers the work environment and tasks as he would describe them. She recalls that Worker 6 worked cleaning tubulars (but did not remember the specific equipment) and that he used cutting torches and welding equipment as a fairly regular part of his job. She also recalls that whenever she visited the yard it was very dusty and that her father's work clothing had to be washed separately because of the dust. While descaling tubulars, Worker 6 did not wear any specialized protective gear such as a dust mask or respirator. Worker 6 would also work very long hours, typically leaving home at 6:00 am and returning at 6:00 pm, 6 days per week. Worker 6's daughter recalls that her father performed all of his work in or near Harvey, LA.

While working as a pipe cleaner between 1968 and 2001, Worker 6 was exposed to alpha radiation from the ingestion and inhalation of scale dust as well as direct gamma radiation from scale build up on the ground and racks of NORM contaminated tubulars. Worker 6's calculated low dose is 273.51 rems while his high dose is calculated to be 905.77 rems. His IREP share is 90.29%, indicating it is more likely than not that Worker 6's cancer was caused by his occupational exposure to radioactive materials.

NOTE: Worker 6's daughter mentioned that her father told her about asbestos exposure when she was young but she did not remember the specifics. This exposure information was not included in any of the risk calculations for Worker 6.

5.7 Worker 7

Worker 7 was born October 14, 1928 and was diagnosed with multiple myeloma during 2009 at the age of 81. Worker 7 passed away just weeks after his diagnosis with cancer and multiple years of surviving with Parkinson's Disease. During his career, Worker 7 worked for Intracoastal Terminal as a pipe cleaner for three years from 1982 to 1984. Following that, Worker 7 worked a long career of 35 years for Avondale Shipyards. With Avondale Shipyards, Worker 7 started out as a roustabout and completed general shipyard duties on barges and at wellheads for the first five years of employment. In 1959, Worker 7 took on a new position as one of the mechanics in the shipyard. For the next 31 years, Worker 7 worked on boats in the shipyard. The majority of his time was spent working on the tugboats that guided the barges in and out of the shipyard, but 25% of the time he was working directly on the actual barges. His work environment was often the inside of the boat on the very bottom level focused on the engines, valves and gears of the barges and boats. Worker 7's son recalls that Worker 7 was always covered in a dirty, black material. He rarely wore a respirator or gloves, and his hands were often stained black from work. He also recalls his father stating that the work environment was not optimal due to the lack of ventilation in the bottom of the boats and the inhalation of whatever materials were being worked on at the time. For both the pipeyard and the shipyard, Worker 7 typically worked ten to twelve hours a day, five to six days a week.

Over the course of his career, Worker 7 was exposed to direct gamma radiation from groundshine from the scale and NORM contaminated tubulars in the pipeyard, and the sludge in the shipyard. He was also exposed to alpha radiation from the inhalation of the scale in the pipeyard, and the ingestion of the scale and sludge from both work environments. His calculated low dose is 369.1 rem while his high dose is calculated as 6336.4 rem. Worker 7's IREP share is 98.08%, indicating that it is more likely than not that Worker 7's cancer was caused by his exposure to radioactive materials while working for Intracoastal Terminal and Avondale Shipyards throughout his career.

5.8 Worker 8

Worker 8 was born October 2, 1937 and was diagnosed with adenocarcinoma of the prostate in late 2003. Worker 8 was employed as a truck driver for much of his career and was ocasssionally required to deliver and pick up oilfield tubulars. From 1965-1966 and 1985-1986 Worker 8 worked for Cactus Pipe and Supply and Intracostal Tubular Services as a truck driver. During the course of a typical work day, Worker 8 would deliver and pick up pipe from various yards. Worker 8 recalled that although he did not physically load and unload pipe himself he was required to remain in close proximity to his truck during the process. Worker 8 would stay with his truck (and within the boundaries of the pipeyard) from anywhere between 30 minutes to 4 hours at a time, depending on the number of other trucks waiting to be unloaded/loaded. It is important to note than the majority of the pipeyards visited by Worker 8 engaged in descaling operations and that he was subject to inhalation and ingestion of scale dust as well as direct gamma radiation while in the yard. Additionally, Worker 8 was subjected to direct gamma radiation from loads of NORM contaminated tubulars while driving his truck.

During the course of his career, Worker 8 was exposed to alpha radiation via the inhalation and ingestion of pipe scale as well as direct gamma radiation from scale built up on the ground and contaminated pipes on his truck. The calculated low dose for Worker 8 is 12.54 rems and his high dose is calculated as 20.67 rems. His IREP share is 11.23%, indicating that work experience is a substantial and contributing factor to Worker 8's cancer.

5.9 Worker 9

Worker 9 was born January 31, 1967 and was diagnosed with chronic lymphocytic leukemia (CLL) during September 2008. Medical records mention a preliminary diagnosis of small lymphocytic lymphoma at the same time, however medical documents from January 2011 state that Worker 9 was diagnosed with CLL.

Throughout his career Worker 9 held a variety of jobs, however his involvement in the oil and gas industry centered on fishing and slickline operations from 1984 to 1999. Fishing operations are typically performed on rigs where tools or other debris has been dropped down hole and must be retrieved. In these instances, a "work string" that is made up of tubulars with a smaller diameter than the main casing is lowered into the bore. The work string enables operators to use a variety of tools to perform a range of downhole operations. Worker 9 recalled that much of his responsibility while working on fishing operations involved handling work string which had been down hole and had been contaminated with mud. Since the work sting was not production tubing and did not have produced fluids or waters flowing through it, there would not have been NORM scale built up in it as is the case with production tubing. However, Worker 9 recalled that sludge was ubiquitous and that he would frequently become covered with it while on the job. Worker 9 also performed work as a slickline operator. This work is similar to fishing operations in that a tool or other hardware is lowered down hole except that a cable is used in place of the work string. Regardless of the specific task, Worker 9 stated that he would work between 40 and 65 hours per week and did not use a respirator or other protective gear.

Worker 9 was exposed to NORM contaminated drilling mud and sludge while working for a variety of employers as a slickline and fishing operator. Incidental ingestion of sludge as well as direct gamma radiation emanating from built up sludge on his clothing contributed to Worker 9's calculated low dose of 1.68 rems and a high dose of 556.05rems. This range of doses results in an IREP assigned share of 97.38%, indicating it is more likely than not that Worker 9's cancer was caused by his exposure to radioactive materials on the job.

5.10 Worker 10

Worker 10 was born May 3, 1950 and was diagnosed with multiple myeloma during 1998. Throughout his career Worker 10 worked a variety of jobs including pipe descaling for Tuboscope during

1976, pipe thread inspection for Vetco-Gray Tool from 1982-1983 and pipeyard security for Van Leeuwen Pipe and Tube Corporation in 1989. It should be noted that the length of time spent at each of these employers given by Worker 10 during his interview does not match his Social Security records and that calculations are based on values he provided.

During his time at Tuboscope, Worker 10 removed scale build up from the inside of used tubulars by sandblasting. Worker 10 described inserting a nozzle into the bore of each tubular in order to remove scale buildup. He recalled that during this time his work area was very dusty and that he did not wear any type of dust mask or respirator. He also recalled that there was a thick buildup of scale in his work area and that he stood approximately two feet away from a rack which held used tubulars. It should be noted that although some literature cites an AMAD of 3 μm for sandblasting particles, exposure calculations for Worker 10 assumed an AMAD of 1 μm, in line with previous RWMA reports. While employed by Vetco-Gray Tool, Worker 10 inspected recently cut threads on tubulars using mechanical gauges. Tubulars were already cleaned, however Worker 10 performed this work in a pipeyard where descaling operations were taking place. Worker 10 also worked briefly for Van Leewuen Pipe and Tube Corporation as a security guard, helping to patrol a yard where descaling operations were taking place. Worker 10 recalls that descaling typically took place in the yard and that he would sometimes be in close proximity to racks of used tubulars during his shift. Regardless of his employer, Worker 10 stated that he typically worked 40 hours per week with occasional overtime.

Worker 10 was exposed to alpha radiation via the inhalation and ingestion of pipe scale as well as direct gamma radiation from racks of NORM contaminated tubulars and scale build up near descaling operations. Based on his work history and interview, Worker 10’s low dose is calculated as 25.49 rems while his high dose is calculated as 514.57 rems. His IREP share is 81.94% indicating it is more likely than not that Worker 10’s cancer was caused by his on the job exposure to radioactive materials.

5.11 Worker 11

Worker 11 was born October 10, 1946 and was diagnosed with lung cancer during 1995. Throughout his career, Worker 11 worked descaling tubulars and occasionally inspected and cut tubulars for a company that often changed names along with ownership. While employed by Universal Tubular Services/ICO-Ultra Sonics Inspection/ICO Inc/ICO Worldwide LP from 1985-2002, Worker 11 worked in pipeyards throughout the South helping to descale NORM contaminated tubulars with an automated wire brush. He recalls that he typically worked six to seven days per week and between nine and eleven hours per day. Although Worker 11 worked in a variety of yards across the South (including in Texas, Oklahoma and Alabama) conditions were similar in that the air was typically dusty and the work area around each descaling machine had a thick scale build up. Worker 11 recalls that the scale on the ground would occasionally be nearly five inches thick due to the fact that there was little time during the day for cleaning the work area. Although descaling tubulars was his primary job, Worker 11 also used an oxy/acetylene torch to cut tubulars that were damaged and he occasionally assisted with radiographic inspections of recently cleaned tubulars. Worker 11 estimates that he performed each of these activities no more than a few hours per week.

Throughout his career, Worker 11 was exposed to alpha radiation via the inhalation and ingestion of pipe scale particulates as well as gamma radiation from built up scale in his work space, NORM contaminated tubulars, and radiography. Worker 11’s low dose is calculated as 783.30 rems while his high dose is calculated as 30938.29 rems. This large dose is due in part to the fact that the lungs (and the associated dose conversion factors) were selected as the target organ resulting in a relatively larger dose from inhalation of particulate. Worker 11's IREP share is 99.39% indicating it is more likely than not that his cancer was caused by exposure to radioactive materials on the job. It should also be noted that Worker 11 smoked about a half pack of cigarettes per day for 30 years and that this has been taken into account for the determination of his IREP assigned share.

5.12 Worker 12

Worker 12 was born July 30, 1922 and was diagnosed with gastric cancer in April of 1996. Worker 12 passed away on October 19, 1997, just over a year after his initial diagnosis from his battle with cancer.

Worker 12 worked for a variety of companies throughout his career in several pipe yards. His performed tasks included welding NORM contaminated pipes for each company. Worker 12 served as a pipe welder when he was employed between the years of 1947 and 1965 for companies such as Brown and Root, Ayer Marine Service, Berwicjk Bay Shipyard, Harms Marine Corporation, Patterson Shipyard, Avondale Shipyard and Berry Brothers Oilfield Service. Worker 12 frequently worked between 50 and 60 hours a week, Monday through Friday and occasionally Saturday. In speaking with his daughter, she recalled that he frequently came home from work covered in a thick layer of black filth (sludge), and that his clothes, boots and skin were soaked with black residue from welding materials on the job site. She remembered that he would return home so dirty, that he would strip of his work clothes before coming inside. Because of the filth, he later was given work uniforms to wear on the job and leave on-site at the end of the day. She also remembers that his hands were stained a dark black from the great amount of time spent at work welding dirty materials. When referring to "welding", his daughter said that her father wasn't always necessarily welding pieces together, but that he was often repairing broken/cracked pipes that were dirty with residue.

Worker 12's work as a welder in the oilfield industry between 1947 and 1965 has resulted in exposure to NORM via the ingestion and inhalation of sludge and direct gamma radiation from sludge and NORM contaminated tubulars. The calculated low dose for all of Worker 12's exposures is 278.8 rems while his high dose is calculated as 1233.3 rems. His IREP share is 95.5% indicating it is more likely than not that Worker 12's gastric cancer was caused by his exposure to radioactive materials on the job.

5.13 Worker 13

Worker 13 was born November 1, 1946 and was diagnosed with chronic lymphocytic leukemia (CLL) and stage 3-B non-Hodgkin's lymphoma (NHL) during November, 2007. Worker 13 worked a variety of jobs throughout his career but primarily worked as a welder. For approximately half of each year from 1966 to 1979, Worker 13 would work within a pipe yard fabricating structures using NORM contaminated tubulars. He would frequently use an oxy/acetylene torch to cut used tubulars and was in the vicinity of radiographic pipe inspections, however he was not issued a radiation monitoring badge or respirator. Worker 13 stated that he worked in a variety of pipe yards and remembers descaling operations typically took place within these yards. Regardless of where he was employed, Worker 13 stated that he would usually not take a job unless he could work 80 hours/week. During his interview, Worker 13 stated that during the summer months he would often work on off shore oil rigs, helping to perform general welding duties on the rig. He stated that during his time off shore he was frequently covered with sludge.

During his career, Worker 13 was exposed to alpha radiation via the ingestion of sludge and inhalation of pipe scale as well as direct gamma radiation from radiographic inspections, NORM contaminated tubulars, and sludge build up his clothing. Worker 13's calculated low dose is 516.1 rems while his high dose is calculated as 19412.1 rems. His IREP share is 99.43% indicating that Worker 13's non-Hodgkin's lymphoma was more likely than not caused by his occupational exposure to radioactive materials.

Although Worker 13 was diagnosed with NHL he was also diagnosed with CLL, a cancer which is sometimes considered to have no link to radiogenic exposures. However, a review by Richardson et al. (2005) finds that the current understanding of CLL pathogenesis describes a process whereby mutational events (which can be produced by ionizing radiation) play an important role in carcinogenesis. CLL is typically considered non-radiogenic in origin partly because the link between CLL incidence and exposure to ionizing radiation is difficult to identify via epidemiologic methods. The long asymptomatic period and protracted period of morbidity associated with CLL make positive associations between CLL and radiation difficult (Richardson et al., 2005). CLL may also be obscured by competing causes of death (Richardson et al., 2005). Richardson et al. (2005) state that studies on the order of one to two decades are likely not long enough to observe effects of radiation on CLL due to the fact that the time between initial exposure and follow up is not sufficient to allow for the induction, latency and morbidity period associated with CLL. Ultimately the authors (Richardson et al., 2005) state that CLL occurrence is like other forms of cancer in that its incidence will be increased by exposure to ionizing radiation. At a fundamental level, the authors (Richardson et al., 2005) state that if CLL has no radiogenic link then it must be an exception to the general principles of radiation carcinogenesis and at the level of DNA damage there is no basis for the assumption that no link exists.

5.14 Worker 14

Worker 14 was born on November 21, 1943 and after struggling with chronic kidney disease (CKD) died on December 25, 2010. This is a non-cancerous disease however CKD is often a preceding condition to Kidney Cancer and studies have found that radioactive exposure is linked to the development of CKD (Moulder & Cohen 2005).

During his career, Worker 14 worked one year (1974) in the railroad industry for Industrial Railroad Service Inc. where he laid tracks in pipe yards. While laying railroad tracks, Worker 14 was exposed to the dust in the pipeyard. Worker 14 worked a span of five years (1982, 1987-1990) for Intracoastal Tubular Services as a pipe cleaner.

Worker 14's wife recalled that he would come home dusty and covered in grease from the pipe yard each night.

During his career, Worker 14 was occupationally exposed to direct gamma radiation from scale on the floor of the pipe yards (groundshine) and from cleaning pipes. His total minimum radiation dose for is calculated to be 155.2 rems while the total maximum radiation dose is calculated to be 1273.19

rems. Worker 14's IREP share is 94.79% indicating that exposure to radiation is more likely than not a contributing factor for the development and cause of his cancer.

5.15 Worker 15

Worker 15 was born January 25, 1949 and was diagnosed with lung cancer early in 2009, requiring removal of part of his lung. It should be noted that Worker 15 is a former cigarette smoker and that this has been accounted for IREP assigned share determination.

Worker 15 worked for a variety of employers during his career but performed similar tasks. Worker 15 stated that he was often contracted to firms and began working as a tank cleaner in 1976 and that his primary task was to clean the inside of tanks recently drained of used drilling mud. These tanks were located in a variety of places including onboard ships and near land based rigs. Although Worker 15's main task was cleaning tanks, he briefly descaled tubulars and worked in the Avondale Shipyard. It should be noted that he also occasionally worked outside of the oil industry and was sometimes employed cleaning tanks that did not contain NORM. Worker 15 stated that he was sometimes unemployed between jobs but this was usually not the case. Later in his career he took on a more supervisory role but still entered tanks frequently in order to inspect them before and after cleaning was performed. Regardless of where he was working or what task was performed, Worker 15 recalled that he frequently worked long hours, sometimes 70-80 hours per week.

Worker 15 describes the insides of used mud tanks as being covered with sludge that would have to be squeegeed off. He stated that the only time he wore a full face respirator was during the late 1980's and early 1990's. The majority of the time spent inside tanks was with minimal personal protective gear. Worker 15 stated that he received training for work in confined spaces and that he was frequently briefed beforehand on the occurrence or NORM in mud tanks. He also stated that he would be scanned with a handheld radiation detector after washing up and before leaving the jobsite.

While inside used mud tanks, either inspecting or cleaning them, Worker 15 was subject to the ingestion of sludge, as well as direct gamma emanating from sludge built up on interior tank surfaces and his clothing. Worker 15 was also subject to the inhalation and ingestion of scale dust while briefly cleaning pipes and while working in the Avondale Shipyards, albeit at a relatively low concentrations. The calculated low dose for all of Worker 15's exposures is 69.1 rems while his high dose is calculated as 876.2 rems. This results in an IREP assigned share of 89.97%, indicating it is more likely than not that Worker 15's lung cancer was caused by exposure to radioactive materials on the job. Worker 15's dose would be even higher if we accounted for the fact that he was likely totally surrounded by NORM contaminated sludge while in tanks; current calculations assume tanks had sludge built up only on the floor and walls. It should be noted that Worker 15 believes he may have been periodically exposed to asbestos between 1981 and 1986 while removing fireproof brick from boiler rooms onboard ships and that this exposure has not been factored into his IREP share determination.

5.16 Worker 16

Worker 16 was born May 8, 1923 and was diagnosed with chronic myelogenous leukemia (also known as chronic myeloid leukemia) in 1985, later succumbing to his disease in 1988. During his career Worker 16 worked for Tube-Kote Inc. (which later became Tuboscope Vetco International) between

1957 and 1983. Worker 16 held a variety of positions at the company, eventually working his way from Pickler, to Pipe Coater to Coating Inspector. Worker 16's son worked with his father several summers and has a good recollection and understanding of what type of work his father did and what the conditions were like when he was there. Worker 16's son recalls that Worker 16 initially worked in pickling operations, helping to remove scale build up from pipes by dipping them in an acid bath and that later Worker 16 operated a machine that would coat recently cleaned tubulars. Worker 16's son recalls that during the final six years of his father's employment, Worker 16 inspected recently coated tubulars. It should be noted that the entire time Worker 16 was working for Tube-Kote/Tuboscope Vetco International, he was in the vicinity of pipe descaling operations. Worker 16's son recalls that descaling in this particular yard was done by sandblasting. Worker 16's son also stated that Worker 16 used an X-ray machine to inspect pipe coating thickness, however based on available information it is unlikely that machines used to measure/inspect coating thickness utilize a radiographic source. Instead it is more likely that machines employing ultrasonic methods were used; these machines do not contribute to Worker 16's radiation dose totals. Regardless of his assignment, Worker 16 would typically work between 40 and 48 hours per week, sometimes working an extra shift. He would also eat his lunch in a break room that was under the same roof as coating/descaling operations and would only occasionally wear a dust mask.

While employed by Tube-Kote/Tuboscope Vetco, Worker 16 was occupationally exposed to direct gamma radiation from pipe racks near his work area as a pickler and pipe coater, as well as alpha radiation via ingestion and inhalation of scale particles his entire time with the company. Worker 16's calculated low dose is 102.02 rems while his high dose is calculated as 1161.02 rems. His IREP share is 99.36%, indicating it is more likely than not that Worker 16's leukemia was caused by his occupational exposure to radioactive material.

5.17 Worker 17

Worker 17 was born October 3, 1956 and was diagnosed with bilateral renal tumors during August, 2008. During his career (1975-2005), Worker 17 worked as a supervisor for a company listed under various names including Patterson Truck Lines, Patterson Tubular Services and Cudd Pressure Control Incorporated. Worker 17 mentioned that he either worked at yards located in Houma, LA or Morgan City LA and conditions were similar regardless of the location. While employed as a supervisor, Worker 17 worked hands on directing the loading, unloading and transport of new and used tubulars. Though he was formally a supervisor, Worker 17 frequently worked alongside laborers handling shipments of pipe and was outdoors in the yard. During the course of his workday Worker 17 would sometimes be in close proximity to pipe descaling operations and the resultant dust and scale build up as well as direct gamma radiation from racks of contaminated pipes. From 1992-1995 Worker 17 stated that he worked almost entirely in an office on site and only occasionally entered the yard. Once he returned to his duties in the yard he was tasked with the extra responsibility of measuring the radiation level of incoming shipments of used pipe. Worker 17 recalled that it was not uncommon for the yard to refuse shipments because they exceeded standards.

Throughout his career with Patterson Truck Lines, Patterson Tubular Services and Cudd Pressure Control Incorporated, Worker 17 was exposed to alpha radiation from the ingestion and inhalation of scale, as well direct gamma radiation from scale on the ground (groundshine) and contaminated drill pipes. The low calculated dose for Worker 17 is 169.82 rems while his high calculated dose is 14684.48 rems. His IREP share is 99.62%

5.18 Worker 18

Worker 18 was born September 20, 1957 and was diagnosed with non-Hodgkin's lymphoma during August 2003. Although preliminary documents mention the occurrence of bone marrow cancer, there is no discussion of this in Worker 18's medical records as of February 2009, three months prior to his death.

Throughout his career Worker 18 worked a variety of jobs within the oil industry including work as a roustabout, crane operator, pipeline installer and later as a manager/foreman for a company involved with cleaning mud tanks. Worker 18's wife recalls that early in his career he was employed by several oilfield service companies and did work similar to that of a roustabout. Worker 18 frequently worked on land based oil rigs but ocasssionally went out to near shore rigs for no more than a few days at a time. Worker 18's wife mentioned that he sometimes worked as a crane operator during the same period he was assigned roustabout duties, though she was not sure as to the relative amount of time spent on each task. Later in his career, Worker 18 ocasssionally worked on pipeline installation crews, helping to install oil and gas pipelines. Worker 18's wife did not recall the exact nature of his work as a pipeline installer except that he performed some welding and worked installing new pipe, not cleaning existing lines. It should be noted that throughout his career, Worker 18 performed a variety of tasks within any given year and had a range of responsibilities. Worker 18's most recent employment was as a manager/foreman for a company that cleaned mud tanks. Worker 18's wife recalled that as a supervisor, Worker 18 was not responsible for physically cleaning the tanks himself.

While working as a roustabout Worker 18 was subject to the ingestion of radioactive drilling sludge as well as direct gamma radiation from sludge on his clothing. While working as a pipeline installer, he was exposed to direct gamma radiation from radiographic sources during pipe inspection activities. Worker 18's calculated low dose is 47.32rems while his high dose is calculated as 146.96rems. His IREP share is 56.74% indicating it is more likely than not that Worker 18's cancer was caused by exposure to radioactive materials on the job.

5.19 Worker 19

Worker 19 was born July 22, 1948 and was diagnosed with distal rectal carcinoma during 2009. Throughout his career Worker 19 worked a variety of jobs, some of which were in the oil industry and included pipe descaling as well as off shore pipeline installation. Worker 19 stated that while employed by McDermott Incorporated he worked on board a barge laying oil pipeline. While on the barge, Worker 19 was part of a crew that performed radiographic inspection of recently completed welds. He described inspection procedures common in the oil industry, including double wall radiography of pipe utilizing a "crank out" gamma source. During this period Worker 19 worked long hours, typically 14 hours on/7 hours off and 28 days on/7 days off.

Worker 19 stated that he worked for Tuboscope for approximately 3-4 years helping to descale pipe as well as machine threads and inspect recently cleaned tubulars with a "Sonoscope" machine. It should be noted that this type of machine relies on an induced magnetic field to identify flaws within tubulars and does not rely on gamma sources or X-rays. Worker 19 recalled that he typically worked up to 60 hours per week and would spend approximately 25% of his time cleaning tubulars and the remainder operating the Sonoscope machine. He could not recall whether or not there was significant scale build up in his work area however he did remember that the work environment was very dusty. While working at the Tuboscope facility Worker 19 also recalled that he would frequently come home covered in dust and that he would eat his lunch in the yard.

Worker 19 was exposed to alpha radiation via the inhalation and ingestion of scale while descaling tubulars at Tuboscope. He was also exposed to gamma radiation from scale build up near cleaning operations and racks of contaminated pipe at Tuboscope facilities. Worker 19 was also subject to gamma radiation while assisting with pipe radiography on board pipe laying barges. Worker 19's calculated low dose is 23.60 rems while his high dose is calculated as 109.85rems. His IREP share is 32.20%, indicating that Worker 19's cancer was significantly influenced by his occupational exposure to radioactive materials.

5.20 Worker 20

Worker 20 was born October 13, 1958 and was diagnosed with malignant neoplasm of the larynx in August 2009. However, Worker 20's medical records indicate that he was initially diagnosed in 2004 but did not seek treatment at the time. These records have since been destroyed by Hurricane Katrina and are not available for reference.

Worker 20 worked for various employers between 1977 and 1999 during which time he performed several tasks, mostly relating to work on board and off shore oil rigs including roughnecking, operating rig based cranes, rig based pipe inspection as well as general help on board the rig. It is important to note that Worker 20 did not keep a consistent work schedule and often worked a variety of jobs for numerous employers throughout his career. He also did not work at all during the late 1980's and mid 1990's due to health issues. During the majority of his time working on rigs, Worker 20 would frequently work a schedule of 12 hours on, 12 hours off for up to three weeks at a time. While roughnecking or working as a general rig hand, Worker 20 would frequently handle and work near used drill pipe becoming covered with sludge. He also occasionally worked cleaning the inside of recently emptied mud tanks for a short period during the late 1970's. Later in his career as a rig based crane operator, Worker 20 recalls that he would frequently help other workers on the rig floor and as a result would often be just as dirty. Worker 20's most recent employment was that of an offshore drill rig mechanic. He recalled that when servicing equipment on rigs he would work more or less continuously until the job was finished and would frequently get covered with used drilling mud and would work around used drill pipe. During the vast majority of his career, Worker 20 wore only basic safety equipment including steel toed boots and safety glasses. He only occasionally wore a dust mask while with Mallard Bay Drilling during the early 1990's.

Over the course of his career, Worker 20 was occupationally exposed to alpha radiation via the ingestion of sludge as well as direct gamma radiation from stacks of used drilling pipe as well as sludge on rig floors, his clothing and inside empty mud tanks. Based on his work history and interview, Worker 20's low radiation dose is calculated to be 17.5 rems and his dose is calculated as 684.4 rems. His IREP share is 82.47% indicating it is more likely than not that Worker 20's cancer was caused by on the job exposure to radioactive materials.

5.21 Worker 21

Worker 21 was born February 13, 1959 and was diagnosed with Colon cancer in 2005. Worker 21 passed away on May 5, 2010, five years after his diagnosis. Between the years of 1979 and 1993, Worker 21 worked for a variety of different companies such as Avondale Shipyards, Circle Barge Drilling Co., Plimsoll Marine Inc., Nola Shipyard Inc., Payne & Keller Gulf Coast Inc, Todd Shipyards Corp., Gulf Industrial Contractors, Brown & Root Inc., Rig Hammers Inc., and Manninos P&M Texaco Service Inc. At these companies, Worker 21 worked as a roustabout and completed general shipyard duties for the entirety of his career.

During his career Worker 21 was occupationally exposed to direct gamma radiation from sludge on the floor of shipyards and alpha radiation from the ingestion of sludge at shipyards as well. His total minimum radiation dose is calculated to be 0.5 rems while the total maximum radiation dose is calculated as 50.9 rems. Worker 21’s IREP share is 61.97% indicating that exposure to radiation is more likely than not a contributing factor for the development and cause of his cancer.

5.22 Worker 22

Worker 22 was born September 20, 1958 and was diagnosed with T cell lymphoblastic lymphoma during July 2005. Worker 22 subsequently died from his illness but it is not clear from available records when this occurred. During his career Worker 22 worked for a variety of employers, however his exposure to NORM occurred while working as a pipe cleaner with Martin Oil Country Tubular Inc. from 1988 through 1996. A relation of Worker 22 recalls that during his employment Worker 22 would typically work 8 hours per day, 5 days per week cleaning used oilfield pipe with an automated wire brush. The relation of Worker 22 recalls that when they occasionally visited the yard the environment was generally very dusty and that the layer of pipe scale was several inches thick in some places. The relation of Worker 22 recalls that Worker 22’s clothing was so dusty that it had to be washed separately from other clothing and that he specifically mentioned the use of VARSOL on the job. Worker 22 typically did not wear any sort of dust mask, though he did eat his lunch in a separate dining area away from the main yard.

It is also worthwhile to note that the relation of Worker 22 stated that Worker 22 was issued a radiation monitoring badge but Worker 22 told her that badges were rarely collected and readings were not properly recorded. The relation of Worker 22 still has one of these badges but this issue has not been investigated further.

While employed as a pipe cleaner by Martin Oil Country Tubular Inc., Worker 22 was occupationally exposed to NORM contaminated pipes and pipe scale. During the course of pipe cleaning operations, Worker 22 ingested and inhaled pipe scale. He was also exposed to groundshine radiation and direct gamma radiation emanating from nearby pipe racks. Based on Worker 22’s occupation history and interview with the relation of Worker 22, the low calculated dose to Worker 22 is 259.96 rems while the high dose is 841.12 rems. His IREP share is 89.53%, indicating that it is more likely than not that Worker 22’s cancer was caused by on the job exposure to NORM.

5.23 Worker 23

Worker 23 was born April 8, 1940 and was diagnosed with colon cancer in 2004 and cholangiocarcinoma (cancer of a bile duct near the liver) in 2008. Worker 23 passed away soon thereafter. Worker 23's widow stated that throughout his career, Worker 23 worked for a variety of employers including a period from 1977 to 1992 when he worked as a truck driver. During this time Worker 23 would routinely pick up and deliver new and used oilfield tubulars to onshore drill rigs and pipeyards. According to Worker 23's widow, Worker 23 would work up to 60 hours per week and would usually come home covered with mud and dirt. She recalls that the tubulars Worker 23 hauled were a mix of new and used, and that he would frequently load and unload his own materials. Regardless of whether or not he was personally loading or unloading pipe, Worker 23 would remain close to his truck and within the confines of pipeyards during the entire process. These yards typically had pipe descaling facilities.

During his time as a truck driver, Worker 23 was exposed to direct gamma radiation while loading/unloading NORM contaminated tubulars as well as when driving a truck loaded with used tubulars. Worker 23 was also subjected to alpha radiation via inhalation of scale particles while in pipeyards participating in descaling operations and from the ingestion of sludge from handling contaminated tubulars. The total low dose to his colon from these exposures is calculated as 89.70 rems while the high dose is calculated as 267.86 rems. Worker 23's IREP share for colon cancer is 70.65%. The total low dose to his liver from previously mentioned exposures is 105.95 rems while the high dose is 1303.91 rems. Worker 23's IREP share for liver cancer is 98.49%. The IREP shares for Worker 23's two independent cancers indicate that both were more likely than not to have been caused by exposure to radioactive materials on the job. The combined probability of these two cancers is 99.56%.

5.24 Worker 24

Worker 24 was born April 10, 1947 and died on September 25, 2007 shortly after being diagnosed with Chronic Myelocytic Leukemia in 2006. Worker 24 performed a variety of tasks during his career and from 1969 to 1984 he operated a hot oiling truck for a range of employers.

Hot oiling trucks service on shore oil production rigs and are used to remove paraffin buildup in well bores, flow lines and other equipment. These trucks operate by heating oil (often provided by production onsite) and circulating it though rig equipment wherever paraffin has build up. This hot oil allows paraffin to become less viscous and it then flows out along with the circulated oil. It is important to note that this work involves coming into contact with production equipment which is likely contaminated with scale (and NORM) in addition to paraffin. Operators of hot oil trucks are required to come into direct contact with rig equipment contaminated with sludge in order to hook up their machinery. Operators are likely to ingest sludge during these instances as well as be exposed to direct gamma radiation emanating from sludge deposited on their clothing and from scale built up in nearby equipment. For Worker 24's exposure calculation, we assume that he was only exposed to NORM containing equipment one third of the time he was working, since the nature of hot oiling trucks would have required him to operate the equipment at a distance from the rig, as well as drive the rig from site to site (it did not carry NORM contaminated materials onboard).

Worker 24's widow had a good recollection of the type of work Worker 24 performed, however she never worked with him and her only knowledge of his job duties was whatever Worker 24 described to her. Worker 24's widow stated that Worker 24's work schedule was variable in that he would sometimes drive to an oil rig, operate for a full day (at least 8 hours) and return home in the evening. Other times Worker 24 would remain onsite, operating for several days at a time. According to Worker 24's widow, Worker 24 did not wear any personal protective gear onsite, other than a set of work gloves.

Worker 24's work with hot oiling trucks resulted in the incidental ingestion of NORM contaminated sludge, as well as direct gamma radiation emanating from scale filled equipment and sludge. His total low dose is calculated as 12.1 rems while his high total dose is calculated as 964.2 rems. This dose results in an IREP share of 94.39%, indicating it is more likely than not that exposure to radioactive materials on the job resulted in Worker 24's cancer.

5.25 Worker 25

Worker 25 was born July 24, 1944 and was diagnosed with colon cancer, specifically intramucosal adenocarcinoma of the ascending colon, during January 2008. Worker 25 was also diagnosed with liver cancer, however this metastasized from his colon and is not considered as an independent cancer for our calculations.

Throughout the course of his career, Worker 25 worked as a machinist for a variety of companies between 1963 and 2002. It should be noted that although Worker 25 was hired by a variety of employers, all work was done at pipeyards in Louisiana. Worker 25's daily tasks involved refurbishing NORM contaminated pipe which required him to machine new threads onto tubulars. No welding or cutting with an oxy-acetylene torch was performed. Work was typically done in a shop setting and according to Worker 25, the environment was extremely dusty with scale build-up that was occasionally as much as one foot thick. Worker 25 did not wear a dust mask and would work long hours, typically no fewer than 80 hours per week and occasionally up to 100 hours per week.

Throughout his career as a machinist, Worker 25 was exposed to alpha radiation via the inhalation and ingestion of pipe scale as well as gamma radiation via scale on the ground and nearby racks of contaminated drill pipe. Based on his work history and interview, Worker 25's calculated low radiation dose is 739.73 rems while his high dose is calculated as 1869.19 rems. His IREP share is 95.49% indicating that it is more likely than not that Worker 25's cancer was caused by his exposure to radioactive materials on the job.

5.26 Worker 26

Worker 26 was born August 4, 1964 and was diagnosed with testicular cancer in June of 2005. Worker 26 has undergone treatments and is currently in remission.

Worker 26 worked as a roustabout and instrumentation specialist for sixteen years for Anadarko E&P Company and DCP Midstream. For the first few years on the job, his primary role was that of a roustabout. However, in the following years, he was trained to be one of the instrumentation specialists in the plant. Worker 26 was responsible for the maintenance and fixing of the tanks, valves and pipes within the plant. These tanks were filled with NORM condensate that came directly from the well heads in the field. Many of the times, his assistance was required when the valves clogged and the tanks would be overflowing. While fixing the equipment, he recalled standing in the sludge material up to his knees and being completely covered in liquid residue. He sometimes wore gloves on his hands, however these were soaked through for the better part of each work day. He also recalled being so filthy with work material, that he would often have to go home halfway through the work day to change his clothes as the skin on his legs would become irritated and sensitive from wearing soaking wet work pants. Worker 26 said that a typical work week was on 50 hours per week on average, however it wasn't uncommon for him to frequently work 70 or 80 hours in a busy work week.

Worker 26 said that regulations became much stricter after he left his position with DCP Midstream. He said that people doing the same position that he held for sixteen years were later required to wear a protective suit, when he had been exposed to all of those same NORM materials with no protection at all for the duration of his employment. He also recalled an instance towards the end of his career with DCP Midstream when he was at work and an environmental investigator came in and ran a Geiger counter throughout the work site. He said that he as well as the other employees were scared and concerned with the high levels of radioactive material that the Geiger counter picked up on, when they had been unaware of just how dangerous their work environment was.

Worker 26's work in the oil industry between 1990 and 2005 has resulted in exposure to NORM via the ingestion of sludge and direct gamma radiation from sludge. The calculated low dose for all of Worker 26's exposures is 51.1 rems while his high dose is calculated as 162.3 rems. His IREP share is 43.87%, indicating that his exposure to radioactive materials is a substantial and contributing factor for the development of his cancer.

5.27 Worker 27

Worker 27 was born March 15, 1955 and was diagnosed with liver cancer early in 2006. Within a few months the cancer had metastasized to his lungs and on September 28, 2006, Worker 27 died due to the cancer. It should be noted that Worker 27's medical records indicate he was in otherwise good health and did not abuse alcohol.

Worker 27 was involved in the oil industry the majority of his career and worked a variety of jobs. Most recently he was employed as a line operator and prior to that worked as an offshore roughneck and tubular descaler. Earlier in his career, he also worked in the Avondale Shipyards as well as with a company that provided general services to onshore oil rigs work. Worker 27's widow has a fairly good recollection of the type of work Worker 27 performed most recently; however she did not remember the specifics of his earliest employment. For the brief time Worker 27 was employed at the Avondale Shipyards we assume only that he inhaled and ingested dust at relatively lower concentrations than individuals who actually operated pipecleaning equipment. Shortly after leaving the Avondale Shipyards, Worker 27 went to work for Soloco LLC. Because Worker 27's widow did not recall exactly the type of work Worker 27 performed with the company, we assume that he performed general labor helping to service land based rigs. Soloco LLC is currently an oilfield services company and it is likely that Worker 27 would have had at least some exposure to sludge while on the job.

Later in his career, Worker 27 was employed as a roughneck on offshore oil rigs. Worker 27's widow recalled that Worker 27 would be on the job between 7-10 days, though he would occasionally go through periods where he worked only 2-3 days at a time. While working for all other employers (those not located offshore), Worker 27's widow recalls that Worker 27 typically would work approximately 45 hours per week. Worker 27's widow never visited Worker 27 on the job, but she does recall that he often came home dirty and smelling of petroleum regardless of where he was working. She also specifically remembers that Worker 27 wore a fitted respirator while employed as a line operator; this likely greatly reduces his incidental ingestion of sludge during that time.

Worker 27 was exposed to NORM via inhalation and incidental ingestion of particulates in pipeyards as well as ingestion of sludge while onboard or while working with oil rigs or related equipment. He was also exposed to direct gamma radiation emanating from scale built up in pipeyards as well as sludge on oil rigs and on his clothing. The calculated low dose from these exposures is 229.8 rems while the high dose is calculated as 8726.2 rems. Worker 27's IREP share is 99.79% indicating it is more likely than not that his cancer was caused by exposure to radioactive materials on the job.

5.28 Worker 28

Worker 28 was born January 2, 1926 and was diagnosed with prostate cancer in 2000. The cancer soon metastasized to other organs including his brain and brain stem. Worker 28 eventually died on December 31, 2004 due to metastic disease of the brain and brain stem.

Worker 28 performed a variety of tasks during his career including many involving the oil and gas business. His widow recalled that he performed different tasks but that his main jobs included working as a roughneck on land based oil rigs, descaling pipe and driving heavy trucks. Worker 28 performed these duties whenever he was employed between 1945 and 1998 by "Beebe" or any variation on that name. It should be noted that early in his career, Worker 28 occasionally worked outside of the oil industry and that his actual tasks within the oil industry likely varied on a daily basis as he did not have a set schedule. Worker 28's widow estimated that the majority of Worker 28's time was spent working as a roughneck on land based rigs and that the remaining time was divided between descaling used tubulars and trucking. Regardless of the specific task, Worker 28 frequently worked more than 40 hours per week and would sometimes be on the job 60 hours per week. Although Worker 28's widow rarely visited her husband at work, she recalled that he frequently came home from work covered in a mix of mud, dust and oil and that descaling was performed either in a dedicated pipe yard or onsite, at the rig. She stated that he may have worn a paper dust mask while descaling pipe because the area was generally very dusty but was not positive on the specific protective equipment used. Worker 28's widow was also not certain what materials Worker 28 was transporting while driving trucks or where he was driving to/from, thus we assume no NORM exposure during those times.

Worker 28's work in the oil industry between 1945 and 1998 has resulted in exposure to NORM via the inhalation and ingestion of scale dust, ingestion of sludge and direct gamma radiation from scale, sludge and NORM contaminated tubulars. The calculated low dose for all of Worker 28's exposures is 75.9 rems while his high dose is calculated as 349.3 rems. His IREP share is 73.09% indicating it is more likely than not that Worker 28's prostate cancer was caused by his exposure to radioactive materials on the job.

5.29 Worker 29

Worker 29 was born March 17, 1955 and died March 7, 1997 after being diagnosed with Acute Myelogenous Leukemia approximately one year prior. Worker 29's formal job title was "pipefitter/boilermaker" and from 1973 to1992 he worked as a subcontractor for a variety of companies. According to Worker 29's widow and his brother, Worker 29's main task was to clean large tanks at petroleum refineries and tank farms (also located at refineries) as part of "turnaround" operations where tanks would be cleaned prior to receiving new chemicals. Worker 29 entered these tanks to help remove residue left over from various chemicals stored inside, typically by shoveling out whatever residue remained on the tank floor. Worker 29's widow recalls that Worker 29 would return from work smelling strongly of petroleum products and that he would store his clothing (and full face respirator) outside of the home due to the odor. Worker 29 sometimes worked with his brother, who recalled occasionally working in tanks which previously contained Butadiene. Worker 29 wore heavy protective clothing for protection from corrosive materials and likely would have worn a respirator while inside each tank (though Worker 29's brother was not sure of the specific type of respirator used, it varied depending on the job). Worker 29's brother also stated that while working with Worker 29 in the early 1970's for the GATX Corporation, they helped fabricate storage tanks on site. Worker 29's brother recalls that during this process, Worker 29 was likely in the vicinity of radiographic inspections that frequently took place. However, Worker 29 was not a radiographer and Worker 29's brother stated it was not typical to work in the immediate vicinity of inspection operations for a prolonged period of time. Worker 29's brother also mentioned that as far as he knows, Worker 29 did not receive confined spaces training.

Worker 19's widow confirmed that Worker 29's primary job was cleaning tanks as a pipefitter/boilermaker. She stated that the only other job he held was working in the family's general store beginning in the late 1980's. This work accounts for apparent gaps in Worker 29's employment history because this income was not listed in his Social Security records. Worker 29's widow also confirmed that Worker 29 did not take on any part time jobs working in pipe cleaning yards or performing other oil related work.

To calculate Worker 29's radiographic exposures, we assume he was near radiographic inspections 50% of the time he was working for GATX Corporation between 1973 and 1976. From personal interviews, we know that Worker 29 worked between 40 and 72 hours per week and that inspections would sometimes take place 10-15 feet away from a worker. Given this, we calculate a total low dose of 26.71 rems and a high dose of 91.25rems to the red bone marrow, yielding an IREP share of 64.86% indicating it is more likely than not that Worker 29's Leukemia was caused by his exposure to radioactive materials on the job.

Worker 29 was likely exposed to toxic and/or carcinogenic chemicals while performing tank turnarounds. Worker 29's brother specifically remembers working with Worker 29 in tanks previously containing Butadiene (also known as 1,3-Butadiene), a known human carcinogen that has been linked to leukemias.[65] Due to the fact that Worker 29 performed turnarounds in petroleum refineries and tank farms it is likely he also had contact with benzene, a known human carcinogen linked to leukemias.[66] Unfortunately, there is no record of the specific chemicals Worker 29 was exposed to, the exact type of

[65] U.S. EPA, Integrated Risk Information System, 1,3-Butadiene (CASRN 106-99-0), Revised 11/05/2002.
[66] U.S. EPA, Integrated Risk Information System, Benzene (CASRN 71-43-2), Revised 04/17/2003.

respirator used for each situation and the air concentration of chemicals in each tank. This set of circumstances makes it difficult to precisely determine the risk associated with Worker 29's work around these chemicals.

5.30 Worker 30

Worker 30 was born on October 12, 1959 and was diagnosed with Lymphoblastic Leukemia September of 2003. Sadly, Worker 30 died in March of 2004, only six months after his diagnosis. During his career between the years of 1988 and 1995, Worker 30 worked for a variety of companies such as Bayou Scale Contractors Inc, Liberty Services, Teledyne Movible Offshore and Transocean Offshore. Worker 30 worked as a roustabout and completed general shipyard duties for the entirety of his career at these companies.

Over the course of his career, Worker 30 was exposed to direct gamma radiation from sludge in the shipyards and alpha radiation from ingestion of sludge at the pipeyards as well. His total minimum radiation dose is calculated to be 0.26 rems while the total maximum radiation dose is calculated as 525.70 rems. Worker 30's IREP share is 97.94% indicating that exposure to radiation is more likely than not a contributing factor for the development and cause of his cancer.

5.31 Worker 31

Worker 31 was born August 30, 1961 and was diagnosed with a malignant neoplasm of the stomach during 2009. During his career Worker 31 worked in a variety of fields, including pipe cleaning operations in 1980 for a company he recalled as "PSI" though no such name is listed in his Social Security records. Worker 31 only performed pipe cleaning for six months and worked approximately 40 hours per week during that period. He recalls that used oilfield pipe was cleaned using a wire brush and that pipes were loaded onto a cleaning machine from a horizontal rack. According to Worker 31 the pipeyard was very dusty and he typically ate his lunch in the yard. Worker 31 did not remember if there was scale built up on the ground, however groundshine radiation from scale was included in dose calculations since it is typical of his type of work environment.

While working in pipe descaling operations for a period of approximately six months, Worker 31 was exposed to alpha radiation from the inhalation and ingestion of pipe scale as well as direct gamma radiation from scale built up on the ground and from scale contaminated drill tubulars. Worker 31's low dose is calculated as 6.26 rems while his high dose is calculated to be 16.82 rems. His IREP share is 29.94%, indicating that work experience is a substantial and contributing factor to Worker 31's cancer.

5.32 Worker 32

Worker 32 was born October 16, 1958 and was diagnosed with thyroid cancer in 2006. Worker 32 has had numerous surgeries and the cancer has spread within his neck.

Worker 32 performed a variety of tasks during his career throughout many employment opportunities with oil companies and working offshore on oil rigs. His performed tasks include working as a roughneck on offshore oil rigs, as a roustabout working in oil field wells, and occasionally as a rattler when he would clean the pipes on an offshore rig. Worker 32 performed these duties during the period of time he was employed between the years of 1979 and 1984 for companies such as Owen Drilling

Company, TransContinental Drilling Company, Penrod Drilling Company and Tyler Drilling Company. Worker 32 frequently worked many hours in a week, ranging from 50 to 85 hours depending on his current employer. He recalled that he often came home from work covered in a thick layer of oily sludge, and that many days clothes were so dirty from work that workers discarded the days clothing to the trash before leaving and would obtain new work clothing the next day. He stated that he did wear gloves, but that these gloves were so saturated that his hands were covered in oily sludge and residue all day long.

Worker 32's work in the oil industry between 1979 and 1984 has resulted in exposure to NORM via the ingestion of sludge and direct gamma radiation from sludge and NORM contaminated tubulars. The calculated low dose for all of Worker 32's exposures is 2.77 rems while his high dose is calculated as 80.68 rems. His IREP share is 36.73% indicating that his work experience is a substantial and contributing factor to Worker 32's cancer.

5.33 Worker 33

Worker 33 was born June 24, 1953 and was diagnosed with pancreatitis in 1998. This is a non-cancerous disease, however some studies suggest that pancreatitis is a preceding condition to pancreatic cancer (Albert et al. 1993; 2006).

Worker 33 was employed as a manual pipe cleaner during his career throughout many employment opportunities with various pipeyard companies. His performed tasks included manually cleaning production pipes with a wire brush (inside and out) and occasionally counting/tallying pipes within the yard. All of this work took place within a pipeyard where descaling operations were under way. Worker 33 performed these duties when he was employed between the years of 1973 and 1988 for companies such as Tom Hicks Transfer Company, Brown and Root, Inc., and Superior Construction Company. Worker 33 frequently worked between 45 and 55 hours throughout a normal work week consistently with each place of employment. He recalled that the pipeyard was constantly dusty and that there was always scale build-up/debris in his work area and throughout the yard. He also noted that he ate lunch on a daily basis within a "shed" in the pipeyard that was also dirty with material from the work site.

Worker 33's work in the pipeyard industry between 1973 and 1988 has resulted in exposure to NORM via the ingestion and inhalation of scale and direct gamma radiation from scale. The calculated low dose for all of Worker 33's exposures is 154.68 rems while his high dose is calculated as 452.46 rems. Although pancreatitis is a non-cancerous disease, literature suggests that pancreatitis is a disease that is and can be affected/caused by direct radiation (Levy et al. 1993). Therefore, with the calculated range of rems that Worker 33 experienced throughout his working career with NORM contaminated material, it can be assumed that his work experience has contributed significantly and/or caused his pancreatitis.

6.0 Radiation Health Effects

6.1 Principle Effects of Radiation

There are two principle concerns that accompany exposure to radiation. One is the formation of genetic defects and the second is induction and promotion of cancer. In both cases, irradiation of cells produces physical and chemical changes. On one hand, the genetic materials in the reproductive cells of parents are damaged. The resultant mutation may be manifest in birth defects or heritable diseases in immediate offspring or may be carried through successive generations to remote offspring. Radiation damage to chromosomes cause changes leading to the induction of various kinds of cancer in the effected organs.

There are many important factors bearing upon understanding of the effects of radiation dose. These include the total dose, the rate at which the dose was delivered, the dose pattern (e.g. intervals between exposure), and the nature of the radiation contributing to the dose. For example, gamma rays can penetrate through the body and deposit only a fraction of their energy. Interactions are thinly distributed over relatively remote cells and organs. On the other hand, alpha-emitting radionuclides, deposited internally, deliver a highly localized radiation dose with a total range of approximately 20 μm (0.0008 inches). Effects are relatively much more likely with alpha particle irradiation. The ICRP accounts for this high energy transfer of alpha particles with a quality factor of 20 in converting rads to rems; for gamma radiation, a rad equals a rem. Another important factor is the stage of cell division. The cell is more susceptible to damage at the last stage of division. Children could be more susceptible because cells are reproducing more rapidly while growing and more cells are in the susceptible stage. This is the same reason why radiation therapy has greater effect on cancerous cells that are multiplying more rapidly. Other factors affecting radiation effects include sex, age at exposure, time of conception (relative to irradiation), location of exposed genes, and genetic susceptibility. The ICRP[67] recently published a treatise on the possible genetic inherited susceptibility to cancer that could modify the effects of radiation exposure. The path and organ dose due to the internal deposition of radionuclides is highly variable. The attendant physical and chemical characteristics result in variable deposition and retention patterns at specific locations in the body. Certain organs and cells can be much more affected than others.

6.1.1 Genetic Effects

One expects that the consequences of irradiation of germ cells in the female are greater than those in the male. Females are born with the entire inventory of germ cells that will form mature oocytes throughout her reproductive life. Therefore those germ cells accumulate any radiation dose over many years. Male sperm is constantly reproduced and would be subject to only short-term exposure.

Mutations in germ cells are characterized by changes within the genes that make up chromosomes in a cell nucleus. The genes consist of specific sequences of deoxyribonucleic acid (DNA) and protein. The genes are components of the chromosomes and determine the hereditary factors and the entire organization and function of the chromosomes and the cells. Genetic diseases occur because of changes in the structure or regulation of DNA within the chromosomes and cells of an organism. These mutations can occur naturally or by action of physical and chemical agents.

Virtually any identified birth defect has genetic alterations that could be a consequence of radiation damage. All mutations are expected to have some harmful effect. Genetic problems are generally classified to three categories: single gene disorders, chromosomal aberrations, and multifactorial disorders. Single gene disorders usually are more drastic and are immediately manifest in offspring.

[67] ICRP, 1998

Major anomalies might include hydrocephalus (fluid in the cerebral ventricles of the brain) and achondroplasia (bone deformities and dwarfing).

Single gene defects are inherited by autosomal transmission (22 pairs of non-sex chromosomes) or by X-linked chromosomes. One copy of the autosomal gene is contributed by the mother and the other by the father. The autosomal traits can be either dominant (immediately expressed) or recessive. Expression of recessive traits requires combination with another copy. A son's X-linked gene will come from the mother and a daughter will receive the X-chromosome from both the father and mother. X-linked traits are expressed only in a daughter and can be either dominant or recessive.

Chromosomal aberrations due to radiation damage are well known and include abnormal numbers of chromosomes, and broken and/or rearranged chromosomes. The chromosomal abnormalities can be passed on at the union of the egg and sperm.

The multifactorial disorders are believed to involve more than one gene and are expected to be a consequence of environmental factors such as drugs, toxins, viral or bacterial agents, and radiation dose. The environmental factors include conditions within which the fetus or embryo are developed. The mother can take in teratogenic radionuclides and the effects transferred to the developing embryo. There is a genetic component, but the other factors contribute to the diseases or abnormalities. The term is used or qualified in reference to a single disorder (e.g. clubfeet) because of the multitude of possible contributing factors.

Newly recognized mechanisms and genetic disease suggest other means of disorders beyond the three described above. In one case there is a combined effect with the existence of both normal cells and cells carrying a mutation. It also appears that the parental origin (mother or father) will determine the genetic manifestation. Other observed phenomena depend upon whether the altered cells originated from both the mother and father.

It is now understood that the cytoplasm within a cell, outside of the nucleus with the genes and chromosomes, also carries genetic information that is passed on through cell division. There is a strictly maternal line of transmission and the abnormalities can be transmitted to her children.

Any of the mechanisms under investigation include abnormalities caused by irradiation even though the means of transmission and manifestation differ.

6.1.2 DNA Damage

Deoxyribonucleic acid (DNA) is bound in double helical chains by hydrogen bonds between the bases forming the material in the chromosomes of the cell nucleus. There are two base pairs, the purine bases adenine and guanine, and the pyrimidine bases thymine and cytosine. The adenine base pairs with the thymine and the guanine pairs with the cytosine. One DNA strand has the complementary sequence of the other. Each gene has a unique sequence of the bases. The genes are linked in linear arrays to form chromosomes in the cell nucleus. A large number of genes, 60,000 to 70,000 are required to control normal functions. Most genes are present in only two copies with each on a separate chromosome. One copy is inherited from the mother and one from the father.

Damage to DNA is the primary event that leads to the development of cancer and hereditary disease. Double strand breaks in the DNA are the most likely cause of mutation in somatic or germ cells.

Ionizing radiation can cause different kinds of damage. The complexity of the damage increases with an increase in the radiation Linear Energy Transfer (LET). Ionizing radiation deposits energy in cells as tracks of ion pairs. The intensity and density of ionizations is a function of the LET of the radiation. Typical low-LET x-ray and gamma radiation can cause about 70 ionizations across an 8 µm cell diameter cell nucleus. A high-LEt alpha particle, such as from Ra-226, will cause over 23,000 ionizations within the nucleus of a single cell[68]. This damage causes mutations and chromosomal changes. Radiation damage transforms cells to a stage in the development of metaplasia that can lead to neoplasia or cancer.

In an attempt to repair single-stranded DNA damage, the DNA replication may bypass the damaged sites by inserting an incorrect base opposite the lost or altered base. Mutations and chromosomal rearrangements are a consequence. The repair of complex DNA double-strand breaks is inherently error-prone and is most likely to be dependent upon dose, dose rate and radiation quality.

The radiosensitivity of normal cells, studied for survival after irradiation in cultures, varies by about a factor of two. In low irradiation dose conditions, this is extended to a factor of three to four[17]. This variation may have a genetic basis.

Cancers induced following lower radiation doses appear as a consequence of gene/chromosomal mutations. The dose-dependent radiation induced mutations add to other tumor-initiating events. It is reasonable to assume the same variable sets of cellular factors serve to suppress or enhance malignant development. The dose response could be dependent upon a change in the post-irradiation processes. The radiation cancer risk might be reduced by error-free DNA repair. However if post-irradiation mutation rates are persistently high, as with genomic instability, then cancer induction would be enhanced.

Qualification of the risks associated with lower radiation doses require information from epidemiology, the shape of the dose-response curve, and the damage mechanisms that could be extrapolated to lower doses.

6.1.3 Radiation Induced Cancer

It is known that radiation dose can lead to the induction of cancer. For over 60 years, the International Commission on Radiation Protection, a body of experts in this field, has produced a series of documents providing the progressive knowledge of radiation effects to enable proper radiation protection. In the United States, since 1931 the National Council on Radiation Protection and Measurements has published similar reports, and continues to do so. In 1959, the Federal Radiation Council was formed to advise the President on radiation matters affecting health for all Federal agencies and for cooperative State Programs. With the formation of the US EPA in 1970, that program became the responsibility of the US EPA. Since the mid 1980s the US EPA has provided a related series of documents to assist Federal and State agencies in their implementation of radiation protection programs. The US EPA has recently (Sept., 1999) updated their published cancer risk coefficients. A successive series of reports by the

[68] UNSCEAR, 2000

Committee on the Biological Effects of Ionizing Radiations (BEIR) of the National Research Council have continued to update the knowledge on the health effects of radiation. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has similarly been issuing successive reports on radiation effects since 1955.

The nature of radiation interactions on cellular components is similar to those that have been described above that can cause genetic defects. Cancer induction is a complex process and the mechanisms of all of the complex factors involved in the process have not been fully developed. A simple summary of the expected processes is that radiation dose causes mutations with altered genes and chromosomes; there can be changes in the gene expression without mutation; and there can be induction of cancer causing viruses. It is believed that cancer induction is a multi-step process that requires two or more intracellular events to transform a normal cell to a cancerous cell. It is also recognized that there is a latency period between the delivered dose and the expression of cancer.

Three successive steps involve initiation, promotion, and finally progression. Initiation involves dose-dependant radiation effects that are usually irreversible. Initiation also requires cell proliferation with changes passed on to daughter cells. Accompanying non-cancer producing conditions and events influence cancer promotion. Tissues tend to become increasingly malignant with the passage of time.

Tumorigenesis is a multi-stage process. First the chromosomal DNA in a normal target is damaged. With the failure to correctly repair that damage, a specific neoplasia initiating mutation can appear. This promotes growth to metaplasia followed by conversion to a malignant phenotype leading to the tumor. According to the National Academy of Sciences, radiation is not only an initiator of cancer, but also a promoter.[69]

A radiation-induced cancer cannot be distinguished from cancer caused by some other carcinogen. The risk of cancer depends upon a number of factors: the kind of cancer, the age and sex of the exposed person, the amount of dose to a particular tissue and organ, the kind of radiation, whether the rate of exposure is brief or chronic, the presence of other carcinogens, the presence of promoting biochemicals, and individual variations and genetic susceptibility.

Cells that survive irradiation, with the loss of repair capacity, are prone to cancer. As a result some individuals can become more radiosensitive. Loss of repair gene function leads to cancer proneness due to increased genetic instability.

It is unanimously agreed that leukemia and virtually all forms all forms of solid cancers in humans can be induced by ionizing radiation.[70] Lymphoma is a group of diseases that involve lymphoid tissue. Multiple myeloma is a malignancy of bone marrow with abnormal plasma cells.

6.1.4 Radiation Protection Standards

The standards for protection against radiation have progressed in accordance with the progress of scientific understanding of the nature and extent of the effects. It has been more recently understood

[69] National Research Council, 1990
[70] Gofman, JW, 1981

that a given amount of radiation dose, through long term chronic irradiation, is more damaging than that of short-term exposure. With improved scientific knowledge, the risk of cancer induction per unit of dose has increased. Estimated cancer risks changed from BEIR III (1980) to those reported in BEIR IV (1990). The level of risk for leukemia increased by a factor of 4.4 for males and a factor of 5.0 for females. The risk for non-leukemia cancers increased by factors ranging from 4.8 to 18.3 for males and 4.6 to 12.7 for females.

6.2 Radiation Risk Analysis for Cancer

This analysis focuses on the risk of the plaintiffs developing cancer, due to both the background risk and the excess risk due to the radiation dose that they received.

6.2.1 Cancer Dose

The cancer dose is the radiation dose that on average leads to one fatal cancer in an irradiated population. The cancer dose depends on age, gender, and cancers included. There is a range of risk estimates in the literature, all of which lead to different cancer doses. In this report, we discuss risk estimates from BEIR V[71], Gofman[72], and Pierce[73], all of which ultimately use data from Japanese bomb survivors in Hiroshima and Nagasaki. However, we employ the IREP program for calculating the likelihood that radiation was responsible for the plaintiffs' cancers. IREP calls this likelihood the assigned share. Combining all radiation pathways, we determine whether it is more likely than not that the pipe yard workers' cancers were caused due to his radiation exposure.

For analysis purposes, we carried out calculations for the pipe yard workers under two different dose methods. We employed dose coefficients from ICRP-30, which assumed a 50-year exposure period and further assumed that his doses, which spanned several years, occurred at the average age while exposed to radioactive materials while working in the pipe yards. This is so we could compare his radiation dose to the allowable dose to a nuclear worker regulated by the Nuclear Regulatory Commission, even though the pipe yard workers were not nuclear workers. However, in order to determine the likelihood that radiation caused the pipe yard workers' cancers, we used the more recent dose coefficients from ICRP-72, that appear on the ICRP CD. This allows us to take into account the workers' ages when each radiation exposure occurred and their commitment period, the time between their exposures to radiation and their cancer diagnoses.

6.2.1.1 Excess Lifetime Risk to Develop Fatal Cancer

The excess risk is the additional risk to develop fatal cancer due to the radiation dose received by the pipe yard workers. This risk is in addition to any background risk to develop fatal cancer. The excess risk of cancer to any organ depends on the TEDE that a worker received, and on the age at which the TEDE was received. Gender would also play a role in the risk analysis. The excess risk of developing cancer in a specific organ depends on the dose to that organ.

[71] National Research Council, 1990
[72] Gofman, JW, 1981
[73] Pierce, DA, et al., 1996

6.2.1.2 Risk Ratio and Likelihood that Specific Cancers Were Caused by Radiation

The Risk Ratio (RR) is defined as the ratio between the total risk and the background risk:

RR = (excess risk + background risk) / background risk

This is a measure to estimate how much more likely it is for a worker to develop cancer due to the radiation dose received while working compared to another person who was only exposed to background radiation. Evidently, the RR has a lower limit of 1 in case of no excess radiation dose. An RR of 2 means that a person's risk to develop cancer has effectively doubled because of the radiation that he received. The dose that leads to an RR of 2 is also referred to as the doubling dose. Obviously, doses that are below the doubling dose lead to an RR between 1 and 2, and doses above the doubling dose to an RR of >2.

Likelihood (cancer was caused by radiation) = Excess risk / (excess risk + background risk)

This likelihood can range between 0 (no relationship between cancer and radiation) to 1 (cancer certainly caused by radiation). It is a measure of the probability that a worker's cancer was effectively caused by the radiation dose he received. In previous reports, we employed risk models from BEIR V, Gofman[74] and Peirce[75]. Like IREP, all are based on Japanese bomb survivor studies. In this report we only employ IREP, which incorporates the latest Japanese bomb survivor data. A more recent study shows that NHL and has been associated with radiation[76].

6.2.2 The Linear-No-Threshold Hypothesis and Bystander Effects

Extensive research has been done in an attempt to quantify the health effects from inhalation, ingestion, and external exposure to radionuclides. The consensus of the international scientific community has accepted the linear no-threshold hypothesis, which posits that dose-effect relationships derived from experiments with high doses of radiation can be scaled linearly to calculate effects from low doses. It also states that there is no "safe" threshold of radiation, that each additional exposure, no matter how small, increases a person's risk of cancer. The hypothesis is based on the understanding that radiation-induced cancer is caused by mistakes in the genetic code produced when radiation comes in contact with DNA. For every additional radioactive disintegration, there will be an increased probability that a cancer-causing DNA mutation will occur. The linear no-threshold hypothesis is also based on epidemiological evidence of Japanese bomb survivors[77]. A significant increased incidence of cancers occurred down to a dose of 5 rems, and an increased incidence occurred down to the lowest doses.

Bystander Effect. Japanese bomb survivors were subjected to external gamma and neutron radiation, but not to internal exposure due to ingestion and inhalation of radionuclides. However, recent studies

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[74] Gofman, JW, 1981
[75] Pierce, DA, et al., 1996
[76] Berrington, A, et al., 2001
[39] Pierce, DA, et al., 1996

suggest that the theory of a proportional dose-response mechanism without threshold significantly underestimates the effects of low-dose radiation. Whereas at high doses, mutagenic effects do seem to be proportional to the radiation received, low doses have shown a different relationship. In one study, the mutagenic effect in a cell culture in which only 10 % of all cells were penetrated with one α-particle was found to be almost the same as when all cells were exposed, due to a strong bystander effect[78]. Other studies have shown that irradiation of other parts of the cell, but not the DNA, also causes mutations, and that mutations are caused in non-irradiated cells by transferring them into culture from irradiated cells.[79] This effect has been observed with both alpha- and gamma- radiation.[80] The bystander effect is thought to be caused by proteins excreted from cells in response to radiation. The bystander effect does not follow a linear dose-response relationship; culture from cells irradiated with low doses causes more mutations in non-irradiated cells than culture from cells irradiated with high doses.[81]

This recent research shows that the linear no-threshold hypothesis may not be sufficiently conservative, as at low doses the effect per dose unit may be significantly greater than at high doses. Therefore, the use of the linear no-threshold hypothesis may significantly underestimate doses from relatively low levels of radiation, particularly in certain circumstances. Unfortunately there is not sufficient data from human studies to prove or disprove the significance of the bystander effect in real-life situations.[82]

6.2.3 Risk Uncertainties for Internal Radiation

According to the Committee Examining Radiation Risks of Internal Emitters (CERRIE)[83], the risk due to exposure by radionuclides taken internally may be as much as 10 times higher. CERRIE was established by the Environment Minister of Great Britain in 2001 for the express purpose of investigating internal risks and consisted of scientists with a broad range of views on the subject. The pipe yard workers were exposed to radionuclides taken internally by inhalation and ingestion, in addition to direct gamma external radiation.

Radiation risks are predominantly determined by epidemiological studies, particularly the study of Japanese bomb survivors.[84] Residents of Hiroshima and Nagasaki were exposed primarily to an instant of external gamma radiation and neutrons. From that epidemiological study, that is still ongoing, international committees like the International Commission on Radiological Protection (ICRP) have extrapolated the bomb survivor results to radionuclides taken internally. But radionuclides that emit beta and alpha short range radiation over long time periods present several issues that have not been studied in detail.

In order to calculate radiation dose and risk from internal emitters, the ICRP follows four steps:

(1) using metabolic models, ICRP first estimates radionuclide concentrations in each organ,

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[78] Zhou, H, et al., 2001
[79] Lorimore, A, PJ Coates, and EG Wright, 2003
[80] Little, JB, 2003
[81] Lorimore, A, PJ Coates, and EG Wright, 2003
[82] Brenner, DJ, et al., 2003
[83] CERRIE, 2004
[84] Preston, DL, et al., 2003

(2) using dosimetric models, these radionuclide concentrations are converted to an absorbed dose (grays or rads), i.e., to an average energy deposited per unit mass of tissue,

(3) using a radiation weighting factor to account for different types of radiation (factor of 20 for alpha particles), the absorbed dose is converted to an equivalent dose (sieverts or rems), and finally,

(4) the equivalent dose is converted to an effective dose by weighting the individual organs to take into account the differing radiosensitivities.

In the past several years, new experimental data and theories have raised questions regarding the uncertainty introduced by each of these steps, particularly, steps (2) and (3). The data and theories, all related to internal emitters, are centered on four issues: genomic instability, bystander effect, multisatellite mutations and the SET theory.

Genomic instability relates to the damage to genomic DNA that results in "detrimental effects in the progeny of the irradiated cell, many cell divisions after the initial insult."[85] There is some evidence that low doses of radiation can lead to much greater frequency of mutations down the road than induced by the direct action of radiation.

Bystander effects are damage to cells that are not directly along a radiation track, but to adjacent cells. Bystander effects have been seen in laboratory experiments and are not linearly related to radiation dose. The data are sparse for whole animals.[86]

Minisatellite mutations are characterized by very high mutation rates and were first observed among the barn swallow breeding close to the Chernobyl reactor. Compared to barn swallows in Italy and the Ukraine, the mutation rates were ten times higher.[87]

The second event theory or SET propounds that a second radiation hit, within a specific time window after the first, enhances the mutagenic effectiveness of radiation. According to SET, this might be the case for Sr-90/Y-90 and certain Pu radionuclides.[88] The CERRIE recommended additional studies of the phenomena.

Taken together, the uncertainties of internal emitters, according to CERRIE, might be as much as ten times greater.

6.2.4 Risk Uncertainties for Exposure at Middle Age

A recent paper in the Journal of the National Cancer Institute[89] shows that the cancer risk due to radiation exposure in middle age do not decrease with increasing age at exposure. The paper, based on data from Japanese bomb survivors, shows that the cancer risk may be twice as high as previously estimated. While it has been thought that the cancer risks due to childhood exposure has been high due to rapidly growing cells, the same theory would suggest the cancer risk less for adults. For older persons, initiation of cancer may not be the factor, but rather, the promotion of preexisting malignant cells. This information has not been incorporated into this report since the information has just become available.

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[85] CERRIE, 2004
[86] *Ibid*
[87] *Ibid*
[88] *Ibid*
[89] Shuryak, I, Sachs, R.K. and Brenner, D.J., "Cancer Risks After Radiation Exposure in Middle Age," JNCI, October 26, 2010.

7.0 Rules and Regulations

As an Agreement State under the federal Atomic Energy Act, the State of Louisiana enacted regulations for radioactive materials. The enabling legislation, setting up the regulatory agency (the Board of Nuclear Energy) and its charge, was enacted by the Louisiana Legislature in 1962. This legislation was called the Nuclear Energy Act. The Board of Nuclear Energy was divided into the Atomic Energy Development Agency and the Division of Radiation Control. Since May 1967, which is when the State assumed regulatory authority from the U.S. Atomic Energy Commission (i.e. became an "Agreement State"), the Louisiana Division of Radiation Control has had sole responsibility for the control of radiation.

The first regulations were promulgated in 1966, and took effect on May 1, 1967. All radioactive materials, not just source and special nuclear materials, were regulated by the Division of Radiation Control. While the term NORM was not specifically defined in the regulations, Ra-226 was specifically regulated. Exemption limits were specified, but these were far below the levels present in the pipe yards in which the plaintiffs worked. Though the Division never enforced the Ra-226 regulations, general licenses were issued and carried over until February 1989 when the State issued a "Declaration of Emergency"[90] and specifically enacted regulations for NORM material. Whether the regulations were enforced before 1989 or not, Louisiana pipe yards were required to satisfy radiation regulations such as the posting of radioactive areas, protecting worker safety (also regulated by OSHA) and controlling soil contamination, specifically, maintaining total radium concentrations less than 5 pCi/g in potential residential areas and 15 pCi/g in industrial areas. The soil contamination limits for operating facilities was relaxed to 200 pCi/g in more recent regulations, but the soil contamination limit for decommissioned sites released for unrestricted use remained the same.

The first rules that specifically addressed NORM in relation to oil fields and pipe yards were promulgated by a "Declaration of Emergency" February 1989. In September 1989, the Division of Radiation Control issued the current regulations regarding radioactive materials associated with oil and gas producing operations through the Department of Environmental Quality (DEQ) under Title 33 Part XV, Radiation Protection. The regulations state that a license is required for the possession, use, transfer, ownership and acquisition of radioactive material, including NORM.

Our calculations assume that all of the pipe yards in which the plaintiffs worked adhered to these regulations beginning September 1989 (even though the regulations were repealed and re-promulgated only in 1992).

According to the regulations, licenses are differentiated into general and specific licenses. For a general license, a licensee must fulfill certain requirements in order to be allowed to process NORM. The licensee has to comply with these conditions, but does not have to apply for a license. In contrast, specific licenses can only be obtained through an application process. Section 1408 requires that licensees notify the Office of Environmental Services by filing NORM Form RPD-36 with the Office of Environmental Services, Permits Division. Section 1410 pertains to pipe yards, granting a general license to "*receive, process, process, and clean tubular goods or equipment which are contaminated with scale*

[90] Louisiana Register, 1989

or residue but do not exceed 50 microroentgens per hour". For the decontamination of pipe that exceeds 50 µR/h, a specific license is required. We do not know whether the pipe yards in which the plaintiffs worked held a specific license.

According to Section §1410, the general license is linked to a series of conditions, which have to be fulfilled in order for the license to be valid. These conditions are:

Notification of DEQ within 90 days of the effective date of the regulations that facility (ITCO) intends to receive equipment contaminated with scale or residue that does not exceed 50 µR/hr.

Program is approved by the DEQ to screen incoming shipments to ensure that 50 µR/h-limit is not exceeded by individual pieces of equipment

Program is submitted to ensure worker protection

Program is submitted to control soil contamination

Program is submitted to prevent release of NORM beyond site boundary

Program is submitted to ensure that soil contamination does not exceed 200 pCi/g of Ra-226 or Ra-228, or an exposure rate 50 µR/h at 1 m above the ground

Plan for cleanup of existing facilities with NORM contaminated soil in excess of 200 pCi/g Ra-226 or Ra-228, or 50 µR/h at 1 m above the ground; must be submitted to DEQ within 180 days of effective date of regulation

Soil on site must be cleaned to below 5 pCi/g of Ra-226 or Ra-228 before release of the site for unrestricted use.

For most of these conditions, we have no knowledge whether the pipe yards complied. Noncompliance with a necessary condition for the general license is equivalent to violating the license (and, by extension, Louisiana State law). As of currently, we have not seen documents that show compliance with any of the other conditions. All programs had to be submitted to DEQ, Office of Environmental Services, Permits Division, for approval.

Chapter 15 of the radiation regulations pertains to the transportation of radioactive material. Material can only be transported by persons/companies that have a license for transportation, unless the activity of the transported material is below 2,000 pCi/g. Since many pipe joints contained scale with concentrations greater than 2,000 pCi/g Ra-226, the pipe yards were required to hold this specific license. It is not clear if they pipe yards held specific transportation licenses.

The plaintiffs who worked in pipe yards were not considered nuclear workers. The external radiation requirements of 50 µR/hr (if enforced) ensured that pipe yard workers received an external radiation dose of less than 100 mrem/yr, the allowable dose for a member of the public. But pipe yard workers received a much greater dose from inhalation of radioactive particulates that were not seriously considered when regulations were drafted.

8.0 Non-Radiological Exposures

8.1 Respirable Particulates

The Occupational Health and Safety Administration's (OSHA) regulation standards in 29 CFR for "Particulates not otherwise regulated" (PNOR) in Table Z-1, and for "inert and nuisance dust" in Table Z-3, are 5 mg/m^3 for respirable dust. As seen in this report, we calculated the air particulate concentrations near the pipe cleaning and cutting operations to be 10 – 30 mg/m^3, or 2-6 times above this limit. Respirable dust includes particles that are small enough to penetrate the nose and upper respiratory system and deep into the lungs. These particles are often small enough to make it past the body's clearance mechanisms of cilia and mucous. Dust is respirable at diameters below 10 µm, with those under 2 µm being the most likely to be retained.[91]

In April 1987, an industrial hygienist, Lindsay Booher, visited the ITCO pipe yard to observe the working environment to which the ITCO workers were exposed[92]. Booher noted that levels of "nuisance dust" were exceeded at the ITCO yard. This means that the workers' health were endangered in two separate ways by the very high dust concentrations they were exposed to at work: the sheer amount of it, and the radionuclides within this dust.

The correlation between exposure to respirable particulates and increased morbidity and mortality is well documented. Health effects for which statistically significant associations with exposure to of less than 10 µm (PM_{10}) were found to include overall mortality, mortality due to cardiopulmonary and cardiovascular diseases and lung cancer, and morbidity due to chronic obstructive pulmonary disease (COPD), bronchitis, asthma, dyspnea, breathlessness, cough, production of phlegm and pneumonia.

This directly applies to the work situation at the pipe yards and oil production rigs at which the plaintiffs worked regarding the general connection between inhalation of particulates and adverse health effects. The major difference is that in epidemiological studies, the subjects are usually exposed to much lower particulate concentrations than the plaintiffs in this report. Under "normal" circumstances, it is very rare that someone is exposed to particulate concentrations of more than 0.1 mg/m^3. In contrast, we assume a scale dust concentration of 10-30 mg/m^3 near the pipe cleaning machines, and of 1.6 – 3.6 mg/m^3 in other parts of the pipe yards.

Numerous references cite a relationship between health effects and dusty conditions at the pipe yards and oil production rigs. The sources for the risk estimates (with measured health outcome in parenthesis) are:

Cardiopulmonary disease (mortality): Pope et al. 2002

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[91] US Department of the Interior, 1987

[92] The ITCO pipe yard is one of the pipe yards from which we derived our particulate air concentration range.

COPD (hospital admissions): Samet et al. 2000
Bronchitis and Asthma (morbidity): Kuenzli et al. 1997
Cough/phlegm and dyspnea (morbidity): Zemp et al. 1999
Myocardial infarction (onset): Peters et al. 2001
Sinusitis (hospital admissions): Gordian et al. 1996

In addition to the studies cited above, the book by Dr. John Gofman collects dose-response studies and quantitatively demonstrates the relationship between radiation and ischemic heart disease.[93]

8.2 Varsol Exposure

Many of the plaintiffs were exposed to the chemical Varsol, a degreasing agent used to clean pipe threads, while working at the pipe yards and oil production rigs. Varsol is a trade name for Stoddard solvent, and was developed and produced by Exxon. Stoddard solvent is a distillation fraction of crude petroleum that contains at least 200 products, many of which are gasoline range hydrocarbons. The mixture is generally composed of 30-50 percent straight-chain and branch-chain paraffins, 30-40 percent naphthenes, and 10-20 percent aromatic hydrocarbons.[94, 95]

Varsol is 4-percent 1,2,4-trimethylbenzene and 0.1-percent ethylbenzene, both of which are known to be toxic for inhalation, ingestion and dermal contact.[96] It is colorless, insoluble in water, volatile, and smells like kerosene or gasoline. Stoddard solvent is used as a dry-cleaning solvent and a metal degreaser. It is also used industrially as a thinning agent in paints, coatings and waxes and as a solvent in printing ink, photocopier toner, adhesives, rubber products, waxes, polishes, and pesticides.[97, 98] Varsol was used at many of the pipe yards and oil production rigs to clean the grease covered pipe ends and thread protectors.

Inhalation is the primary route of exposure to Stoddard solvent due to its high volatility, although dermal absorption can be enhanced by cuts or abrasions on the skin and through prolonged dermal contact with the liquid. Stoddard solvent enters the bloodstream quickly following inhalation. It is then absorbed by tissues throughout the body, and may enter the brain. It is primarily stored in fat due to its lipophilicity. Its transport throughout the body following dermal absorption is not known, although it is thought to be similar to that following inhalation. Due to Stoddard solvent's similarity to other refined petroleum solvents, metabolism is likely to occur in the liver and excretion would occur through the respiratory tract and kidneys. Acute exposure can lead to irritation of the respiratory tract and neurologic effects. Stoddard solvent is a moderate skin irritant and exposure can lead to dermatitis, lesions, and defatting of the skin.[99, 100]

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[93] Gofman, JW, 1999
[94] Agency for Toxic Substances and Disease Registry (ATSDR), 2000
[95] ATSDR, 1995
[96] ExxonMobil
[97] ATSDR, 2000
[98] ATSDR, 1995
[99] ATSDR, 2000
[100] ATSDR, 1995

Due to the complexity of Stoddard solvent's composition, the International Agency for Research on Cancer (IARC) has not evaluated the carcinogenic potential. Epidemiologic studies of painters and dry-cleaning workers, who were exposed to Stoddard solvent as well as other mixed petroleum products, have not yielded consistent findings. Some studies have found increased incidences of respiratory tract, bladder, and kidney cancers. Exposure has been associated with neuropsychiatric disorders, hepatotoxicity (toxicity of the liver), kidney damage, and changed in blood-forming capacity.[101, 102]

NIOSH recommends that workers exposed to refined petroleum products have medical surveillance examinations for blood count, urinalysis, and testing of the liver, nervous system, and kidneys. The Occupational Safety and Health Administration (OSHA) has established a time-weighted average standard for Stoddard solvent of 2,900 mg/m^3 in air for an 8-hour workday during a 40-hour workweek. NIOSH recommends an exposure limit of 350 mg/m^3 for a 10-hour workday, with a ceiling level of 1,800 mg/m^3. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a threshold limit value time-weighted average of 525 mg/m^3 for an 8-hour workday.[103, 104] In addition, work with Varsol should only be conducted in a well ventilated area and impervious (non-cloth) gloves should be utilized to limit dermal absorption. It is recommended that respiratory protection be worn if airborne concentrations are unknown or exceed the recommended exposure limit.[105] The odor threshold for Stoddard solvent is less than 2 mg/m^3, although after six minutes it can no longer be detected due to olfactory sense fatigue.[106] We have not seen evidence that any of the pipe yards and/or oil production rigs at which the plaintiffs worked monitored the air for Varsol concentrations.

[101] ATSDR, 2000
[102] ATSDR, 1995
[103] ATSDR, 2000
[104] ATSDR, 1995
[105] ExxonMobil
[106] ATSDR, 1995

9.0 Tables and Figures

Table 1a. TEDE Dose Rates for different pipe yard work situations (exposure types)

Radiation Pathways	**Type A (mrem/hr)**	**Type B (mrem/hr)**	**Type C (mrem/hr)**
Inhalation of particulates through 1989	47	13.3	12.7
Inhalation of particulates after 1989	10.5	2.1	2.7
Ingestion of particulates through 1989	1.12	1.12	
Ingestion of particulates after 1989	0.25	0.25	
Groundshine through 1989	3.56 - 10.05	3.56 - 10.05	
Groundshine after 1989	.78 - 2.2	.78 - 2.2	
External radiation (pipe cleaning rack) though 1989	.61-.85		
External radiation (pipe cleaning rack) after 1989	.13-.18		
External radiation (pipe storage rack) though 1989		0.073	
External radiation (pipe storage rack) after 1989		0.016	
Total Dose rate through 1989	52.3 - 59.5	18.1 - 24.5	12.7
Total Dose rate after 1989	11.6 - 13.1	3.1 - 4.6	2.7

A.) Physical work in pipe yard near pipe cleaning and cutting processes
B.) Physical work in pipe yard away from pipe cleaning and cutting processes
C.) Work inside of auxiliary buildings (office buildings, warehouses, etc.) adjacent to pipe yard

Table 1b. TEDE Dose Rates for different drill rig work situations (exposure types)

Radiation Pathways	Type A (mrem/hr)	Type B (mrem/hr)	Type C (mrem/hr)
Incidental Sludge Ingestion	.00093 - 5.74	.00093 - 5.74	.00093 - 5.74
External radiation (sludge on clothing)	0.35	0.35	0.35
External radiation (NORM contaminated pipe)		.03 - .2	.03 - .2
Groundshine from sludge	0.3 - 2.38	2.38	0.3 - 2.38
Total Dose Rate	.65 - 8.47	.68 - 8.67	.68 - 8.67

Exposure Types
A = Physical work as a Roustabout
B = Physical work as a Roughneck
C = Physical work as a Derrickman

Table 2a. Cancer Types, Total Radiation Doses, and Assigned Shares for Coleman vs. H.C. Price Co. Pipe yard Plaintiffs

Plaintiff Name	Primary Cancer Type	Total Radiation Dose		IREP Assigned Share
		Low (rem)	High (rem)	
Worker 2	CGL	118.65	1868.78	99.73%
Worker 3	APL	12.34	455.65	97.49%
Worker 4	Lung	927.57	32933.65	99.63%
Worker 5	Colon	97.9	268	88.52%
Worker 6	Colon	273.51	905.77	90.29%
Worker 7	MM	369.1	6336.4	98.08%
Worker 10	MM	25.49	517.57	81.49%
Worker 11	Lung	783.30	30938.29	99.39%
Worker 12	Gastric	278.8	1233.3	95.5%
Worker 13	CLL, NHL	655.0	20153.1	99.43%
Worker 14	CKD*	155.2	1273.19	94.79%
Worker 16	ML	101.02	1161.02	99.36%
Worker 17	Kidney	169.82	14684.48	99.62%
Worker 19	Rectal	23.60	109.85	32.20%
Worker 22	TLL	259.96	841.12	89.53%
Worker 25	Colon	739.73	1869.19	95.49%
Worker 27	Liver	229.8	8726.2	99.79%
Worker 31	Stomach	6.26	16.82	29.94%
Worker 33	Pancreatitis*	154.68	452.46	NON-CANCER

* Indicated a non-cancer ailment

Cancer Type Abbreviations:

MM: Multiple Myeloma
CGL: Chronic Granulocytic Leukemia
APL: Acute Promyeloctic Leukemia
CLL: Chronic Lymphocytic Leukemia
NHL: Non-Hodgkin's Lymphoma
CKD: Chronic Kidney Disease
ML: Myelogenous Leukemia
TLL: T-Cell Lymphoblastic Lymphoma
CML: Chronic Myelocytic Leukemia
AML: Acute Myelogenous Leukemia
LL: Lymphoblastic Leukemia

Table 2b. Cancer Types, Total Radiation Doses, and Assigned Shares for Coleman vs. H.C. Price Co. Rig Plaintiffs

Plaintiff Name	Primary Cancer Type	Total Radiation Dose		IREP Assigned Share
		Low (rem)	High (rem)	
Worker 9	CLL	1.68	556.05	97.38%
Worker 18	NHL	203.87	355.70	73.54%
Worker 20	Larynx	17.5	684.4	82.47%
Worker 21	TLL	259.96	841.12	89.53%
Worker 15	Lung	69.1	876.2	89.97%
Worker 26	Testicular	51.1	162.3	43.87%
Worker 28	Prostate	75.9	349.3	73.09%
Worker 30	LL	0.26	525.7	97.94%
Worker 32	Thyroid	2.77	80.68	36.73%

Cancer Type Abbreviations:

MM: Multiple Myeloma
CGL: Chronic Granulocytic Leukemia
APL: Acute Promyeloctic Leukemia
CLL: Chronic Lymphocytic Leukemia
NHL: Non-Hodgkin's Lymphoma
CKD: Chronic Kidney Disease
ML: Myelogenous Leukemia
TLL: T-Cell Lymphoblastic Lymphoma
CML: Chronic Myelocytic Leukemia
AML: Acute Myelogenous Leukemia
LL: Lymphoblastic Leukemia

Table 2c. Cancer Types, Occupation, Total Radiation Doses, and Assigned Shares for Coleman vs. H.C. Price Co. Other Plaintiffs

Plaintiff Name	Occupation	Primary Cancer Type	Total Radiation Dose		IREP Assigned Share
			Low (rem)	High (rem)	
Worker 1	Pipeline Worker	MM	17.15	102.89	26.83%
Worker 8	Truck driver	Prostate	12.54	20.67	11.23%
Worker 23	Truck driver	Colon Cholangiocarcinoma	81.04 97.31	252.28 1288.38	69.66% 98.38% Combined: 99.54%
Worker 24	Truck driver	CML	12.1	964.2	94.39%
Worker 29	Tank Cleaner	AML	26.71	91.25	64.86%

Cancer Type Abbreviations:

MM: Multiple Myeloma
CGL: Chronic Granulocytic Leukemia
APL: Acute Promyeloctic Leukemia
CLL: Chronic Lymphocytic Leukemia
NHL: Non-Hodgkin's Lymphoma
CKD: Chronic Kidney Disease
ML: Myelogenous Leukemia
TLL: T-Cell Lymphoblastic Lymphoma
CML: Chronic Myelocytic Leukemia
AML: Acute Myelogenous Leukemia
LL: Lymphoblastic Leukemia

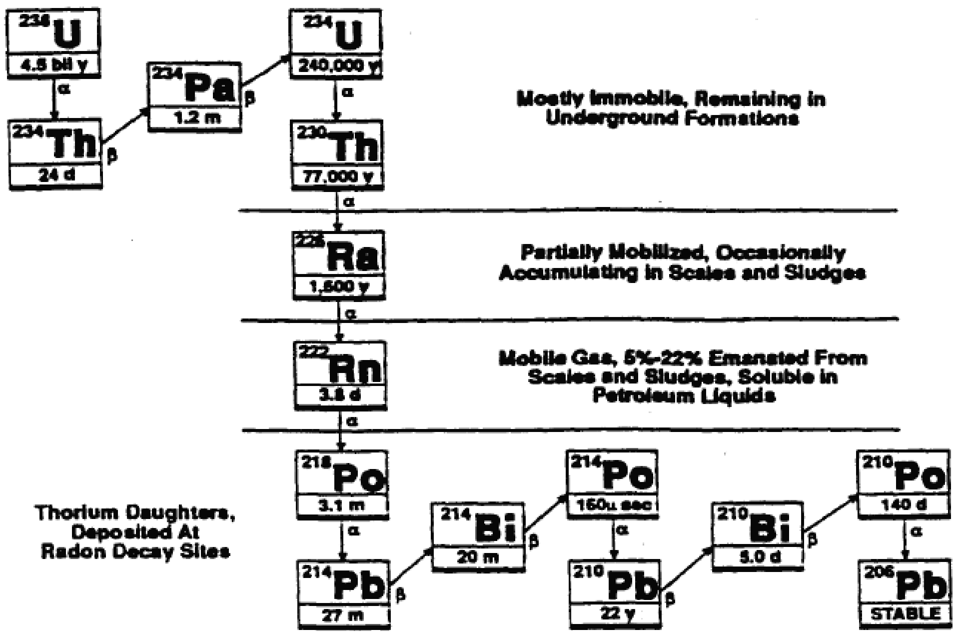
Table 3. Representative Radionuclide Activities of Ra-226 and Ra-228 and Various Progeny in Sludge*

	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Po-210 (pCi/g)	Pb-210 (pCi/g)	Reference
Minimum	1.35	13.5	0.108	2.7	IAEA[107]
Maximum	21,600	1,350	4,320	35,100	IAEA[108]

*The above table includes only the radionuclides for which an activity was given by IAEA. However, all radionuclides of the Ra-226 and Ra-228 decay chains were considered in our sludge calculations.

[107] IAEA, 2003
[108] *Ibid*

Fig. 1. Ra-226 and Ra-228 Decay Chains



Uranium-238 Decay Series

Fig. 2. Air Rattlers for Straight Tubes

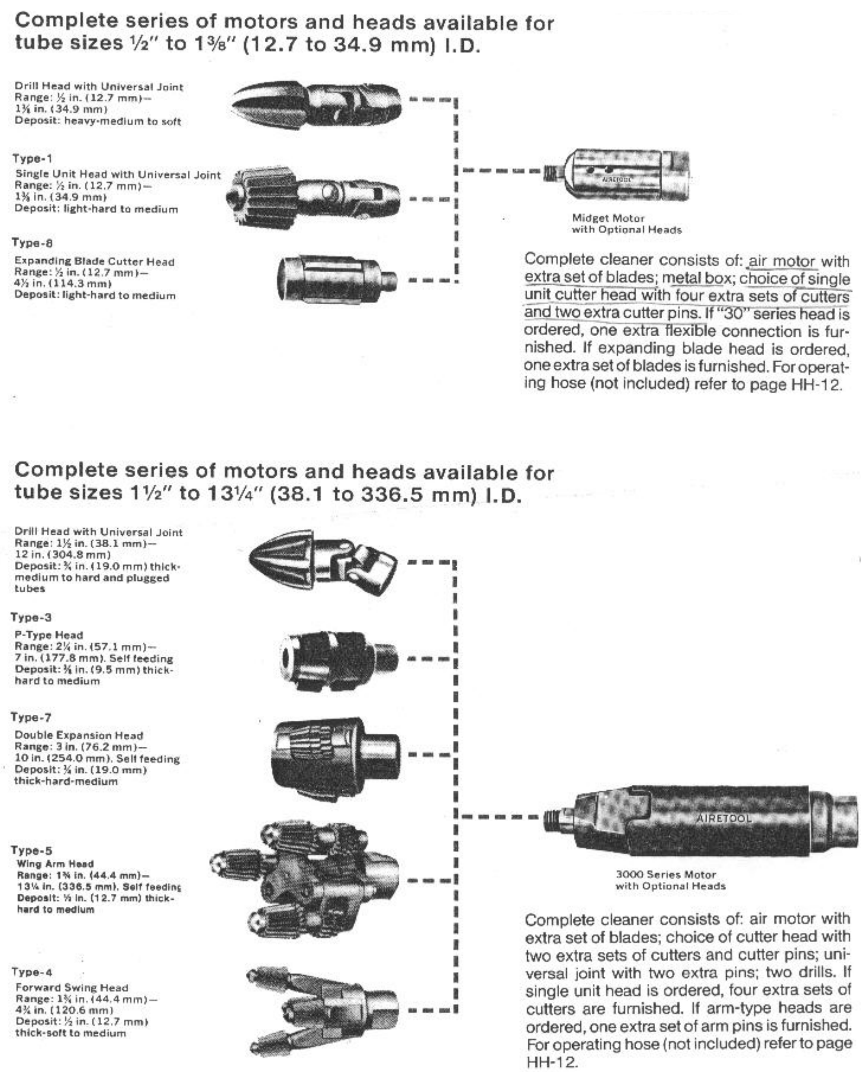


Figure 2. Air rattlers for straight tubes.

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