Occupational Exposure of Mr. John L. Carter to Radioactive Oil Field Pipe Scale at the Brown and Root Yard, Belle Chasse, LA.

Submitted in Reference to:

John L. Carter versus Exxon Mobil Corporation, et al.

25th Judicial District Court for the Parish of Plaquemines, State of Louisiana

No. 59-783 Division B

February 6, 2015

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Summary of Exposure

John Carter was born August 20, 1936 and was diagnosed with multiple myeloma in 2002 and later diagnosed with colon cancer in June of 2009. During his career, Mr. Carter worked for Ribault Trucking services from 1965 to 1970. While employed by Ribault Trucking, Mr. Carter's work weeks were normally 40-50 hours per week, depending on whether or not they were working 8 or 10 hours a day. His primary task was to drive trucks. Mr. Carter would pick up dirty NORM-contaminated pipes, drive them to pipe-cleaning facilities such as Brown and Root, and then truck the cleaned pipes to another location for the pipes to be loaded onto oil rigs. He stated that although he was trucking pipes the majority of the time, there were also days that he was trucking other equipment not affected by NORM residue.

When trucking the pipes, Mr. Carter said that he almost always had to wait at the pipe-cleaning yard for other trucks ahead of him in line and for his own pipes to be loaded/unloaded from the truck. He would assist the crane operator and one other worker from the yard with unloading the truck, as it was necessary to have one person on each end of each pipe to stabilize it when moving it on/off the truck. He recalls that he wore gloves to protect himself from the hoisting cables and straps, but would still get dirty and covered with black residue from the pipe throughout the process. Mr. Carter also recalled that during his time spent waiting for service in the pipeyard, he would stand in a dusty area next to yellow caution tape labeled "DANGEROUS" which separated him from workers on the other side who were cleaning the pipe. These workers were equipped with safety equipment and breathing respirators for protection. However, just feet away, Mr. Carter was always exposed to the same material and dusty environment without any of that same safety equipment.

During his employment Mr. Carter was exposed to direct gamma radiation and alpha radiation from scale while waiting for service, loading and unloading pipes in the pipeyard as well as direct gamma radiation from scale while driving truck and spending time in the cab of the truck with NORM contaminated pipes loaded on the back, from ground radiation in the pipeyard and from handling pipe. His total minimum committed radiation dose to red bone marrow is calculated to be 11.61 rems while the total maximum radiation dose is calculated as 160.23 rems. The likelihood that his multiple myeloma was caused by his radioactive exposures was determined to be 60.12%. His total minimum committed radiation dose to the colon is calculated to be 7.98 rems while the total maximum radiation dose is calculated as 44.95 rems. The likelihood that his colon cancer was caused by his radioactive exposures was determined to be 30.59%. The probability of causation due to occupational radiation exposure for all primary cancers combined is 72.32%.

We next compare his calculated dose equivalent to the allowable dose equivalent to the general public according to the nuclear regulatory agency at the time, the Atomic Energy Commission. His total calculated dose equivalent for the six-year period ranged between 17.48 and 386.39 rems, or an average yearly dose equivalent of 2.9 to 64.4 rems compared to the allowable public dose of 0.5 rems a year.

Introduction

This report is concerned with Mr. John Carter, and the radiation exposures that he received while providing trucking and loading services in an oilfield pipe yard that was not licensed to have radioactive materials, and was owned and operated by Brown and Root in Belle Chasse, Louisiana in the 1965 – 1970 timeframe. Mr. Carter has contracted two separate forms of cancer, and radiation is a well-established cause of cancer. During this time period, pipe-cleaning operations were performed at the Brown and Root pipe yard in Belle Chasse, Louisiana. Other companies leased space from Brown and Root and also performed pipe-cleaning operations at the Brown and Root yard at times. The pipe cleaning and de-scaling operations generated large amounts of radioactive airborne dust concentrations. Radioactive dust accumulated on the ground and other surfaces. Scale in oil field pipe and equipment contains technologically enhanced naturally occurring radioactive materials (TENORM). These radioactive substances accumulate as scale or sludge in piping and equipment that receives oilfield-produced water. Radium-226 and radium-228 are the primary radioactive constituents in the scale and sludge.

This report recounts, the work conditions for workers at the operations at the Brown and Root and ITCO pipe yards, as they are pertinent to the work environment that Mr. Carter, a truck driver for Ribault, would have been exposed. He was also exposed to scale contaminated pipe when driving and unloading production pipes. The pipe cleaning operations at the Brown and Root yard also involved occupational exposure to petroleum solvents (e.g. Varsol), which contains polycyclic aromatic hydrocarbons and benzene. In addition, Mr. Carter was occupationally exposed to lead and crystalline silica. Lead exposure would have resulted from handling pipe with thread dressings of lead and lead compounds and from re-suspension of lead-laden dust. All of these substances are regarded as carcinogens. Brown and Root did not supply personal protective equipment or train Mr. Carter on how to work around these substances safely.

The estimated radiation doses, and the probability that Mr. Carter's two cancers that were attributable to the radiation dose he received at the Brown and Root pipe yard and hauling pipe to or from the yard are developed in a separate section of this report.

At the Brown and Root yard there was no radiation protection program, no training, no sampling and analysis, no monitoring, and no radiation dosimetry system in place during the 1965-1970 time frame. Since radiation levels and concentrations were not measured by radiation monitoring badge or bioassay, the radiation exposures and doses must be reconstructed. To do this, it was necessary to estimate the dust levels, ingestion rates, external radiation dose rates and exposure periods for Mr. Carter.

To prepare this report, we reviewed social security records, exhibits, deposition transcripts, and previous work in similar cases. We also interviewed Mr. Carter twice. The contents of this report may be subject to change if additional information becomes available.

Primer on Radiation

Radioactive atoms have too much energy for their nuclei to remain intact. Such atoms are unstable. To reach stability, these atoms emit the excess energy as ionizing radiation through a process called decay. The emitted ionizing radiation is either (electromagnetic) waves or particles.

Gamma radiation and x-rays are examples of ionizing electromagnetic radiation. Gamma radiation originates in the nucleus while x rays come from the electron cloud of the atom. Both gamma rays and x-rays can travel an appreciable distance in living tissue, air, and water. They can penetrate objects like bricks or soil.

Beta and alpha radiation are examples of particles of ionizing radiation. Alpha particles consist of a fast moving ion. As subatomic particles go, alpha particles don't travel very far. They are regarded as "non-penetrating," because most alpha particles can be stopped by a sheet of paper.

However, alpha emitters can be inhaled or ingested. When ingested or inhaled, alpha emitters can be deposited in tissues and organs. Radioactive substances inside the body that decay by emitting alpha particles deliver radiation dose which can damage DNA.

Beta particles are high-speed electrons. They tend to have a greater range than alpha particles and thus are more penetrating and travel further. Beta particles from a source outside the body tend to be penetrating enough to easily deliver radiation dose to the living tissue of the skin.

Externally delivered radiation or internally deposited radioactivity expends energy into living tissue. Radiation "dose" is a measure of the amount of energy deposited divided by the weight of the tissue that absorbed it. The traditional unit of radiation dose in the U. S. is the millirad or "mrad." Scientists have determined that radiation from internally deposited alpha emitters is more damaging to tissue in a way that may lead to cancer than are beta radiation and gamma radiation. For this reason, doses to tissue are usually referred to in units of millirem or "mrem." The mrem is a unit of radiation dose equivalent that approximately accounts for the different biological effectiveness of alpha, beta and gamma radiation at inducing cancer. The mrem of radiation that a particular tissue or organ receives can be translated into an estimate of the likelihood of that tissue or organ becoming cancerous.

Oil and gas wells are drilled to extract hydrocarbons from geological formations. Water, often salty, is produced by the wells along with oil and gas. TENORM (technologically enhanced naturally-occurring radioactive material) is a major type of radioactive waste that results from oil and gas production. It consists of mixtures of radioactive material with other substances, many of which are toxic. The radioactive materials decay by emission of alpha particles, beta particles and gamma rays. The primary radioactive isotopes of concern in E & P waste are radium-226, radium-228, and their respective radioactive decay products, including radon. Radium is primarily present in the produced water, sludges, and scale. Radon is present in each of these, petroleum and natural gas. Produced water can contaminate equipment, soil, ground water and surface water.

Both radium-226 and radium-228 decay to form a series of other radioactive materials. Many of these isotopes are more dangerous than plutonium on both a mass and activity basis. The radium-226 and radium-228 decay series are depicted in Figures 1 and 2.[1] In these figures, alpha decay is depicted by an arrow pointing down the page while beta decay is represented by arrows across the page. When an atom of radium-226 or radium-228 decays, it transforms into another radioactive element, which decays into other radioactive isotopes of another element. Each decay chain ends when the last radioactive isotope in the sequence transforms into a stable (non-radioactive) isotope of lead. Radium-226 remains radioactive for thousands of years and radium-228 remains radioactive for decades.

[1] (USGS) 2011. E.L. Rowan, M.A. Engle, C.S. Kirby, and T.F. Kraemer. Radium Content of Oil- and Gas-Field Produced Waters in the Northern Appalachian Basin (USA): Summary and Discussion of Data. Scientific Investigations Report 2011–5135. U.S. Department of the Interior U.S. Geological Survey.

Figure 1. Radium-226 decay chain (USGS 2011)

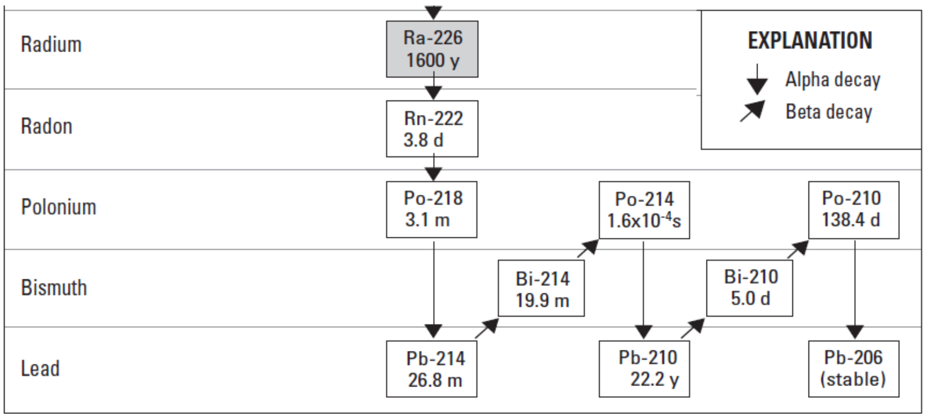
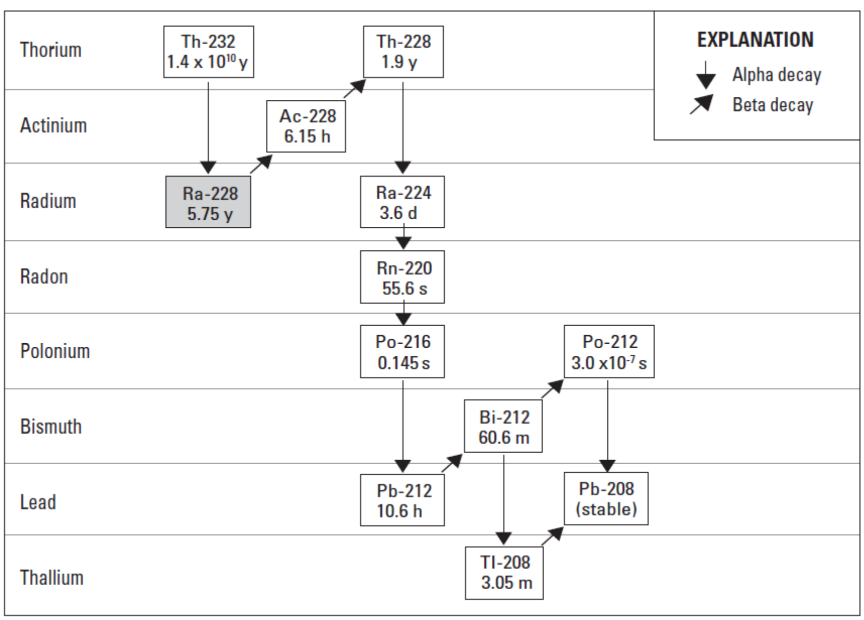


Figure 2. Radium-228 decay chain (USGS 2011).



Exposure Pathways from Radiation

Potential exposure pathways include direct gamma radiation from the radium-226 and radium-228, chains scrapes and injuries to the skin, ingestion, and inhalation of these substances. Their radioactive decay products (radon-220 and radon-222, thorium-228, radon daughters, lead-210 and polonium-210) are also dangerous.

The pipe yard workers at the Brown and Root yard were exposed to radiation through:

1. Inhalation of airborne radioactive materials, including radioactive particulate, radon gas, and radon-decay products.
2. Incidental ingestion of radioactive dust through hand to mouth transfer, licking the lips, and from contamination of food brought onsite,
3. Injection injury, which would be from radioactive material getting into scrapes, abraded skin, cuts or punctures.
4. External exposure due to radiation emitted from the radioactive material in pipe hauled as cargo, from pipe in racks, and from radioactive material (scale) accumulated on surfaces in the pipe yard.

These exposures occurred while cleaning, testing, inspecting, transporting and handling pipe, or carrying out other work on the Brown and Root premises. The workers' vehicles and clothing would have become contaminated, so that intakes of radioactive material and exposure to radiation continued even when the workers were off-site. Radiation doses also occurred from breathing radon-222 and radon-220 (sometimes called "thoron") and their progeny from the radium contamination present on the site.

Radiation Health Effects

Acute and Non-Cancer Health Effects

There are two kinds of radiation effects depending upon the duration and magnitude of the radiation dose. A large dose delivered in a short period of time is an "acute" dose. Examples would include early atomic bomb casualties, and workers at the Chernobyl and Fukushima-Daiichi nuclear power plant accidents. Acute effects are relatively prompt and include damage to blood forming organs, to the gastrointestinal tract and to the central nervous system. The symptoms can appear within a few days to a few weeks depending on the magnitude of the dose.

Some of the isotopes in the radium-226 chain are infamous for their acute health effects. In the last century women who painted watch dials with radium-laden "glow in the dark" paint would use their tongues to form a fine tip on their paintbrushes. Many absorbed so much radium that it killed their living bone tissue and they died from complications of bone necrosis. Polonium-210, a decay product of radium-226 that is present in pipe scale, was used to kill Alexander Litvinenko, a Russian defector in November 2006 in the United Kingdom. The Litvinenko murder was intensely covered by the news media. These bone necrosis and radiation poisoning cases are examples of the health effects of acute exposures that resulted from large doses of radioactive material that occurred over a relatively short period of time. Lower doses, delivered over a period of years, have recently been shown to increase the risk of cardiovascular disease and other chronic non-cancer diseases[2], as well as the well-known increase in cancers.

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[2] UNSCEAR. 2006. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR Report 2006, Annex B: Epidemiological evaluation of cardiovascular disease and other non-cancer diseases following radiation exposure.

These lower intakes of radioactive material and exposures to radiation do not cause the dramatic life shortening experienced by the dial painters and Mr. Litvinenko. However, there is a risk of developmental abnormalities in offspring who are irradiated in the womb. The severity of these types of non-cancer health effects usually depends on the dose received

Cancer

Exposure to radiation and intakes of radioactive materials are known to cause cancer. For over 60 years, the International Commission on Radiation Protection (ICRP), a body of experts in this field, has produced a series of documents updating the knowledge base of radiation effects to enable proper radiation protection. In the United States since 1931, the National Council on Radiation Protection and Measurements has been publishing reports. 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 Environmental Protection Agency in 1970,the Federal Radiation Council became its responsibility. 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 updated their published cancer risk coefficients in 1999.[3] A series of reports by the 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. UNSCEAR published a comprehensive study of the risk of getting cancer from exposure to radiation in 2006.[4] Recently the European Committee on Radiation Risk has begun publishing radiation risk evaluations and recommended standards for radiation exposure limitation.[5,6]

Radiation dose can cause cancer, as well as damage to DNA. Cancers are complex diseases and all of the factors involved are not well understood.

Three steps in cancer induction may be thought to occur. These are initiation, promotion, and finally progression. Initiation can involve dose-dependent radiation effects that are usually irreversible. Initiation also requires cell reproduction with the cancerous changes passed on to daughter cells.

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[3] US EPA. 1999. Cancer Risk Coefficients for Environmental Exposure to Radionuclides. EPA 402-R-99-001. Federal Guidance Report No. 13, U.S. Environmental Protection Agency. Sept. 1999. hph2564.

[4] UNSCEAR. 2006. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR Report 2006, ANNEX A Epidemiological studies of radiation and cancer.

[5] ECRR. 2003. C. Busby, Rosalie Bertell, Schmitze-Feuerhake, Scott Cato, Yablokov Recommendations of the European Committee on Radiation Risk: Health Effects of Ionizing Radiation Exposure at Low Doses for Radiation Protection Purposes Regulators' Edition 2003. European Committee on Radiation Risk. dt100002.

[6] ECRR, 2010. Recommendations of the European Committee on Radiation Risk. The Health Effects of Exposure to Low Doses of Ionizing Radiation, Chris Busby, Rosalie Bertell, Inge Schmitz-Feuerhake, Molly Cato, Alexey Yablokov. ECRR. hph2557

According to the National Academy of Sciences, radiation both initiates and promotes the development of cancer.[7]

A radiation-induced cancer cannot be distinguished from cancer caused by some other carcinogen (such as tobacco smoke). However, it is recognized that certain types of cancers are more likely to be caused radiation than others.

The risk of cancer depends upon a number of factors: the kind of cancer, the age and sex of the exposed person, attained age, the amount of dose to a particular tissue and organ, the kind of radiation, the dose distribution over time, 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 can become more prone to becoming cancerous.

Heritable Effects

Girls are born with their entire inventory of germ cells that will form mature eggs (technically, “oocytes”) for her whole reproductive life. Therefore those germ cells continue to accumulate radiation dose over many years. Male sperm cells, in contrast, are constantly produced and expelled, and would be subject to relatively short-term radiation exposures.

Mutations in germ cells consist of changes within the genes that make up the chromosomes in the 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, organization and function of the chromosomes and thus 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 by the action of physical and chemical agents (radiation, various chemicals), or even spontaneously.

Birth defects may result from developmental abnormalities or from mutations. Radiation is capable of causing either type of birth defect. Many mutations are either lethal, causing miscarriages, or have some harmful effect.

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.

Mutations, or heritable effects of radiation have been demonstrated in the offspring of test animals, but not in humans. Nonetheless, the BEIR VII report considers such effects to be possible in humans, and has published risk coefficients for heritable effects.[8] Obviously, it is prudent to assume that heritable effects can occur in humans exposed to ionization radiation.

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[7] National Academy of Sciences. 1990. Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V (Committee of the Biological Effects of Ionizing Radiation). National Academy Press, pp. 136-139. dt100012.

[8] BEIR VII, 2005. Health Risks From Exposure to Low Levels of Ionizing Radiation, BEIR VII–Phase 2. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. Board on Radiation Effects Research Division on Earth and Life Studies. National Research Council. Hph2492, page 117.

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. DNA occurs in two strands, and one is sort of a “backup copy” of the other. DNA strands, with proteins, make up genes. Each gene has a unique sequence of genetic information. The genes are linked sequences, forming the chromosomes in the cell nucleus. A large number of genes, 60,000 to 70,000 are required to control normal functions in humans. Most genes are present in two copies (one inherited from the mother and the other from the father), with each on a separate chromosome.

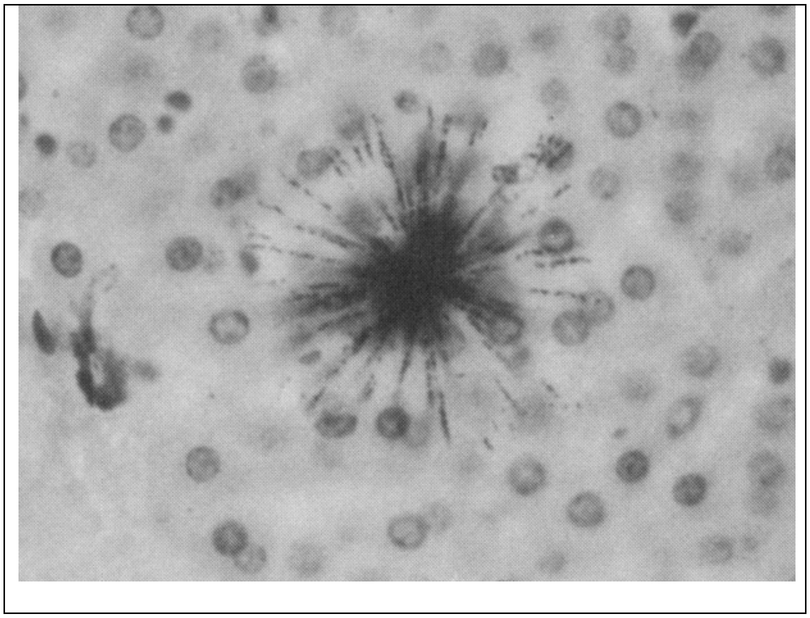
Damage to DNA, whether by radiation or other cause, is the primary event that leads to the development of cancer or hereditary disease. Double strand breaks in the DNA are the most likely cause of mutation in cells.

Ionizing radiation can cause different kinds of damage. The xtent of the damage increases with the radiation’s Linear Energy Transfer (LET) value. Ionizing radiation deposits energy in cells as tracks of ion pairs, formed when the radiation or radioactive particle tears through the cell structure. 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-micrometer diameter cell nucleus. In contrast, a high LET alpha particle, such as from radium-226, will cause over 23,000 ionizations within the nucleus of a single cell.[9] Figure 3 is a photomicrograph of the resulting radiation damage to liver tissue from a tiny particle of an alpha emitter in Chinese hamster liver. This figure also illustrates that alpha particles travel only a very short distance. The track length crosses only a few cell diameters.

Figure 3. Alpha star photomicrograph showing alpha radiation tracks emanating from hot particle in hamster liver.[10]

[9] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 2000. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR Report 2000, Volume II Effects, Annex F: DNA Repair and Mutagenesis. HPH2250

[10] Brooks, A. L., Benjamin, S. A.,Hahn, F. F., Brownstein, D. G., Griffith, W. C. and McClellan, R. O. (1988). The Induction of Liver Tumors by 239 Pu Citrate or 239 Pu02 Particles in the Chinese Hamster. Radiation Research, Vol. 96, No. 1 (Oct., 1983), pp. 135-151..



This damage can have several possible outcomes:

1. Cell death,
2. Repair so that the proper DNA sequence is restored (but the cell may be weakened by the injury),
3. Improper repair resulting in cell survival but with changes to the DNA sequence.

Outcome number three causes mutations and chromosomal changes. Chromosomal changes in somatic ("body") cells can lead to the development of cancer, while those in germ cells (eggs or sperm) can lead to non-viable embryos (miscarriages) or to offspring who carry genetic abnormalities that are often harmful. Outcomes 1 or 2 may also lead to mutations and cancer through "bystander effects" or induced "genomic instability".

In an attempt to repair single-stranded DNA damage, the DNA replication process can insert an incorrect base opposite the lost or altered base. Mutations and chromosomal rearrangements are a consequence. The repair of complex DNA double-strand breaks (DSB) is inherently error-prone and will depend upon dose, dose rate and radiation LET.

Overall, ionizing radiation is able to produce a unique type of damage in which multiple lesions within close proximity result. Even a single track of ionizing radiation through a cell is likely to induce these characteristic clustered damages. Although cells have a vast array of damage response mechanisms for repair of DNA damage and the removal of damaged cells, these mechanisms are not foolproof, and clustered radiation-induced lesions pose a particular problem. Currently emerging evidence suggests that closely spaced lesions can compromise the repair machinery. On this basis, it appears that there is no "safe" dose of radiation.[11]

[11] International Commission on Radiological Protection. 2005. Low-dose Extrapolation of Radiation-related Cancer Risk, ICRP No. 99, Pergamon Press, Elsevier Science Inc., New York. hph2259.

No-Threshold Hypothesis

Extensive research has been done in an attempt to quantify the health effects from inhalation, ingestion, and external exposure to radionuclides. The international scientific community has accepted the no-threshold hypothesis, as a prudent working assumption. It posits that dose-effect relationships derived from experiments with high doses of radiation can be scaled to calculate effects from low doses. It implies that each additional exposure, increases a person's risk of cancer. The hypothesis is based on the understanding that radiation-induced cancer is caused by radiation damage to DNA. For every additional radioactive disintegration, there will be an increased probability that a cancer causing DNA mutation will occur. The no-threshold hypothesis is also based on epidemiological evidence of Japanese bomb survivors.[12] A significantly increased incidence of cancers occurred down to a dose of 5 REMS, and an increased incidence occurred down to the lowest doses. The implication of this finding is that either there is no radiation threshold, or the threshold is not very large.

The Biological Effects of Ionizing Radiation (BEIR) VII committee recently reviewed the evidence for and against the Linear-No-Threshold Hypothesis. Significantly, the BEIR VII report[13] concluded:

> *"… the weight of available evidence would argue against the presence of a low dose threshold for tumor induction based upon error-free repair of initial DNA damage. In summary, the Committee judges that the balance of scientific evidence tends to weigh in favor of a simple proportionate relationship at low doses between radiation dose and cancer risk."*

This is a very strong statement for a scientific report to make, considering how scientists like to beat around the bush. In effect the BEIR Committee is saying that **even small doses of radiation are likely to carry some risk.**

Genomic Instability

The term 'radiation-induced genomic instability' refers to a phenomenon that has been observed in a number of different cellular systems. Basically, radiation exposure appears to cause cells to pass on a tendency to mutate more rapidly than is normal. This phenomenon has been studied by examining the occurrence of such genetic effects in cloned populations derived from single cells surviving radiation exposure. The changes observed include transformations, gene mutations, and cell death.

The evidence is that even low doses of radiation induce genetic instability in cells, which enhances the rate of malignant transformation or other harmful genetic events occur in descendants of the irradiated cells which continues even after many generations of cell replication.[14]

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[12] Cardis, E, et al. 2005. Risk of Cancer after Low Doses of Ionizing Radiation: Retrospective Cohort Study in 15 Countries. British Medical Journal, doi: 10.1136/bmj.38499.599861.EO, June 29, 2005. hph2576.

[13] BEIR VII, 2005. Health Risks From Exposure to Low Levels of Ionizing Radiation, BEIR VII–Phase 2. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. Board on Radiation Effects Research Division on Earth and Life Studies. National Research Council page 432. hph2492.

[14] ICRP 2005, Low-dose Extrapolation of Radiation-related Cancer Risk, ICRP No. 99, International Commission on Radiological Protection, Pergamon Press, Elsevier Science Inc., New York. hph2259.

It hasn't been demonstrated how important genomic instability is in causing radiation-induced cancers in human populations, however.[15] Genomic instability, however, is one reason why radiation biologists might argue that the linear no-threshold model may underestimate the risk of cancer from radiation exposure.

Bystander Effect.

ICRP Publication 99 and Annex C of the UNSCEAR 2006 reports have addressed the "bystander effect" and summarized recent research.[16] The UNSCEAR report defines the bystander effect as "*the ability of cells affected by an agent to convey manifestations of damage to other cells not directly targeted by the agent or not necessarily susceptible to it per se. Thus radiation-induced bystander effects are effects manifesting in cells that were non-irradiated neighbors of irradiated cells or that received factors secreted or shed by irradiated cells.*" These effects are illustrated by Figure 4, taken from UNSCEAR 2006, Annex C.

Most bystander studies have been *in vitro* radiation experiments. In one study, the mutagenic effect in a cell culture in which only 10 % of all cells were penetrated with one alpha particle was found to be almost the same as when all cells were exposed.[17] 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.[18] This effect has been observed with both alpha- and gamma- radiation.[19]

The bystander effect has also been studied on whole organisms. UNSCEAR 2006, Annex C describes an *in vivo* study.

"*Chinese hamsters were injected with different sized particles of the internally deposited alpha emitter plutonium. The radioactive particles concentrate in the liver and produce chronic low-dose radiation exposure, with the dose and dose rate being highest to cells located closest to the largest particles. However, analysis of induced chromosome damage in these livers revealed increased cytogenetic damage that was not directly related to the local dose distribution.[20] These observations were interpreted as indicating that all the cells in the liver were at the same risk of induced chromosome*

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[15] UNSCEAR. 2006. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR Report 2006, Annex C: Non-targeted and delayed effects of exposure to ionizing radiation. Page 22.

[16] UNSCEAR. 2006. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR Report 2006, Annex C: Non-targeted and delayed effects of exposure to ionizing radiation.

[17] Zhou et al, 2001. Radiation Risk to Low Fluences of Alpha Particles May be Greater than We Thought. Proceedings National Academy of Science USA. Volume 9, Issue 25, pp: 14410-5. hph2552.

[18] Lorimore et al. 2003. Radiation-induced genomic instability and bystander effects: interrelated nontargeted effects of exposure to ionizing radiation. Oncogene. Volume 22, pp: 7058-7069. hph2526.

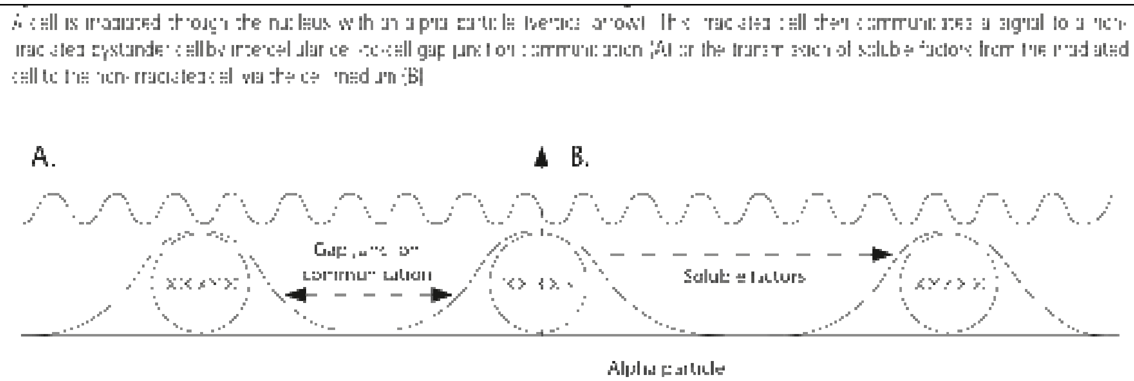
[19] Little JB. 2003. Genomic instability and bystander effects: a historical perspective. Oncogene. Volume 22, pp: 6978-6987. hph2242.

[20] Brooks, A.L., J.C. Retherford and R.O. McClellan. Effect of 239PuO2 particle number and size on the frequency and distribution of chromosome aberrations in the liver of the Chinese hamster. Radiat. Res. 59(3): 693-709 (1974).

damage despite only a small fraction of the total liver being exposed to the radiation. The cumulative incidence of liver cancer as a function of time after plutonium injection and total dose was also determined. Neither the time of tumor onset nor the tumor incidence varied with particle size, indicating that the number of cells hit by alpha particles was not a factor in tumor induction in irradiated livers.[21] "

UNSCEAR 2006 Annex C also summarizes a study involving a 3-dimensional human tissue culture. "*Belyakov et al. have described bystander responses in a three-dimensional, normal human tissue system. While not a true in vivo assay, this model skin system does provide some semblance of multicellular interactions. End points were induction of micronucleated and apoptotic cells. Non-irradiated cells up to 1 mm distant from irradiated cells showed a significant enhancement in the effect over background levels, with an average increase in effect of 1.7-fold for micronuclei and 2.8-fold for apoptosis. The surprisingly long range of bystander signals in a human tissue model system suggests that bystander responses may be important in extrapolating potential radiation effects from epidemiologically relevant doses down to very low doses (<200 mGy), where non-hit bystander cells would likely predominate.*[22]" (Apoptosis is normal,"programmed" cell death.)

Figure 4. Signal transmission from irradiated cells to non-irradiated cells



The bystander effect does not follow a linear dose-response relationship; culture from cells irradiated with low doses causes more mutations than would otherwise be expected.[23]

The bystander effect research indicates 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.

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[21] Brooks, A.L., S.A. Benjamin, F.F. Hahn et al. The induction of liver tumors by 239Pu citrate or 239PuO2 particles in the Chinese hamster. Radiat. Res. 96(1): 135-151 (1983).

[22] Belyakov, O.V., S.A. Mitchell, D. Parikh et al. Biological effects in unirradiated human tissue induced by radiation damage up to 1 mm away. Proc. Natl. Acad. Sci. U.S.A. 102(40): 14203-14208 (2005).

[23] Lorimore et al. 2003. Radiation-induced genomic instability and bystander effects: interrelated nontargeted effects of exposure to ionizing radiation. Oncogene. Volume 22, pp: 7058-7069. hph2526.

Thus, the linear no-threshold hypothesis may significantly underestimate doses from relatively low levels of radiation. It hasn't been demonstrated how important the bystander effect is in the genesis of radiation induced cancers in human populations, however. The bystander effect is another reason why radiation biologists might argue that the linear no-threshold model may underestimate the risk of cancer from radiation exposure.

Excess Radiation Risk from Internally Deposited Radionuclides?

There is debate in the scientific community concerning whether dose from internally deposited radioactivity is properly accounted for by the ICRP system of radiation dose limitation. The Committee Examining Radiation Risks of Internal Emitters (CERRIE) studied the issue in 2004 and wasn't able to issue a consensus report. The CERRIE majority report (e.g. paragraph 60 p27) concludes that there is a conceptual uncertainty of a factor of 10 associated with the use of absorbed dose.[24] The CERRIE Minority Report argued that radiation from internally deposited radioactive materials creates risk that is not properly accounted for by ICRP internal dose models.

Our impression is that there is wide agreement that risk estimation factors for internal and external radiation exposure are uncertain. There is also agreement that the uncertainty in risk factors for internally deposited radionuclides is greater than for external exposure. The US EPA published studies addressing the magnitude of this uncertainty. EPA Federal Guidance Report 13 classified selected radionuclides by exposure pathway (e.g. ingestion, inhalation, and external) and then categorized them by the amount of uncertainty in the risk factors. Table 2.4 of that report indicates that alpha emitters have uncertainties for inhalation and ingestion in the range of 50 to 150. The meaning of an uncertainty of 50 would be that their published risk factor might be a factor of 7 (actually the square root of 50) too low or a factor of 7 too high.[25]

Effects of Acute and Chronic Radiation Exposure

There are two kinds of radiation effects depending upon the period and magnitude of the radiation dose. A large dose delivered in a short period of time is an acute dose. Examples would include early atomic bomb casualties, and workers at the Chernobyl and Fukushima-Daiichi nuclear power plant accidents. Acute effects are relatively prompt and include damage to blood forming organs, to the gastrointestinal tract and to the central nervous system. The symptoms can appear within a few days to a few weeks depending on the magnitude of the dose.

Lower protracted doses, delivered over a period of years, lead to increased risk of cancer and hereditary effects. In addition, specific epidemiological studies have included induction of cardiovascular disease and other non-cancer diseases.[26] More recently, the non-targeted and delayed effects of chronic radiation exposure have shown that the manifestation of effects can appear months to years after the radiation dose is delivered. Chronic exposures are assessed based upon the extent of the risk posed by exposure. Acute doses provide relatively prompt, predictable effects.

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[24] CERRIE. 2004a. Goodhead, et al., Report of the Committee Examining Radiation Risks of Internal Emitters (CERRIE), Crown Copyright, Great Britain, October. hph2277.

[25] US EPA. 1999. Cancer Risk Coefficients for Environmental Exposure to Radionuclides. EPA 402-R-99-001. Federal Guidance Report No. 13, U.S. Environmental Protection Agency. Sept. 1999. hph2564.

[26] UNSCEAR 2006 Annex B.

Protracted or chronic exposures have effects that are more variable, and follow a statistical distribution.

How Much Radiation Is Harmful?

The natural radiation background averages:[27]

Radiation from space	35 mrem/yr
Breathing radon and thoron	230 mrem/yr
Eating or ingesting	30 mrem/yr
Other Terrestrial sources (external)	20 mrem/yr

Most regulations limit dose equivalent exposure to members of the public to 100 mrem/yr from all non-natural sources, exclusive of radon and thoron daughter inhalation. During the time period that Mr. Carter worked, 1965 – 1970, the dose limit was 500 mrem/yr. The U.S. Environmental Protection Agency has indicated that an acceptable level of risk for cancer induction should be in the range of one chance in 10,000 to one chance in 1,000,000 to develop cancer as a result of radiation dose.[28] The dose and risk depend on the dose pathway and the organs and tissues that are irradiated. The levels of risk (according to the National Academy of Sciences) associated with the radiation doses allowed by various regulations are provided in Table1.

NORM and TENORM

History

Long before radiation protection regulations were promulgated, the oil and gas industry was aware that radioactivity was present in equipment, waste and product. A Kimbrell and Associates report submitted in Benoit, et al. v. ITCO, et al. exhaustively details this early knowledge[29]

The Society of Petroleum Engineers paper SPE 23384, which was written by Texaco employee Thomas Grice in 1981, provides a history of papers showing the association of NORM with natural gas and petroleum.[30] Radioactivity in oil and brine was reported as early as the 1930's[31] and the

[27] NCRP 2009. Ionizing Radiation Exposure of the Population of the United State, NCRP Report No. 160, Recommendations of the National Council on Radiation Protection and Measurements, March 3, 2009.

[28] EPA 1999a. Memo: Distribution of OSWER Radiation Risk Assessment Q&A's Final Guidance. From Stephen. D Luftig, Director, Office of Emergency and Remedial Response (OERR), US Environmental Protection Agency. December 17, 1999.

[29] Kimbrell, William Clay. 2010. Malvin D. Benoit, et al. v. Intracoastal Tubular Services, Inc., et al., Civil District Court Parish of Orleans, 2001-21094 "B-15", C/W 2002-12334 "K-5"; and C/VV 2003-14235 "B-15" Expert Report, October 24, 2010, Prepared by Kimbrell and Associates, LLC. Itcow35858.

[30] Grice, K. J.1981. Naturally Occurring Radioactive Materials (NORM) in the Oil and Gas Industry: A New Management Challenge. SPE 23384, Society of Petroleum Engineers. ind0901.

[31] Kurbatov, I. D. (1934) Concentrations of Radium and Mesothorium I in Nature and Regularity of

USGS reported radioactivity in Kansas oil fields[32] in the 1950's. The American Petroleum Institute was aware of an association between natural radioactivity and petroleum and funded Project 43C, "Studies of the effect of radioactivity on the transformation of marine organic materials into petroleum hydrocarbons" in about 1940. Bell, Goodman and Whitehead reported in 1940 that:

> "… crude oils and the waters and brines associated with crude oils have a high degree of radioactivity as compared with that of ordinary ground waters found in regions remote from oil fields."[33]

In 1943 Russell studied the radioactivity of sedimentary rocks and reported in the journal Geophysics that very high radioactivity precipitates were associated with some oil field produced water:

> "A discovery of considerable possible importance is that some oil field waters may make deposits of extremely high radioactivity, compared with the average sedimentary rock. Thus, waters produced with the oil in the Barbers Hill Pool, Chambers County, Texas, deposit on the ground over which they flow precipitates having radioactivities of 2050 to 4550 units. Similar deposits apparently occur in the wells and the possibility that waters ascending through fractures have made similar deposits in the rocks must be considered. However, it is only waters of abnormally high radioactivity which can produce such deposits. The ordinary type of connate water found in oil wells does not make highly radioactive deposits and has little or no effect on radioactivity logs."[34]

In 1951, John Campbell published a paper entitled "Radioactivity Well Logging Anomalies," which describes the formation of radioactive crusts on casing in wells that have been in production. Campbell noted that the radioactive intensity can be extremely high.[35]

A study by Gesell in the 1970s identified radon-222 in natural gas and natural gas liquids and recognized the potential for lead-210 accumulation.[36] The American Petroleum Institute (API) issued a report in 1982 that analyzed the potential impact of the inclusion of radionuclides into the CERCLA process on 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.[37] The report concluded, *"The regulation of radionuclides could impose a severe burden on API member*

Their Migration. J. Phys. Chem. 38, pages 521-532. hph2503.

[32] Gott, G and Hill, J.W. 1956, Radioactivity in Some Oil Fields of Southeastern Kansas, Geological Survey Bulletin 988-E. U. S. Department of the Interior, Geological Survey. ind0975.

[33] Bell, K. G., Clark Goodman and W. L. Whitehead (1940) Radioactivity of Sedimentary Rocks and Associated Petroleum, Bulletin of the American Association of Petroleum Geologists, vol 24, no. 9, 1529-1547.

[34] Russell, W. L. (1944) The Total Gamma Ray Activity of Sedimentary Rocks as Indicated by Geiger Counter Determinations. Geophysics, 19 (2): p. 180-216.

[35] John Campbell (1951) Radioactivity Well Logging Anomalies. June 1951 p. B-7 to B-12. Ind0970.

[36] Gesell, T. 1975, Occupational Radiation Exposure Due to 222Rn in Natural Gas and Natural Gas Products, Health Physics, Vol. 29 (November), pp. 681-687. ind0905.

[37] American Petroleum Institute. 1982. An Analysis of the Impact of the Regulation of Radionuclides as a Hazardous Air Pollutant on the Petroleum Industry, Committee for Environmental Biology and Community Health, Department of Medicine and Biology. October 19, 1982 (THRA000013- 45).

companies". In 1985, Summerlin et al. describe a serious lead-210 and polonium-210 internal exposure hazard in liquefied petroleum gas refineries.[38]

In 1986, Dr. Max Scott notified Chevron that pipe scale sent to him for analysis was radioactive (6,000 pCi/g radium-226). The letter indicated that the material should be considered a "hazardous waste" and provided a recommendation for respiratory protection.[39]

A 1987 API document included an analysis of Louisiana radiation regulations[40]. API concluded that radium-226 in NORM was subject to licensing under regulations in effect at the time.

Probable NORM Concentrations

Halliburton NUS conducted a site characterization of the Brown and Root property in Belle Chasse and issued a final report.[41] The report summarized what characterization had been performed. Page 3-3 of the report (Itcow03881) provides a numbering system for work zones, and work zone 5 is the area which Halliburton NUS claims has the known history of pipe storage, cleaning and maintenance. Itcow03878 (the page before 3-1) is a drafted map of the site showing the different work zones and also "areas of potential environmental concern". Pages 3-4 and 3-5 (Itcow 03882-03883) provide a description of each area of concern. Page 5-7 (Itcow03898) documents lead concentrations in soil samples ranging up to 1.2%. Exhibits 19 and 20 of the LeFleur deposition documents exposure rates up to 700 microR/hour in the year 1991.[42]

There are no measurements of radiation levels at the Brown and Root yard that apply to the time period that Mr. Carter was present on the property.

Chevron USA, Inc. found a range from non-detectable to 35,000 pCi/g radium-226 in scale inside tubing and pipe with an average of 5,500 pCi/g.[43]

Minerals in TENORM and Impact on Lung Clearance

Oilfield pipescale contains naturally occurring radioactive materials including isotopes of radium, radon, thorium, lead, bismuth and polonium. How quickly these poisons clear from the respiratory tract and the extent to which swallowed material is subsequently absorbed from the digestive tract affects how much dose is received by the various organs in the body.

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[38] Summerlin, J. and Prichard, H. 1985. Radiological Health Implications of Lead-210 and Polonium-210 Accumulations in LPG Refineries, American Industrial Hygiene Association Journal, 0002-8894, Volume 46, Issue 4, 1985, Pages 202 – 205. hph1120.

[39] Scott, 1986. Letter from L. Max Scott to Frank Mize, RE need of TENORM to be regarded as hazardous waste. April 18, 1986. pgref101884-1886.

[40] American Petroleum Institute. 1987. Title unknown; an analysis of NORM radiation licensing regulations. 5/29/1987 (ITCO-A00273-0329).

[41] Broussard, Mark, 1994. Phase IIII Final Site Characterization Of The Brown & Root, Inc. Belle Chasse Facility, Belle Chasse, Louisiana. Prepared By Halliburton NUS Environmental Corporation Southwest Region, January 1994. Itcow03869.

[42] Deposition of D.K. LeFleur, August 28, 1996, Francis M. Vercher v ITCO, Exhibits 19 and 20.

[43] Chevron USA, Inc. Final Report Naturally Occurring Radioactive Materials in Production Operations. NORM Study Team, March 1990, p. ii-24, CAS0244973.

Pipescale is a complicated solid material, which precipitates from produced fluids in oilfield or geothermal wells. The chemical composition of pipescale is influenced by the temperature, and pressure and composition of the brine that is produced by a given well. Barite is not the only thing in pipescale that contains radium. Other substances are also known to be present in pipescale, like calcium carbonate[44],[45], native lead, galena (lead sulfide)[46], lead-copper-zinc alloys[47], calcium sulfate (gypsum and anhydrite)[48], and strontium sulfate (celestine).[49]

Some of these minerals, such as celestine, have a stronger capacity to concentrate radium than does barite, as the Figure 5 from Langmuir and Riese[50] illustrates. A chemist would say the same thing by remarking that "Figure 5 shows that the distribution coefficient for partitioning of radium between celestine and brine is much greater than for partitioning between barite and brine."

At a given concentration of sulfate in solution at 64ºF, celestine is greater than 4,000 times more soluble than barite. Thus the bioavailability of radium in celestine is expected to be much greater than in barite. [51] The radium in anhydrite and calcium carbonate is expected to be much more available as well.

Langmuir and Riese also reported that calcium sulfate (anhydrite) and anglesite (lead sulfate) have a higher affinity for radium than barite as well.[§] Furthermore it is not difficult to find examples of pipescale where calcium sulfate is present at higher percentages than barite. The radium in such scales is expected to be much more bio-available than the radium in barite, Figure 4.[52]

In conclusion, scale doesn't consist entirely of barite. The lung clearance behavior of radium is expected to vary in relation to the mineral constituents of a particular scale. Not all pipescale can be expected to strongly retain all of its radium. A range of radium retention behavior can be expected by

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[44] Miller, H. T. (1987) Radiation Protection: The Identification and Handling of Scale Samples Containing Naturally Occurring Radioactive Materials (NORM). Memo to R.A. Berry. CAS0219289-9291

[45] Rogers, W. F. (1960) Scale Deposit, Heidelberg Field, Mississippi. Memo to T.R. Coffield. Gulf Oil Corporation. (Memo about a scale sample that was predominantly calcium carbonate). cas0200914-0200915

[46] Carpenter, Alden, Michael Trout, and Edward Pickett (1974) Preliminary Report on the Origin and Chemical Evolution of Lead-and Zinc-Rich Oil Field Brines in Central, Mississippi, Economic Geology, vol 69, No 8.Scale_Solubility\ind1375.pdf

[47] Saunders, J. A. and E. L. Rowan (1990) Minerology and Geochemistry of metallic well scale, Raleigh and Boykin Church Oilfields, Mississippi, USA. Transactions of the Institution of Mining and Metallurugy Section B Applied Earth Science, v90, B54-B58. Scale_Solubility\ind1365.pdf

[48] Costello, M. J.(1986) Raleigh Project. Memo to J. G. Fitzgerald. CAS0233934-3935.pdfCAS0233934-3935

[49] Neilson, Kirk K, Rogers and Associates Engineering Corporation, Letter to David L. Miller, American Petroleum Institute, (November 3, 1989). orpsesh0002228-0002298

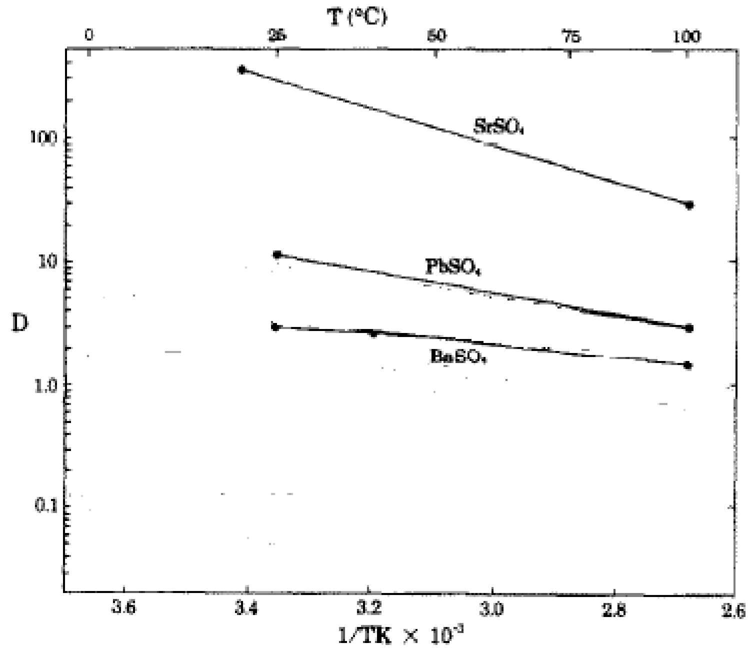
[50] Langmuir, Donald and Riese, Arthur (1985) The Thermodynamic Properties of Radium. Geochimica et Cosmochimica Acta, vol 49, p 1593-1601.1-s2.0-0016703785902649-main

[51] CRC Handbook of Chemistry and Physics, 54th edition. (1974), p B-232. (CRC_Handbook_KSP)

[52] Raju, Kris (2008) Gas Wells: Scale/Corrosion Mitigation. Dowloaded from http://cohesion.rice.edu/engineering/brinechemistry/emplibrary/7.%20Saudi%20Aramco-GasWells%20pdf.pdf on April 2, 2014. (7. Saudi Aramco-GasWells)

various scale samples. It is prudent to use both inhalation dose coefficients that assume M (for Medium) and S (for Slow) lung clearance as part of a radiation dose sensitivity analysis. In the case of doses to the respiratory tract, lower doses can be expected with the Class M assumption. For other internal organs, higher doses can be expected with the class M assumption.

Figure 5. Relative Tendencies of Different Scale Constituents to Concentrate Radium from Brine. (from Langmuir and Reise, 1985).



Likely Airborne Dust Concentrations: Survey of OSHA Measurements

Attachment A is a summary of air concentration results for dust by gravimetric determination (OSHA Method PV2121) and was derived from the OSHA Chemical Health Database. Columns 5, 7 and 8 include samples with sample weights that were not detected, while columns 4 and 6 include only samples with sample weights that were detected. Columns 7 and 8 are the estimated average concentrations and sample standard deviations. The results are presented for Oil and Gas Services Not Elsewhere Classified (SIC 1389), and for a variety of SICs for construction and manufacturing. These are reasonable in my professional opinion to compare against because the operations at the Brown and Root yard resemble oil and gas services, construction, and manufacturing in many respects. Mr. Carter was often in close proximity to pipe cleaning activities in the Brown and Root yard. In effect many of the activities associated with Mr. Carter's exposure could be considered re-conditioning tubing and casing.

In Appendix A, flow rates that are close to 1.7 liter/minute, strongly suggest a respirable dust sampling procedure was used. Average flow rates of 2 liter/minute strongly suggest a total dust sampling method was used. Total dust air samples can consist of respirable dust as well as coarser dust particles.

These results support our opinion that dust concentrations in Mr. Carter's breathing zone probably averaged 10 to 30 mg/m^3 at the Brown and Root yard.

TENORM Regulation

Specific Radioactive Material License Required

A more complete regulatory chronology is provided in Chronology of Louisiana Radiation Protection Regulations Related to Technologically Enhanced Naturally Occurring Radioactive Material (TENORM).[53] Based on this report, Brown and Root did not comply with many of their obligations that were in effect under Louisiana radiation control regulations between May 1967 and 1970.

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 Louisiana Radiation Protection regulations were promulgated in 1966, and took effect on May 1, 1967. The Division of Radiation Control regulated all radioactive materials, not just source and special nuclear materials. Ra-226 was specifically regulated. 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. The limits on the amount of radioactive material that could be held under the general license tended to be quite limited. While the term NORM was not specifically defined in the regulations, Ra-226 was listed as one of many radionuclides included in the regulations; thus radium and radium-containing pipe scale were regulated by the Division of Radiation Control.. Exemption quantities were specified, but these would have been far below the levels present in the Brown and Root yard.

The 1966 Louisiana Radiation Regulations[54] required licensees to comply with exposure limits (Sec.C.I01-106, D.I02-106); survey requirements (Sec.C.201); personnel monitoring requirements (Sec.C.202); placement of caution signs, and notice (Sec.C.203-205); disposal restrictions (Sec.C.302-305). Specifically, "Each licensee or registrant shall make or cause to be made such survey as may be necessary for him to comply with this part." Sections D. 301- 304, sets out procedures and prohibitions for the land disposal of radioactive material. The restrictions include that the potential disposer submit a application, and that "The Division will not approve any application for a license to receive radioactive material from other persons for disposal on land not owned by a state or the United States Government."

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[53] Waligora, Stanley, 2009. Chronology of Louisiana Radiation Protection Regulations Related to Technologically Enhanced Naturally Occurring Radioactive Material (TENORM). reg0550.

[54] Louisiana Radiation Regulations, March 1, 1966. REG0170.

Table 1. Radiological Risk Summary for Various Regulations[55]

Table 7.2. Lifetime cancer risks corresponding to selected radiation exposures and EPA guidances and regulations for controlling exposures of the public[a]

Risk	Exposure or guidance or regulation
4×10^{-2}	Mill tailings standards (cleanup of contaminated land and buildings)
$0.2\text{-}3 \times 10^{-2}$	Concentration of radon in homes of 150 Bq/m^3 (EPA and DHHS 1994)[b]
2×10^{-2}	Annual dose equivalent to whole body from external exposure to all controlled sources combined of 5 mSv (existing FRC guidance)
1×10^{-2}	Average annual effective dose equivalent from exposure to natural background radiation, including indoor radon, of 3 mSv (NCRP 1987a)
$0.7\text{-}9 \times 10^{-3}$	Average indoor radon concentration of 50 Bq/m^3 (EPA and DHHS 1994)[b]
4×10^{-3}	Annual effective dose equivalent from all controlled sources combined, excluding indoor radon, of 1 mSv (proposed federal guidance)
4×10^{-3}	Indoor gamma radiation level of 20 μR/h and indoor residence time of 85%
2×10^{-3}	Concentrations of ^{226}Ra in soil of 0.2 Bq/g in top 15 cm and 0.6 Bq/g below 15 cm and continuous external exposure indoors and outdoors
9×10^{-4}	Annual dose equivalent to whole body of 0.25 mSv
5×10^{-4}	Annual effective dose equivalent of 0.15 mSv
4×10^{-4}	Annual effective dose equivalent of 0.1 mSv
2×10^{-4}	Concentration of uranium in drinking water of 20 μg/L
2×10^{-4}	Concentration of ^{226}Ra in drinking water of 0.2 Bq/L
1×10^{-4}	Goal for cleanup of radioactively contaminated sites (CERCLA and NCP)
1×10^{-4}	Annual effective dose equivalent of 0.04 mSv (proposed drinking-water standard for beta-or gamma-emitting radionuclides)
1×10^{-4}	Annual dose equivalent to lungs from inhalation of insoluble natural uranium of 0.25 mSv (uranium fuel-cycle standards)
4×10^{-5}	Annual dose equivalent to bone surfaces from ingestion of soluble natural uranium of 0.25 mSv (uranium fuel-cycle standards)
3×10^{-8}	Containment requirements for disposal of spent fuel, high-level waste, and transuranic waste (average risk in US population)

[a] Values assume continuous exposure over 70 y and, unless otherwise noted, risk of fatal cancers per unit effective dose equivalent of 5×10^{-5} per millisievert (EPA 1994c; NCRP 1993a; ICRP 1991).
[b] Lower bound for risk applies to individuals who have never smoked, and upper bound applies to smokers; for former smokers, risk may lie in between.

[55] NRC 1999. Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials. National Research Council, Board on Radiation Effects Research. National Academy Press, Washington DC.

Current Louisiana Cleanup Standard

The current (2012) version of Louisiana NORM licensing regulations (LAC Title 33 XV 1417, Release for Unrestricted Use) establishes limits for release of land for unrestricted use. Concentrations less than the limits specified below, in samples averaged over any 100 square meters with no single non-composited sample to exceed 60 picocuries per gram of soil:

- 5 picocuries per gram or less of radium-226 or radium-228, above background, averaged over the first 15 centimeters,
- 15 picocuries per gram above background averaged over each subsequent 15-centimeter-thick layer of soil, or
- 30 picocuries per gram or less of radium-226 or radium-228, averaged over 15-centimeter-depth increments, provided the total effective dose equivalent (from the contaminated land) to individual members of the public (continually present) does not exceed 0.1 REM (1mSv) in a year.

The current Louisiana cleanup standard is based on a much older regulation for cleaning up uranium mill tailings, the Uranium Mill Tailings Radiation Control Act. It allows a very high risk of cancer incidence from residual radioactivity in soil, 4% according to the National Academy of Sciences, See Table 1.

As Low as Reasonably Achievable

An important concept that is contained within all radiation protection regulations is ALARA, which is an acronym meaning that control of radiation exposure levels are to be “As Low As Reasonably Achievable”. There should be no radiation exposure without some commensurate benefit. It is not appropriate to expose people to radiation without their knowledge and consent.

Pipe Yard Operations

Additional descriptions of conditions and operations at the Brown and Root yard are provided in reports issued by Travers, Resnikoff and Waligora in connection with Benoit v ITCO. [56], [57] Figures 6 and 7 are photographs of pipes encrusted with scale and of a pipe cleaning demonstration.

Intracoastal Tubular Services Co. and others cleaned and inspected pipe at the Brown and Root yard in Belle Chasse. This pipe had been used in the oil field industry. Thousands of oil field pipes (tubes and cases) were brought in by barge and truck from the Gulf Coast region to the Brown and Root yards in Belle Chasse. Affidavits of truck drivers indicate that they hauled loads of used pipe from the Belle Chasse yard to various ITCO yards in Harvey, Louisiana.[58] ITCO employees, and numerous personnel who were supplied by various staffing companies, cleaned, handled, and processed pipe at various locations for ITCO including the Brown and Root yard at Belle Chasse. Brown and Root managed the inventory of pipe on its yard. Brown and Root was also responsible for yard

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[56] Haaker, Richard F. 2010 Occupational Exposure to Radioactive Scale During Oil Pipe Cleaning Operations at Brown and Root and ITCO. Submitted in Reference to: Malvin Benoit et al. v. Intracoastal Tubular Services, et al., James Bailey, et al. v. Exxon Mobil Corporation, et al., Eugene Castell, Deceased vs. Exxon Mobil Corporation, et al. October 18, 2010. Itcow37353.

[57] Travers, Jackie, Resnikoff, Ph. D., Marvin and Waligora, CHP, Stanley 2010, Occupational Exposures to Radioactive Scale During Oil Pipe Cleaning Operations Report October 25, 2010 Report. Itcow36928-37222.

[58] Affidavits of Mr. Rudy Breaux and Mr. Andrew Jackson, Castellex103227 – 103228.

maintenance and the handling and movement of pipe on its yard. This has been verified by multiple sources, including plaintiffs testimony in other cases (Curtis Arwood[59], Jeffrey Holmes[60], James Richardson[61]), Mr. Durwin K. LeFleur (a representative of Brown and Root)[62], and the contract between Brown and Root and ITCO.[63] Functioning in this capacity placed Brown and Root in direct violation of Louisiana regulations restricting any person from using, transporting, transferring, receiving, acquiring, owning, or possessing any source of radiation unless it was properly registered or licensed.

At the pipe yards, pipe was stacked up in layers on racks, which were several feet high. After cleaning, inspection, and testing, the pipe was stored and eventually returned to the oil fields, again either on barges or directly by truck, depending on the location of the oil production sites. Witnesses have testified that the Brown and Root yard was operated in a similar fashion to other yards. This includes testimony by Curtis Arwood[64].

Used pipe and casing contained precipitated radioactive materials in a matrix of other compounds and mixtures. The phenomenon of technologically enhanced naturally occurring radioactive material (TENORM) in association with oilfield produced-water has been recognized and understood since at least 1933. Accumulation of the salts inside the pipe depends on the characteristics of these salt matrices. Some scale looks like fine sand, whereas others resemble rust. The quantity of radioactive material in the deposits is small from a mass standpoint, but can emit high levels of radioactivity. Only one billionth of an ounce of Ra-226 in an ounce of soil is equivalent to 1,000 pCi/g. The radioactive material within the pipe scale cannot be visibly distinguished from the salts and other deposits.

Figure 6. Tubulars encrusted with pipe scale.[65]

[59] Curtis Arwood deposition, castellex103504: line citations 85:9, 86:5, 100:2, 171:7.

[60] Jeffrey Homes deposition, castellex103665: line citations 110:19, 178:14.

[61] James Richardson deposition, castellex103435, pages 282-283.

[62] Deposition of D.K. LeFleur, August 28, 1996, Francis M. Vercher v ITCO, page 45. lines 11-19.

[63] Contract between Brown and Root and ITCO, M. Vercher v ITCO, Exhibit 21.

[64] Curtis Arwood deposition, castellex103504: page 111 lines 18-22.

[65] Weatherford Corporation brochure.
http://www.weatherford.com/ECMWEB/groups/web/documents/weatherfordcorp/WFT100054.pdf

Figure 7. Scale Removal Experiment.[66]

ITCO cleaned pipe at the Brown and Root yard in Belle Chasse. ITCO also had three pipe yards in Harvey (the main yard or yard 1 and lower yards 3 and 4) with a total area of 303 acres (main yard: 62 acres, lower yards 241 acres)[67], and other pipe yards in Amelia, LA (near Morgan City, LA), Houston, TX and Flomaton, AL.

[66] L. Wang, J. D. Wanjura, C. B. Parnell, R. E. Lacey, B. W. Shaw. Performance Characteristics of a Low-Volume PM10 Sampler. Transactions of the ASAE Vol. 48(2): 739−748 American Society of Agricultural Engineers. .

[67] ITCOW1988.

At ITCO, both tubing and casing were cleaned, but since the process to clean tubing and casing is very similar[68], this report refers to both as simply "pipe". Tubing is the inner pipe through which production fluid is pumped, whereas casing surrounds and protects the tubing. Both casing and tubing were in contact with brine and therefore both were contaminated with scale. Pipe was cleaned with air rattlers and/or wire brushes, depending on the degree of contamination. A rattler or reamer is a rotating metal device attached to an air gun that spins at high speeds inside of the pipe. During this process, the rattler grinds and pulverizes the scale attached to the pipe wall. Large amounts of particles and dust are blown out of the pipe by the compressed air that powers the rattler. At the same time, scale is brushed off the outside of the pipe. The outside scale was sucked into a dust collector, where the larger particles fell into a catcher. The smaller particles were blown through the stack out into the air. The dust collector did not catch particles and dust coming out of the inside of the pipe. Depending on the thickness of the rind of pipe scale in the pipe, the cleaning process removed about 0.5 - 2 pounds of scale from the inside of each 30-foot pipe joints[69,]

Eyewitnesses (LeFleur and Arwood) have testified that ITCO had at least one stationary pipe-cleaning machine at the Brown and Root yard. In addition, various pipe cleaning companies including Alpha Technical and ITCO had mobile pipe cleaning machines set up in the pipe storage area at the Brown and Root yard, often on the sides of the roadways or in between racks of pipe[70,71] . At times, several pipe cleaning machines would have been operating simultaneously in the Brown and Root yard.

The process to clean pipe was principally similar for the stationary and the mobile units, with the main difference being the extent of mechanization and therefore the rate at which pipe was cleaned. In stationary pipe cleaning machines, both the outside and the inside of the pipe were cleaned automatically as the pipe was moved back and forth along a track of rotating wheels. The inside was cleaned by the reamer or brush, (powered by compressed air) and mounted on a rod, while large wire brushes cleaned the outside. The operator had to steer these processes, but he did not have to manually brush and ream pipe. In mobile units, the air powered brush or rattler/reamer had to be moved (or "walked") manually through the pipe, and the pipe cleaners brushed the outside of the pipe with hand-held brushes. Also, mobile units did not have a dust collector. Thus, on a stationary machine, about 300 pipe joints could be cleaned per day[72], whereas the cleaning rate of the mobile units was about half of that. The pipe cleaning machines were usually used to capacity, which means that assuming 8 hours of actual cleaning per day, a pipe joint was cleaned about every 1.6 minutes.

Pipe cleaners recall a dense cloud of dust during pipe cleaning (Richardson[73] and Fennidy III[74]). Mr. LeFleur of Brown and Root also remembers seeing clouds of dust related to pipe cleaning[75.] Large particles of scale fell to the ground near the pipe end, whereas smaller particulates stayed airborne

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[68] Testimony of Milton Vercher in *Grefer* Case, p. 27.

[69] Testimony of Mike Bulot in Grefer Case, p. 26.

[70] Deposition of D.K. LeFleur, August 28, 1996, Francis M. Vercher v ITCO, 62:19, 71-10.

[71] Castellex103504, page 113.

[72] Testimony of Mike Bulot in Grefer Case, p. 16.

[73] James Richardson deposition, castellex103435, 192:25.

[74] Horace Fennidy III deposition, Castellex103662, 267:13, 279:23.

[75] Deposition of D.K. LeFleur August 28, 1996, Francis M. Vercher v ITCO, 107-23.

for a period of time, before finally settling to the ground. Darrell Calvey testified that the wind would blow this dust all around and it settled on everything, including the cars in the parking lots[76]. Curtis Arwood testified that the dust got everywhere: he observed it floating into the surrounding neighborhoods[77] and saw it on the leaves of nearby trees[78]. According to testimony, Brown and Root did not supply respirators to the pipe yard workers[79, 80, 81, 82] even though by all accounts the dust levels were appallingly high. Sometimes workers would try to protect themselves by putting a handkerchief or rag around their faces.[83, 84]. Rags, handkerchiefs, painter masks and similar items are not an acceptable substitute for a respirator. They would have been unreliable and largely ineffective at protecting workers from airborne dust.

The larger scale fragments accumulated on the ground near the cleaning machine and had to be shoveled out of the way. Scale would accumulate on the ground up to 10 inches thick at the location of mobile units according to the testimony of James Richardson.[85] This material as well as the scale from the stationary units was spread over the yard or used as fill material for potholes at the Brown and Root yard [86]. Former workers testified that some areas were covered with about 5 to 7 inches of scale[87].

Scale dust and particles came off the inside and outside of pipe during other processes, such as loading/unloading of pipe, lifting bundles of pipe with a crane, stacking pipe onto racks and moving it around the yard. As long as pipe was not cleaned, handling would release scale fragments and dust.

Also carried out in the yard was the greasing, de-greasing and hydro testing of pipe, where pipe joints were filled with water under pressure to detect leaks. The yards also served as pipe storage. Pipe had to be loaded onto and unloaded off trucks and barges, and also moved around within the yard between the testing, cleaning and inspection facilities. Brown and Root personnel were in charge of moving and storing pipe on the Brown and Root pipe yard. Many workers performed several different jobs in the yard, either consecutively over the years, or simultaneously in the same year. Many yard workers ate their lunch sitting in the scale under the pipe racks to get some shade, often without washing their hands and faces.

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[76] Darrell Calvey deposition, Castellex103516 page 200.

[77] Castelltex103504, pages 125.

[78] Castelltex103504, pages 126.

[79] Darrell Boyer deposition, Castellex103449, 179:5, 180:2.

[80] Cedric Guidry Jr. Deposition. Castellex103427, 162:7.

[81] Troy Richard deposition, Castellex103523, 193:3-5, 194:1-4.

[82] James Richardson deposition, castellex103435, 162:7.

[83] Horace Fennidy III deposition, Castellex103662, 79:16, 80:11-20.

[84] Jeffrey Homes deposition, Castellex103665 pages 93-94 and 101-102.

[85] James Richardson deposition, castellex103435,page 280-281.

[86] Curtis Arwood deposition, castellex103504, 189:14.

[87] Vercher Deposition, Vercher trial10021(26 January 1996), 106:14 -108:12.

Workers stated that they usually came home covered with scale from head to toe.[88] Mr. Batiste testified that his bathtub filled with "dirt" when he would bathe after getting home.[89]. Horace Fennidy III testified his shower stall and bathtub would have a black ring in it after he showered [90,] James Richardson testified that he would get so dirty that he would need to take a shower before he got home.[91] When Dolin Calvey came home at the end of the day, he would partially disrobe before entering the house, because the dirt and dust on him was so thick, but his children would rush up to him regardless, before he had a chance to clean himself off. [92]

Workers recall coughing up visible dust and sneezing or blowing dust from their noses several hours after work[93, 94].

The workers at the Brown and Root pipe yard were never fully informed of the potential danger of TENORM, nor were they given adequate respiratory protection. The workers near the cleaning machines in the yard and inside the inspection units were exposed too much higher dust levels than those who worked in other parts of the pipe yard. However, according to interviews with workers, it was dusty everywhere, even though there was less dust at locations further away from pipe cleaning operations.

It is unclear to us why Brown and Root did not inform the workers on its pipe yard of the presence of TENORM in the pipe cleaning process. Radioactivity in oil and brine had been reported as early as the 1930's,[95] the USGS reported radioactivity in Kansas oil fields[96] in the 1950's and the American Petroleum Institute (API) issued a report in 1982 that analyzed the potential impact on the petroleum industry of the inclusion of radionuclides into the CERCLA process. That report described in detail where specific radionuclides were prevalent: uranium in crude oil, radium in brine, and radon in both oil and brine[97]. The report concluded, "The regulation of radionuclides could impose a severe burden on API member companies". Additional information about the history of NORM knowledge is provided in earlier sections of this report.

During the time when the workers were exposed to radiation at the Brown and Root and ITCO yards, Brown and Root was a subsidiary of Halliburton. Halliburton is a large and sophisticated company with recognized expertise in well logging[98]. The Halliburton website stated that it has more than 76

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[88] Horace Fennidy III deposition, Castellex103662, 280:16.

[89] Dwayne Batiste deposition, Castellex103506, 39:22.

[90] Horace Fennidy III deposition, Castellex103662, 281:2.

[91] James Richardson deposition, castellex103435, 185:14-21.

[92] Darrell Calvey deposition, Castellex103516, page 201.

[93] Troy Richard deposition, Castellex103523,140:9.

[94] Jeffrey Homes deposition, Castellex103665, 162:9.

[95] Kurbatov, I. D. (1934) Concentrations of Radium and Mesothorium I in Nature and Regularity of Their Migration. J. Phys. Chem. 38, pages 521-532. hph2503.

[96] USGS, "Radioactivity in Oil Fields in Southeast Kansas," 1953. ind0975

[97] American Petroleum Institute, *An Analysis* of *the Impact of the Regulation of* « *Radionuclides »* as a *Hazardous Air Pollutant on the Petroleum Industry,* Committee for Environmental Biology and Community Health. Department of Medicine and Biology, October 19, 1982 (THRA000013-45).

[98] Deposition of Harry D. Smith, Jr., itcow22218, pgs. 27 and 28.

years of specialized experience in cased-hole logging, including experience in the interpretation of natural gamma ray logs.[99]

Mr. John L. Carter

Mr. Carter sat for two depositions concerning this case on January 10, 2013.[100, 101]

Social security records show that Mr. Carter worked for Joseph Ribault Trucking from the last quarter of 1965 through the third quarter of 1970, a total of 20-quarter years.[102] Dr. Resnikoff had interviewed Mr. Carter twice. The dose assessment is based on that interview, his deposition, social security records and information provided from other workers about working conditions at the Brown and Root yard.

[99] See http://theyesmen.org/agribusiness/halliburton/esg/sd0913.html saved as a tiff file on 10/16/2010.

[100] jcarter001689-001734. Discovery Deposition of John L Carter. January 10, 2013.

[101] jcarter001668-001688, Deposition of John L Carter. January 10, 2013.

[102] jcarter000526-000532. Social Security Administration Report of Earnings for John L Carter.

Highlights of Mr. Carter's Depositions

Ribault Employment

Deposition	Bates Reference	Summary
Discovery	jcarter001706, p67-68	Worked for Ribault five days a week usually. Sometimes 6 days a week. At least 3 days a week if it was raining.
Discovery	jcarter001707, p69	Worked for 10 - 18 hours per day for Ribault. Did a lot of hauling for Brown and Root. Also hauled for Glazer Steel.
Discovery	jcarter001705, p63	Doesn't remember working for more than one trucking company at a time.
Discovery	jcarter001705, p64	Did not drive a specific route for Ribault
Discovery	jcarter001706, p65	At Ribault hauled for different clients
Discovery	jcarter001707, p71	Picked up pipe in Morgan City and hauled it to Brown & Root. Sometimes hauled bags of sulfur to the wharf from a plant in Belle Chasse.
Discovery	jcarter001708, p74	Also hauled sheet piling for construction of levee around I-10 in Kenner.
Discovery	jcarter001708, p75	Did not remember any loads going to Alpha Technical.
Discovery	jcarter001708, p75-76	Regarding Belle Chasse, most often when he hauled pipe from the Brown and Root facility (at Engineers Road in Belle Chasse) pipe went to a Morgan City pipe yard that could load them onto barges.
Discovery	jcarter001709, p80	Agreed that pipe he picked up from Brown and Root had been cleaned.
Discovery	jcarter001710, p81	Provided a description of the cleaning operation as noisy and dusty.
Discovery	jcarter001710, p81	Sometimes had to wait for his truckload.

Deposition	Bates Reference	Summary
Discovery	jcarter001710, p84	ITCO had its own trucks, so Ribault did not do a lot of hauling pipe for ITCO. Mr. Carter was aware that Brown and Root and ITCO were separate yards located near one another. He rarely picked up from ITCO yard.
Discovery	jcarter001711, p86-87	Doesn't recall any details about what he picked up at HC Price pipe yard, or the condition (new/old, large/small clean/dirty). Wore gloves and street clothes, not a uniform.
Discovery	jcarter001711, p88	Doesn't recall details about what the pipe-cleaning machine at Brown and Root looked like or how many there were.
Discovery	jcarter001712, p89	Doesn't recall details about what the pipe-cleaning machine at Brown and Root looked like or how many there were.
Discovery	jcarter001712, p90	Picked up from pipe yards at least 3 days a week.
Discovery	jcarter001712, p91	Usually if he was picking up from a yard, he would pick up from that yard all week.
Discovery	jcarter001712, p92	The pipe cleaning area was roped off and it wasn't as dusty where Mr. Carter would be at the Brown & Root yard.
Discovery	jcarter001713, p95	Not aware of whose pipe he was transporting.
Discovery	jcarter001715, p102-103	For Ribault he drove flatbed trucks, rarely drove refrigerator or "closed-in" trucks
Discovery	jcarter001715, p104	Occasionally hauled sheetrock or Manville pipe. He was typically a day hauler instead of a cross-country driver.
Discovery	jcarter001716, p105	Spent a couple of months hauling sheet piling for Ribault.
Discovery	jcarter001716, p106	Occasionally hauled oil to Plaquemines Parish (to Venice).
Discovery	jcarter001716, p107	Hauled a load of Sulfur every couple of months
Discovery	jcarter001716, p108	Hauled pipe from other places to Brown and Root, and also from Brown and Root to other places. More often it was hauling pipe from Brown and Root.

Deposition	Bates Reference	Summary
Discovery	jcarter001717, p109	Dust wasn't uncomfortable enough at Brown and Root that cause him to wear anything on his face.
Discovery	jcarter001718, p114	Sometimes was within 10 feet of pipe cleaning operation. Other times farther away.
Discovery	jcarter001718, p115	Would go to the pipe yard area at Brown and Root yard.
Discovery	jcarter001719, p118	Pretty much all pipe hauling involved the Brown and Root yard. Never owned his own truck. Did not do the maintenance on the trucks he drove.
Perpetuation	jcarter001671, p 14	Ribault was located in Gretna, LA. This involved trucking around pipe yards. Mostly hauled pipe and related items for Brown and Root.
Perpetuation	jcarter001671, p 15-16	Freight that Mr. Carter hauled included large diameter (12 inch) pipe (casing probably), and also smaller pipe. Learned later that it was oilfield pipe. He would see pipe-cleaning activities with machines running and dust flying. These operations at Brown and Root occurred in a little roped off section. He would get within about 10 feet of these operations. The roads and work area at Brown and Root were unpaved. Would see dust flying around the pipe cleaning area.
Perpetuation	jcarter001672, p 17	Mr. Carter described pipe was loaded onto his truck. He would do work a rigger, by connecting the cable to the pipe prior to lifting and disconnecting after it was loaded onto the truck.
Perpetuation	jcarter001672, p 18	Mr. Carter would sit and eat lunch in the yards while they waited to be loaded. The truck he drove was not air-conditioned.
Perpetuation	jcarter001672, p 19	They would have the windows rolled down in the truck. Dust would get in the truck.
Perpetuation	jcarter001672, p 20	The inside surfaces of the pipes that Mr. Carter hauled were often dirty. Neither Brown and Root nor anyone else told him that he needed to wear protection from the dust at the yard. No one ever told him that the material in the yard was radioactive.

Deposition	Bates Reference	Summary
Perpetuation	jcarter001673, p 21	Neither Brown and Root nor anyone else told him that he needed to wear protection from the dust at the yard. No one ever told him that the material in the yard was exposing him to radiation.
Perpetuation	jcarter001673, p 22	The pipe yards did not warn him that radiation could cause cancer.
Perpetuation	jcarter001673, p 22-23	The pipe yards did not warn him that radiation could cause cancer.
Perpetuation	jcarter001673, p 23	Mr. Carter was not provided with a respirator for protection against airborne radioactive dust in the pipe yard, or warned that a respirator was necessary. He would wear his street clothes and gloves while loading and unloading pipe.
Perpetuation	jcarter001673, p 24	Mr. Carter was not warned to get more frequent medical examinations or to get blood tests because of his exposure to radioactive materials and radiation at the pipe yard.
Perpetuation	jcarter001674, p 25	No one ever provided Mr. Carter with training in procedures to protect himself from radiation and radioactive materials.
Perpetuation	jcarter001674, p 26	Mr. Carter would have looked for other work if he had known that he was being exposed to radiation. He would have avoided the dust if he had known it was radioactive and can cause cancer.
Perpetuation	jcarter001674, p 27	Mr. Carter would have wanted to know whether that the Brown and Root pipe yard had radioactive material in it.
Perpetuation	jcarter001674, p 28	Mr. Carter testified that he had contracted multiple myeloma cancer about 15 years before (e.g. about 1998).
Perpetuation	jcarter001682, p59-60	Hauled pipe while working for Ribault. Frequent yards were ITCO in Harvey, Brown and Root in Belle Chasse, H.C. Price yard on the west bank. Hauled oil for Texaco. Also hauled sulphur & sheet pilings.
Perpetuation	jcarter001683, p61-62	Doesn't remember hauling between Brown and Root and HC Price or ITCO. Remembers hauling pipe between Belle Chasse.

Deposition	Bates Reference	Summary
Perpetuation	jcarter001683, p63	Mostly remembers picking up clean pipe at Belle Chasse.
Perpetuation	jcarter001683, p64	Admits confusion about whose pipe was at Belle Chasse or what it was used for.
Perpetuation	jcarter001684, p66	Attorney Beth Rambin and Mr. Carter discussed how he had only been to HC Price pipe yard a few times.
Perpetuation	jcarter001684, p71	Only went to the ITCO yard a few times.

Other Employment

Deposition	Bates Reference	Summary
Discovery	jcarter001702, p52	There are companies listed in Mr. Carter's social security record that he did not work for: Louisiana Erectors, TS Rental of New Orleans, Synergy Staffing,
Discovery	jcarter001703, p53	After Ribault, he owned a rental company (J.L. TV Service), rented stereos, televisions, and other items
Discovery	jcarter001703, p54	J. Hayward & Company, worked for a bean packing company in the 50s.
Discovery	jcarter001704, p58	Did not work for Fort Wayne Literacy Council as indicated in Social Security Report.
Discovery	jcarter001704, p59	Worked for Winn-Dixie as indicated on social security report.
Discovery	jcarter001705, p61	Did not work for George Matthews and Son as indicated in Social Security Report. Did work for Rabalis, a grocery store.
Discovery	jcarter001705, p62	Hauled paper for Roadway Express
Discovery	jcarter001705, p63	Doesn't remember working for more than one trucking company at a time.
Discovery	jcarter001713, p94	Mr. Carter's other employments were not dusty. Never filed a Worker Compensation claim on any job.

Personal, Family and Home Life

Deposition	Bates Reference	Summary
Discovery	jcarter001697, p32	Had seven children, 6 still living.
Discovery	jcarter001714, p97	Mother passed away at about 75. Not cancer. Diabetes and other organ problems. Unclear on causes of death of his various siblings.
Perpetuation	jcarter001670, p 11	Born near Magnolia, MS. Father lived to age 102. Moved to New Orleans area in 1950s at age 17 looking for work opportunities. Found work as a truck driver for Hayward Bean mostly hauling groceries.
Perpetuation	jcarter001671, p 13	Got married and had seven children. Began driving for Ribault in 1965.
Perpetuation	jcarter001674, p 28	Mr. Carter testified that he had contracted multiple myeloma cancer about 15 years before (e.g. about 1998).
Perpetuation	jcarter001675, p 30	Also had colon cancer. Had a tumor surgically removed?
Perpetuation	jcarter001675, p 31	Had seven children, six are still living. Has five grandchildren.
Perpetuation	jcarter001676, p33-34	There was no family history of multiple myeloma.
Perpetuation	jcarter001681, p54-55	Mr. Carter agreed under cross-examination that he was diagnosed with cancer sometime around 2002.
Perpetuation	jcarter001682, p59-60	Hauled pipe while working for Ribaul. Frequent yards were ITCO in Harvey, Brown and Root in Belle Chasse, H.C. Price yard on the west bank. Hauled oil for Texaco. Also hauled sulphur & sheet pilings.
Perpetuation	jcarter001683, p61-62	Doesn't remember hauling between Brown and Root and HC Price or ITCO. Remembers hauling pipe between Belle Chasse.
Perpetuation	jcarter001683, p63	Mostly remembers cleaning up clean pipe at Belle Chasse.
Perpetuation	jcarter001683, p64	Admits confusion about whose pipe was at Belle Chasse or what it was used for.

Deposition	Bates Reference	Summary
Perpetuation	jcarter001684, p66	Attorney Beth Rambin and Mr. Carter discussed how he had only been to HC Price pipe-yard a few times.
Perpetuation	jcarter001684, p68	Smoked for fifteen years. Was paid hourly at rate of $2.25 per hour.
Perpetuation	jcarter001684, p71	Only went to the ITCO yard a few times.
Perpetuation	jcarter001688, p8-82	Quit smoking 20 or 25 years ago. Smoked a pack a day.

His Cancers and Complications

Deposition	Bates Reference	Summary
Discovery	jcarter001694, p20	Deterioration in vertebra in neck.
Perpetuation	jcarter001674, p 28	Mr. Carter testified that he had contracted multiple myeloma cancer about 15 years before (e.g. about 1998).
Perpetuation	jcarter001675, p 30	Also had colon cancer. Had a tumor surgically removed.
Perpetuation	jcarter001675, p 31	Had seven children, six are still living. Has five grandchildren.
Perpetuation	jcarter001676, p33-34	There was no family history of multiple myeloma.
Perpetuation	jcarter001681, p54-55	Mr. Carter agreed under cross-examination that he was diagnosed with cancer sometime around 2002.
Perpetuation	jcarter001684, p68	Smoked for fifteen years. Was paid hourly at rate of $2.25 per hour.
Perpetuation	jcarter001688, p8-82	Quit smoking 20 or 25 years ago. Smoked a pack a day.

Brief Outline of Medical Records

Mr. Carter has developed two types of cancer, multiple myeloma and also colon cancer. Multiple myeloma is a type of cancer that begins in plasma cells (white blood cells that produce antibodies). There is confusion over the exact date that Mr. Carter was diagnosed with multiple myeloma. Not all of Mr. Carter' medical records could be obtained as of August 2013. There is mention of the condition going back to 2003 in available medical records. Mr. Carter's depositions indicate he first may have been diagnosed around 1998 or 2002. Colon cancer appears on charts in June 2009.

Bates Reference	Summary
jcarter000005-000020	Date of birth 08/20/36, John L. Carter, prescribing history, radiology reports (MRI scans indicating multiple myeloma history)
jcarter000021-000517	Colon cancer, metastatic multiple myeloma
jcarter000518-000525	Prescribing records
jcarter000533-000573	Billing records
jcarter000574-001667	Colon cancer appears on charts on 6/10/2009 jcarter000639, myeloma pathology report jcarter000695
jcarter000574-001667	Multiple myeloma suspected from MRI & MRA imaging 3/3/2008. jCarter000742 Multiple myeloma may date to 2003. Cytogenetic report jcarter000760 10/06/2011
jcarter001805-001829	Billing records
jcarter002289-002328	Billing records
	-
jcarter003242-003944	11/16/2006 multiple myeloma with bone metastases jcarter003940
-	-
jcarter004314-004318	Billing records
jcarter004319-004374	Billing records
jcarter001668-001688	Carter Deposition, Jan 10, 2013

Exposure to Radiation

While on the Brown and Root yard, Mr. Carter suffered intakes of radioactive material from breathing radioactive material (inhalation), by ingestion, and by injection. Inhalation of radioactive material occurs when it becomes airborne in the breathing zones of persons like Mr. Carter. Incidental ingestion of radioactive material occurs by pathways such as hand to mouth transfer when loose radioactive material is present in an uncontrolled workplace.

Mr. Carter received additional radiation dose due to external radiation at the Brown and Root yard, and while he was hauling pipe to the Brown and Root yard. Brown and Root neither told Mr. Carter that these radiation exposures were occurring, nor did they obtain his consent.

These and additional radiation exposure pathways are detailed in subsequent sections of this report

Dose Reconstruction Results and Probability of Causation

Mr. Carter's develops radiation dose estimates were calculated and the NIOSH Interactive Radio Epidemiological Program (e.g. IREP) was then used to calculate the probability that the cancers were caused by the radiation exposures. NIOSH-IREP was created for use by the Department of Labor for adjudication of claims in accordance with the Energy Employees' Occupational Illness Compensation Program Act of 2000 (EEOICPA).[103, 104]

Sensitivity of Inhalation Dose to Lung Clearance Class

Mr. Carter's inhalation dose estimates assume that the radioactive material in pipe scale had lung clearance characteristics as recommended by ICRP publication 68. The inhalation dose is sensitive to the lung clearance behavior. This section assesses the impact of alternative lung clearance assumptions on the inhalation dose. ICRP publication 72 includes more lung clearance types than ICRP Publication 68, and ICRP Publication 72 inhalation and ingestion dose conversion factors are provided in Table 2 below and Appendix C. Assuming slower lung clearance has the effect of reducing the inhalation dose to the colon (by 68%) and red marrow (by 79%), but it also increases the effective dose due to inhalation (by 94%).

The effect of lung clearance on inhalation dose estimates was not accounted for in the inhalation dose calculations. If taken into account, it would have had the effect of reducing the lower bound inhalation dose estimates by less than a rem for the colon and red marrow and increasing the lower bound inhalation effective dose estimates by a few rem. Overall, the changes to the lower bound inhalation dose estimates would have had an insignificant impact on the probability of causation.

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[103] User's Guide for the Interactive Radio Epidemiological Program (NIOSH-IREP) Version 5.7 (2013), SENES Oak Ridge.

[104] Kocher, David C.; Apostoaei, A. Iulian; Henshaw, Russell W.; Hoffman, F Owen; Schubauer-Berigan, Mary K.; Stancescu, Daniel O.; Thomas, Brian A.; Trabalka, John R.; Gilbert, Ethel S.; Land, Charles E., Interactive Radio Epidemiological Program (Irep): A Web-Based Tool for Estimating Probability of Causation/Assigned Share of Radiogenic Cancers, Health Physics. 95(1):119-147, July 2008.

Table 2. Inhalation Dose Factor Sensitivity Analysis.

Nuclide	Type	Colon	Red Marrow	E
Pb-210	**F**	**1.20E-07**	**3.20E-06**	**9.00E-07**
Pb-210	*S*	*1.50E-08*	*2.10E-07*	*5.60E-06*
Pb-212	**F**	**5.10E-09**	**1.10E-08**	**1.80E-08**
Pb-212	*S*	*4.00E-09*	*1.00E-10*	*1.90E-07*
Bi-210	M	2.30E-09	4.70E-11	9.30E-08
Bi-212	M	9.40E-11	2.10E-11	3.10E-08
Po-210	**F**	**1.50E-07**	**1.30E-06**	**6.10E-07**
Po-210	*S*	*1.10E-08*	*2.30E-08*	*4.30E-06*
Ra-224	**M**	**3.20E-08**	**4.00E-08**	**3.00E-06**
Ra-224	*S*	*3.00E-08*	*2.70E-09*	*3.40E-06*
Ra-226	**M**	**4.40E-08**	**5.20E-07**	**3.50E-06**
Ra-226	*S*	*2.30E-08*	*7.00E-08*	*9.50E-06*
Ra-228	**M**	**3.10E-07**	**4.70E-06**	**2.60E-06**
Ra-228	*S*	*1.20E-07*	*1.70E-06*	*1.60E-05*
Th-228	S	1.50E-07	1.90E-06	4.00E-05
Aggregate DCF, Sv/Bq. assuming equilibrium in the decay chains and a radium-228 /radium-226 ratio of 1/3.				
		Slower Clearance	ICRP68 Default Clearance	
	Colon	1.53E-07	4.82E-07	
	Red Marrow	1.50E-06	7.23E-06	
	Effective	3.93E-05	2.03E-05	

Radiation Dose Calculations and Risk

John Carter worked as truck driver for Ribault Transfer from 1965 through 1970. He hauled pipe, both clean and contaminated, from pipeyards to drilling rigs and back again, and was exposed, without his knowledge, to technologically enhanced naturally occurring radioactive material (TENORM) in the course of his work. Pipeyards, such as Brown & Root, were involved in descaling of radioactively contaminated oil field pipe. Workers and visitors at pipeyards were exposed to radiation through inhalation of the scale dust, incidental ingestion of radioactive dust, and to external gamma radiation from the scale in the pipe and from the scale deposited on the ground. Mr. Carter was also exposed to direct gamma radiation from contaminated pipes as he drove from the oil rigs to the pipeyards. In addition to driving a truck, Mr. Carter would help to load pipes at the oil rigs and unload pipes at pipeyards. Mr. Carter often aided with the loading of pipes to and from his truck by physically guiding and steadying the pipes as they were taken on and off his truck. To calculate direct gamma dose rates in his truck and elsewhere, we used the standard software, MicroShield Version 8.02[105], by Grove Software, Incorporated. MicroShield is a program used to estimate dose rates due to a specific external radiation source. He worked between 40 and 60 hours per week, 8 to 10 hour days.

At the pipeyards, there was no radiation protection program. Therefore, no measurements were made at the time the work was performed, so the true radiation doses will never be known. In this report, based on the technical literature and air measurements from other pipeyards, a range of likely radiation doses is estimated. It is very likely that workers and non-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 activity, breathing rates, dust loadings, and so on). Mr. Carter suffers two types of cancer, multiple myeloma and colon cancer. He has had his colon removed and has undergone chemotherapy to hold his multiple myeloma in remission. The radiation dose received by Mr. Carter, more likely than not, caused his cancer.

After calculating Mr. Carter's radiation dose to specific organs, such as the colon and red bone marrow, we employed NIOSH's Interactive RadioEpidemiological Program (IREP), version 5.7[106] 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 specific types of cancer[107].

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

[105] Grove Software Incorporated, 2008

[106] NIOSH and SENES Oak Ridge Inc., 2009

[107] *Ibid*.

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 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, then 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. As more information becomes available, we reserve the right to supplement this report.

Pipeyards

Pipeyards, such as Brown & Root, cleaned and inspected pipe used in the oil field industry. Thousands of oil field tubings and casings were brought in by barge and truck from the Gulf Coast region; their origins would be identified on trucking tickets or work audits. Each truck carried between 150 to 200 joints (30 foot sections), and would transport the used oilfield pipe to the pipe yards at various locations. Pipe was also trucked in directly from production sites in Louisiana and neighboring states.

The pipe was stacked on racks, up to eight layers, which were several feet high[108]. After cleaning, inspection, and testing, the pipe was stored and eventually returned to the oil fields, again either on barges or directly by truck, depending on the location of the oil production sites.

Precipitated technically enhanced NORM or TENORM-containing salts and scale, are in a matrix of other compounds and mixtures. Accumulation of the salts, inside the pipe depends on the characteristics of these salt matrices. Some scale looks like fine sand, whereas others resemble rust. Radium-226 has a half-life of 1600 years. The quantity of radioactive material in the deposits is small from a mass standpoint. One gram of radium-226 is one curie of radioactivity, or one billionth of a gram of Ra-226 is equivalent to 1,000 pCi/g. Radioactive material within the pipe scale cannot be distinguished from the salts and other deposits.

Mr. Carter recalled transporting pipes to a Brown & Root pipeyard in Harvey, LA and another in Morgan City, LA. Pipe includes tubing and casing. Tubing is the inner pipe through which production fluid is pumped, whereas casing surrounds and protects the tubing from outside pressure. Both casing and tubing were in contact with radium-contaminated water or brine which plated out on pipes, scale. At the pipeyards, both tubing and casing were cleaned, but since the process to clean tubing and casing is very similar[109], we refer to both as simply "pipe". Pipe was

[108] Testimony of Milton Vercher in Grefer Case, p. 33.

[109] Testimony of Milton Vercher in Grefer Case, p. 27.

cleaned with air rattlers and/or wire brushes, depending on the degree of contamination. A rattler or reamer is a rotating metal device attached to an air gun that spins at high speeds inside of the 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 was sucked into a dust collector, where the larger particles fell into a catcher. The smaller particles were blown through the stack out into the air. The dust collector did not catch particles or dust coming out of the inside of the pipe. Depending on the degree of contamination, the cleaning process removed between 0.5 and 2 lbs of scale from the inside of one, 30-foot pipe joint[110].

Pipe cleaning machines were manufactured by Hub City Ironworks of Lafayette, Louisiana. Hub City referred us to Intool, Inc. a company that currently manufactures tube cleaners. A variety of different rattlers are shown in Appendix B.

On a stationary machine, about 300 pipe joints could be cleaned per day[111], whereas the cleaning rate of the mobile units was about half of that. The pipe cleaning machines were usually used to capacity, which means that assuming 8 hours of actual cleaning per day, a pipe joint was cleaned about every 1.6 minutes.

Men who worked as pipe cleaners and Mr. Carter recall a dense cloud of dust during pipe cleaning[112]. Large particles of scale fell to the ground near the pipe end, whereas smaller particulates stayed airborne for a period of time, before finally settling to the ground. The fine dust was transported wherever the wind blew, as far as the parking lot or even off the property into neighboring areas[113]. The larger scale fragments accumulated on the ground near the cleaning machine and had to be removed twice per week. This material as well as the scale from the dust collector boxes (emptied 2-3 times per week) was spread over the yard or used as fill material for potholes and pipe racks that had sunk into the soft ground[114]. Former workers testified that some areas were covered with about 5 to 7 inches of scale[115].

Scale dust and particles came off the inside and outside of pipe also during other processes, such as loading/unloading of pipe, lifting bundles of pipe with a crane, stacking pipe onto racks and moving it around the yard. Until a pipe was cleaned, every heavy impact would cause the pipe to release a certain amount of scale fragments and dust.

Workers and Mr. Carter stated that they usually came home covered with scale from head to toe[116]. The personal vehicles that were parked in the yard had thick dust inside and out. Some workers' wives reported that they would not allow their husbands into the house without first disrobing and/or cleaning up[117]. In one incident, a worker's neighbor complained about her line-

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[110] Testimony of Mike Bulot in Grefer Case, p. 26.

[111] Testimony of Mike Bulot in Grefer Case, p. 16.

[112] Telephone conversation with Mike Bulot; corroborated by Milton Vercher, Ricky Benoit and James Armand (all telephone conversations)

[113] Testimony of Mike Bulot in Grefer Case, p. 19.

[114] Testimony of Mike Bulot in Grefer Case, p. 41.

[115] Vercher Deposition, Civil District Court, Parish of Orleans, State of Louisiana, No. 95-15159 (26 January 1996).

[116] Testimony of Mike Bulot in Grefer Case, p. 19.

[117] Interview with Robert V. Torry and David C. Torry Jr. by Stan Waligora on October 16, 2001.

drying laundry being dirty[118] from the dust that the worker brought home on his vehicle and his clothes[119]. Workers recall coughing up visible dust and sneezing or blowing dust from their noses several hours after work.

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 estimated the air particulate concentrations near the pipe-cleaning machine to be 10–30 mg/m^3, or 2-6 times above this limit, based upon empirical data[120,121], discussed later in the report.

During his April 1987 visit, Lindsay Booher Exxon's Industrial Hygienist, noted that levels of "nuisance dust" exceeded OSHA standards 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. A report by Lindsay Booher[122] discusses the dust situation. Booher writes: "*…a considerable amount of airborne dust is generated during pipe cleaning. The results suggest that the exposure to the machine operators exceeded the American Conference of Governmental Industrial Hygienists Threshold Limit Value (TLV) for nuisance dusts.*" In other words, Exxon's expert deemed an exposure to this amount of dust unsafe, even without factoring in the presence of radioactivity.

Radiation Pathways

Dose Rate from Inhalation of Radioactive Particulates

In order to calculate the radiation dose rate due to inhalation of radioactive particulates we first calculate the amount of radioactivity that a person inhaled in a particular time period, and apply standard dose conversion factors (DCF), as recommended by the International Commission on Radiological Protection (ICRP)[123]. These DCF convert an amount of a specific inhaled radionuclide into the resulting inhalation dose to specific organs.

Different DCF exist for different exposure assumptions. For our calculations, we assume that the respirable scale dust has default ICRP-68 lung clearance behavior for an adult worker, and

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[118] Interview with Floyd Thomassie Sr. by Stan Waligora on October 16, 2001.

[119] Interview with Charles Narcisse Jr. by Stan Waligora, October 2001.

[120] ITCOEX 925

[121] Radiation Technical Services of Baton Rouge, *Air Sample Collected in Location Approximating Breathing Zone of Most Exposed Person*, X-ref. # 930415.01-2 (April, 1993).

[122] Booher L.E., *et al*, *Report of Industrial Hygiene Evaluation of the Controlled Environmental Cleaning Facility*, Intracoastal Pipe Repair and Supply Company, Inc, ITCO-A 23192 (February, 1988).

[123] International Commission on Radiological Protection (ICRP), *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients*, ICRP 72 (1996).Table A.2.

that the particles have a particle size distribution of 1 μm AMAD. Dose conversion factors for inhalation are presented in App. C.

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.

The total amount of inhaled radioactive material is equal to the dust loading in the working environment, multiplied by the radioactive concentration of the dust, and by the ventilation (breathing) rate. The inhalation dose rate can therefore be calculated as follows:

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

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 rate (breathing rate, m^3/time)
DCF_{inh}	Dose conversion factor for inhalation for Ra-226 and Ra-228 chains (mrem/pCi)

Because the Brown and Root yard is no longer in operation and the workers were exposed years before discovering the dangers associated with cleaning of oil pipe, actual measurements of the average air particulate concentration in the pipe yard are not available. The workers were exposed to different concentrations of particulates, depending on their exposure type(s). However, isolated measurements of particulate air concentration showed 11 mg/m^3 in the ITCO yard[124], and 53 mg/m^3 at another pipe yard[125]. Both measurements were taken while pipe was being cleaned, but presumably at different distances from the cleaning machine (the exact locations of the measurements were not given). A review of data from OSHA inspections for similar industries also supports the 10 – 30 mg/m^3 range.

Because of these uncertainties, we apply an air particulate concentration range, as opposed to a single value. We expect this range to include the "true" average air particulate concentration to which the pipe cleaners were exposed. In the vicinity of the pipe cleaning process, we apply 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 measurement carried out at ITCO, but it is below the measurement obtained at another pipe yard of 53 mg/m^3.

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[124] ITCOEX 925

[125] Radiation Technical Services of Baton Rouge, *Air Sample Collected in Location Approximating Breathing Zone of Most Exposed Person*, X-ref. # 930415.01-2 (April, 1993).

Based on testimony of former ITCO workers, the visible dust cloud emanating from the pipe cleaning machine reached at least 50 yards downwind[126].

To calculate the radioactivity (A) in the dust, we use scale measurements taken in the ITCO pipe yard. We apply a scale activity of A = 6,000 pCi/g for Ra-226, and of A = 2,000 pCi/g for Ra-228. This estimate is based on measurements by the EPA[127], Chevron[128] [129] and Reed[130] 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[131] of V = 1.5 m^3/h.

Using information about a worker's job history, we then calculate the total dose he received by multiplying the dose rate with the exposure time:

$Dose_{inh}$ (mrem) = DR_{inh} (mrem/time)* exposure time

Information regarding the type of exposure and the exposure time in the vicinity of the pipe cleaning machines, and in other parts of the yard, was gathered from personal interviews with former workers of the ITCO pipe yard in Harvey, LA, and/or their families.

We ignore the inhalation dose due to emanation of radon and thoron from the ground. The calculation of the inhalation dose rate is similar to that of the inhalation dose rate for particulates.

Dose Rate from Incidental Soil Ingestion

The incidental soil ingestion dose rate is calculated in a way 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:

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[126] Telephone conversations with M. Bulot and R. Benoit.

[127] United States Environmental Protection Agency (US-EPA*), Letter from Charles R Porter to Eddie S Fuentz (MS DOH), with attached report on radiological survey of the Case Property* (23 January 1987).

[128] NORM Study Team, *Final Report: Naturally Occurring Radioactive Materials in Production Operations*, Chevron USA, Inc. (1990).

[129] PGREF 101884

[130] Reed G, Holland B, and A McArthur , *Evaluating the Real Risks of Radioactive Scale in Oil and Gas Production*, in Proceedings of the First International Conference on Health, Safety and the Environment, held in The Hague, Netherlands, Society of Petroleum Engineers, Richardson, TX (1991).

[131] International Commission on Radiological Protection (ICRP), *Human Respiratory Tract Model for Radiological Protection, Annals of the ICRP 24 (1-3)* (1994). International Commission on Radiological Protection (ICRP), *Human Respiratory Tract Model for Radiological Protection, Annals of the ICRP 24 (1-3)* (1994).

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

where

DR_{ing} Ingestion dose rate (mrem/time)

IR Ingestion rate (mg/time)
A Activity of Ra-226 and Ra-228 in scale (pCi/g)

$DCF_{ing}.$ Dose conversion factors for ingestion for Ra-226 and Ra-228 chains (mrem/pCi).

For incidental soil ingestion, we apply a scale ingestion rate of IR = 20 mg/h. This is the incidental soil ingestion rate for outdoor yard work as given by EPA[132]. 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. The upper bound assumes that all of the incidentally ingested soil/dust corresponds to pipe scale, whereas for the lower bound, only half of the ingested material is assumed to be pipe scale, and the other 50 % is ordinary dust/dirt.

We apply the scale activity as used above in the calculation of the inhalation dose rate of 6,000 pCi/g of Ra-226, and 2,000 pCi/g of Ra-228. Again, we assume secular equilibrium between the parent and daughter nuclides.

The total ingestion dose is calculated by multiplying the ingestion dose rate by the exposure time:

D_{ing} (mrem) = DR_{ing} (mrem/time) * exposure time

The type of exposure and the exposure time in the yard depend on the personal history of each worker, which was determined from interviews and the type of job held during employment.

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. Mr. Carter stated that he often ate lunch in his truck, as he waited for his turn to load his truck.

Mr. Carter also ingested sludge while loading pipes at oil rigs. Since we do not have measurements of sludge concentrations present in production pipes of the oil rigs on which Mr. Carter worked, we use a range of sludge concentrations provided by the International Atomic

[132] United States Environmental Protection Agency (US-EPA), *Exposure Factors Handbook,* I EPA/600/P-95/002Fa:4-21 (August, 1997).

Energy Agency (IAEA)[133]. 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. According to the IAEA, we have the following ranges: Ra-226 (pCi/g): Ra-226 (1.35, 21600), Ra-228 (13.5, 1350), Po-210 (0.108, 4320), and Pb-210 (2.7, 31500). 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. According to the IAEA, Po-210 and Bi-210 have a range 2.8 to 35,100 pCi/g and Po-210 ranges between 0.108 and 4320 pCi/g. If the range is several orders of magnitude, we use the geometric mean.

Dose Rate from External Radiation

The workers and visitors were further exposed to external radiation from the scale deposited on the ground and from scale within the pipe as it was stored, cleaned and inspected in the yard. External radiation coming off the soil is also called groundshine.

External radiation is directly measured as a radiation dose, as opposed to ingestion and inhalation, for which we first calculate the uptake. The external radiation dose rate to the whole body due to soil contamination is based on the radioactivity in the contaminated layer, and the thickness of this layer.

To calculate the groundshine dose rate, we use the same scale radioactivity as above, 6,000 and 2,000 pCi/g of Ra-226 and Ra-228, respectively, and secular equilibrium.

For scale thickness, we use a lower and upper bound of 1 and 5 cm, respectively. If we multiply the activity in scale with these two sets of DCF, we obtain a groundshine dose rate in mrem/h:

$$DR\gamma = A * DCF_{\gamma}$$

where

DR_{γ} Groundshine dose rate (mrem/time)

A Activity of Ra-226 and Ra-228 in scale (pCi/g)

DCF_{γ} Dose conversion factors for external radiation for Ra-226 and Ra-228 chains (mrem*g/h-pCi)

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[133] International Atomic Energy Agency (IAEA), 2003. *Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry*, Safety Reports Series No. 34.

The resulting effective dose is calculated by multiplying the dose rate with the exposure time. The dose rate at the pipeyard from groundshine was calculated using Microshield: 3.576 mr/h (1 cm depth) and 10.192 mr/h (5 cm depth). Mr. Carter spent 50% of his time driving the truck, and a total of 25% of his time at the pipeyard and the drill rig, which we took as 12.5 % at each end.

To calculate the external radiation dose that the workers received directly from pipe (as opposed to scale deposited on the ground), we employed Microshield. As inputs to MicroShield, we assumed an outer pipe diameter of 2 7/8 inches (7.3025 cm), a range of scale thickness from 0.2 cm to 1 cm, and a pipe wall thickness of 0.551 cm, as suggested by the US EPA[134]. 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. We calculated contact dose rates of 0 0.20875 m/h to 0.8773 mr/h to the colon and 0.2248 mrem/h to 0.94395 mr/h to the red marrow from one joint.

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 0.08 (scale thickness 0.2 cm) to 0.36 (scale thickness of 1 cm), the other percent of the volume is steel and air. This results in a dose rate range of 0.124 mr/h to 0.538 mr/h to the colon and 0.109 mr/h to 0.471 mr/h to red marrow. This dose rate takes into account 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. Finally, Mr. Carter incurred a small direct gamma dose from contamination on his clothing.

Radiation Dose to Mr. Carter

Mr. Carter worked as a driver for Ribault Transfer from 1965 through 1970. He hauled pipe, both contaminated and clean, between pipeyards and rigs. He stated to us in an interview that he hauled pipe 75% of the time however in our calculations we assume that he hauled pipe 50% of the time. We assume that 25% of his day was spent loading and unloading pipes from his truck at either a pipe yard or drill rig. Of that 25%, we assume that half (12.5%) of the pipes he loaded and unloaded were NORM contaminated and that half (12.5%) of the pipes he loaded and unloaded were clean.

Mr. Carter transported pipes between pipe yards and drill rigs and spent approximately 12.5% of his day loading and unloading pipes at either location. At the pipe yard, Mr. Carter was exposed to the inhalation and incidental ingestion of scale in addition to the direct gamma from

[134] *A Preliminary Risk Assessment of Management and Disposal Options for Oil Field Wastes and Piping Contaminated with NORM in the State of Louisiana*, RAE-9232/1-1, Rev.1, Prepared by Rogers and Associates and S. Cohen and Associates Inc.

the scale on the ground and on the pipes he was handling. At the drill rig, Mr. Carter was exposed to the incidental ingestion of sludge.

Mr. Carter received a gamma dose from the scale that was present on the ground at pipeyards, from open ends of pipes while driving, from contaminated pipes while loading and unloading his truck and from sludge on his clothing at the drill rig. In calculating the dose while driving, we took into account shielding from the cab of the truck. Mr. Carter stated that while a crane took pipes off the truck, two additional workers, at each end of the pipe, were needed to steady the pipe.

The dose calculations appear in the spreadsheet, Carter,John_calcs.xml. We added the direct gamma radiation doses to bone marrow and to the colon, with radiation doses to these organs due to inhalation and ingestion using ICRP dose conversion factors, to calculate the total radiation dose to these organs.

The higher radiation doses were multiplied by a factor of ten, following the CERRIE report. According to the Committee Examining Radiation Risks of Internal Emitters (CERRIE)[135], 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 [136]. Japanese atomic bomb survivors were exposed primarily to an instant of external gamma radiation and neutron, and many committees 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.

Mr. Carter's total minimum committed radiation dose to red bone marrow was calculated to be 11.61 rems while the total maximum radiation dose is calculated as 160.23 rems. Employing IREP, we determined that the likelihood that his multiple myeloma was caused by his occupational radioactive exposures was 60.12 %. His total minimum committed radiation dose to the colon was calculated to be 7.98 rems while the total maximum radiation dose is calculated as 44.95 rems. Using IREP, we determined that the likelihood that his colon cancer was caused by his radioactive exposures was 0.30.59 %. The probability of causation due to occupational radiation exposure for all primary cancers combined is 72.32%.

Finally, we compared his calculated total effective dose equivalent to the allowable dose to the general public according to the nuclear regulatory agency at the time, the Atomic Energy Commission. His total calculated dose equivalent for the six-year period ranged between 17.48 and 386.35 rems, or an average yearly dose equivalent of 2.9 rems to 64.4 rems compared to the allowable public dose of 0.5 rems a year. That is, Mr. Carter's radiation dose equivalent exceeded the allowable radiation dose to the public.

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[135] Committee Examining Radiation Risks of Internal Emitters (CERRIE), 2004. *Report of the Committee Examining Radiation Risks of Internal Emitters,* Crown Copyright, Great Britain (October 2004).

[136] Preston, DL, Y Shimizu, DA Pierce, A Suyama, and K Mabuchi, *Studies of Mortality of Atomic Bomb Survivors. Report 13: Solid Cancer and Noncancer Disease Mortality: 1950-1997.* Radiation Research, 160: 381-407.

Appendix A: Survey of Gravimetric Dust Concentrations in Industry.

Table A. Summary Statistics for Air Concentrations by Gravimetric Determination by Standard Industrial Code (SIC).

1 SIC	2 Type of Industry	3 Average Flow Rate (LPM)	4 Number Of Samples with Detected Dust	5 Total Number of Samples	6 Average Concentration in Samples with Detected Dust (mg/m^3)	7 Estimated Average Concentration (mg/m^3)	8 Sample Standard Deviation, S (mg/m^3)
1389	OIL AND GAS FIELD SERVICES, NOT ELSEWHERE CLASSIFIE	1.7	7	7	224.4	224.4	576.3
1522	GENERAL CONTRACTORS-RESIDENTIAL BUILDINGS, OTHER TH	1.8	86	87	9.5	9.4	20.3
1542	GENERAL CONTRACTORS-NONRESIDENTIAL BUILDINGS, OTHER	1.7	294	305	10.7	10.4	43.8
1629	HEAVY CONSTRUCTION, NOT ELSEWHERE CLASSIFIED	1.7	159	162	11.2	11	94.1
1721	PAINTING AND PAPER HANGING	1.8	224	229	144.9	141.7	402.1
1741	MASONRY, STONE SETTING, AND OTHER STONE WORK	1.7	1200	1225	16.4	16.1	70.9
1742	PLASTERING, DRYWALL, ACOUSTICAL, AND INSULATION WOR	1.8	100	103	23.1	22.5	58.6
1751	CARPENTRY WORK	1.8	19	19	11.4	11.4	18.6
1761	ROOFING, SIDING, AND	1.8	85	87	12.1	11.8	31.2

1 SIC	2 Type of Industry	3 Average Flow Rate (LPM)	4 Number Of Samples with Detected Dust	5 Total Number of Samples	6 Average Concentration in Samples with Detected Dust (mg/m^3)	7 Estimated Average Concentration (mg/m^3)	8 Sample Standard Deviation, S (mg/m^3)
	SHEET METAL WORK						
1791	STRUCTURAL STEEL ERECTION	1.8	47	48	7.4	7.3	19.8
1796	INSTALLATION OR ERECTION OF BUILDING EQUIPMENT, NOT	1.8	11	11	19.8	19.8	38.5
1799	SPECIAL TRADE CONTRACTORS, NOT ELSEWHERE CLASSIFIED	1.7	601	631	46.1	44	193.1
3412	METAL SHIPPING BARRELS, DRUMS, KEGS, AND PAILS	1.9	11	11	7.2	7.2	16.2
3431	ENAMELED IRON AND METAL SANITARY WARE	1.8	50	50	26.7	26.7	109.6
3441	FABRICATED STRUCTURAL METAL	1.9	327	334	75.7	74.1	436.6
3443	FABRICATED PLATE WORK (BOILER SHOPS)	1.9	252	253	148.1	147.5	1573.2
3444	SHEET METALWORK	1.9	168	170	9.3	9.2	20.4
3448	PREFABRICATED METAL BUILDINGS AND COMPONENTS	1.8	93	94	31.2	30.9	196.8
3449	MISCELLANEOUS STRUCTURAL METALWORK	1.8	58	59	85.4	83.9	354.6

1 SIC	2 Type of Industry	3 Average Flow Rate (LPM)	4 Number Of Samples with Detected Dust	5 Total Number of Samples	6 Average Concentration in Samples with Detected Dust (mg/m^3)	7 Estimated Average Concentration (mg/m^3)	8 Sample Standard Deviation, S (mg/m^3)
3463	NONFERROUS FORGINGS	1.9	18	19	10.3	9.8	37.9
3471	ELECTROPLATING, PLATING, POLISHING, ANODIZING, AND	1.8	309	330	25.4	23.8	106.6
3479	COATING, ENGRAVING, AND ALLIED SERVICES, NOT ELSEWH	1.9	297	304	37.7	36.8	201.2
3492	FLUID POWER VALVES AND HOSE FITTINGS	2	5	5	870.4	870.4	1123.5
3495	WIRE SPRINGS	2	14	14	18.6	18.6	65.8
3498	FABRICATED PIPE AND PIPE FITTINGS	1.8	84	85	12.2	12.1	55.1
3499	FABRICATED METAL PRODUCTS, NOT ELSEWHERE CLASSIFIED	1.9	497	513	11.9	11.6	77.4
3511	STEAM, GAS, AND HYDRAULIC TURBINES, AND TURBINE GEN	2	26	26	88.7	88.7	179.5
3531	CONSTRUCTION MACHINERY AND EQUIPMENT	1.8	88	89	25.6	25.3	133.4
3532	MINING MACHINERY AND EQUIPMENT, EXCEPT OIL AND GAS	1.9	19	19	17.5	17.5	21.3
3533	OIL AND GAS FIELD	1.9	25	25	21	21	83.5

1 SIC	2 Type of Industry	3 Average Flow Rate (LPM)	4 Number Of Samples with Detected Dust	5 Total Number of Samples	6 Average Concentration in Samples with Detected Dust (mg/m^3)	7 Estimated Average Concentration (mg/m^3)	8 Sample Standard Deviation, S (mg/m^3)
	MACHINERY AND EQUIPMENT						
3536	OVERHEAD TRAVELING CRANES, HOISTS, AND MONORAIL SYS	1.8	27	27	8.4	8.4	13.1
3537	INDUSTRIAL TRUCKS, TRACTORS, TRAILERS, AND STACKERS	1.9	36	36	54.1	54.1	166
3544	SPECIAL DIES AND TOOLS, DIE SETS, JIGS AND FIXTURES	1.8	39	39	89.5	89.5	288.9
3559	SPECIAL INDUSTRY MACHINERY, NOT ELSEWHERE CLASSIFIE	1.8	92	92	22.6	22.6	87.6
3569	GENERAL INDUSTRIAL MACHINERY AND EQUIPMENT, NOT ELS	1.9	42	45	12.1	11.3	35.2
3578	CALCULATING AND ACCOUNTING MACHINES, EXCEPT ELECTRO	1.9	10	10	26.4	26.4	25.5
3585	AIR-CONDITIONING AND WARM AIR HEATING EQUIPMENT AND	1.9	122	125	17	16.6	51.7
3586	MEASURING AND DISPENSING PUMPS	2	2	2	9.7	9.7	11.8

1 SIC	2 Type of Industry	3 Average Flow Rate (LPM)	4 Number Of Samples with Detected Dust	5 Total Number of Samples	6 Average Concentration in Samples with Detected Dust (mg/m^3)	7 Estimated Average Concentration (mg/m^3)	8 Sample Standard Deviation, S (mg/m^3)
3589	SERVICE INDUSTRY MACHINERY, NOT ELSEWHERE CLASSIFIE	2	23	24	100.7	96.5	222.3
3599	INDUSTRIAL AND COMMERCIAL MACHINERY AND EQUIPMENT,	1.8	257	262	34.5	33.9	205.8
3713	TRUCK AND BUS BODIES	1.9	173	173	36.8	36.8	351.6
3715	TRUCK TRAILERS	2	81	82	82.1	81.1	414.6
3716	MOTOR HOMES	2	15	15	7.7	7.7	10.6
3728	AIRCRAFT PARTS AND AUXILIARY EQUIPMENT, NOT ELSEWHE	1.8	62	64	6.6	6.4	39.9
3731	SHIP BUILDING AND REPAIRING	1.9	169	170	276	274.3	1445.6
3732	BOAT BUILDING AND REPAIRING	1.8	106	108	40.6	39.8	69.1
3743	RAILROAD EQUIPMENT	1.8	95	97	76.8	75.3	588.7
3792	TRAVEL TRAILERS AND CAMPERS	1.9	43	45	128.3	122.6	244.3
3799	TRANSPORTATION EQUIPMENT, NOT ELSEWHERE CLASSIFIED	1.9	33	33	16.6	16.6	46

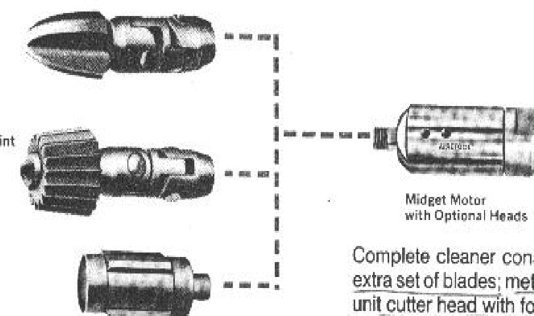
Appendix B. Rattlers used to clean pipes at pipeyards

Complete series of motors and heads available for tube sizes ½" to 1⅜" (12.7 to 34.9 mm) I.D.

Drill Head with Universal Joint
Range: ½ in. (12.7 mm)—1⅜ in. (34.9 mm)
Deposit: heavy-medium to soft

Type-1
Single Unit Head with Universal Joint
Range: ½ in. (12.7 mm)—1⅜ in. (34.9 mm)
Deposit: light-hard to medium

Type-8
Expanding Blade Cutter Head
Range: ½ in. (12.7 mm)—4½ in. (114.3 mm)
Deposit: light-hard to medium



Midget Motor
with Optional Heads

Complete cleaner consists of: air motor with extra set of blades; metal box; choice of single unit cutter head with four extra sets of cutters and two extra cutter pins. If "30" series head is ordered, one extra flexible connection is furnished. If expanding blade head is ordered, one extra set of blades is furnished. For operating hose (not included) refer to page HH-12.

Complete series of motors and heads available for tube sizes 1½" to 13¼" (38.1 to 336.5 mm) I.D.

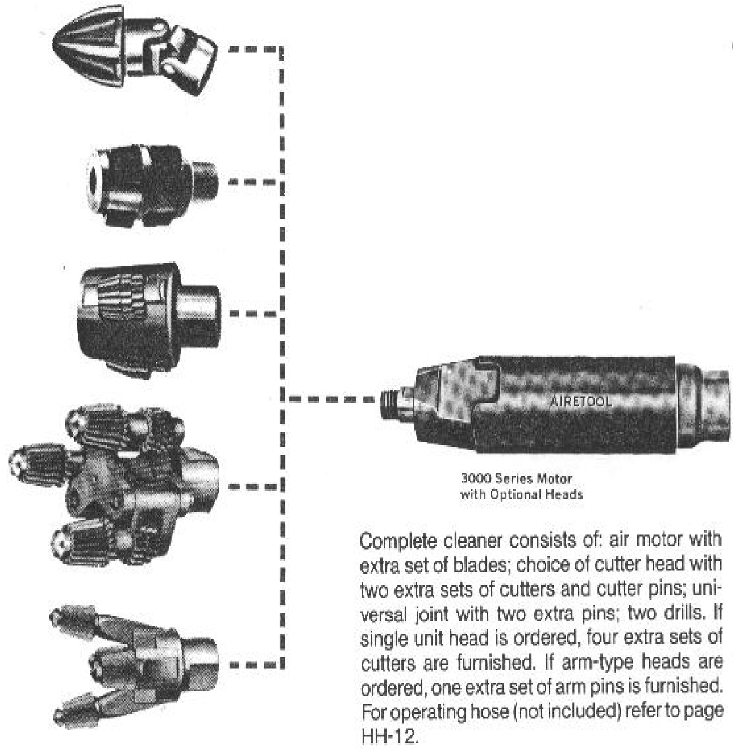
Drill Head with Universal Joint
Range: 1½ in. (38.1 mm)—12 in. (304.8 mm)
Deposit: ¾ in. (19.0 mm) thick-medium to hard and plugged tubes

Type-3
P-Type Head
Range: 2¼ in. (57.1 mm)—7 in. (177.8 mm). Self feeding
Deposit: ⅜ in. (9.5 mm) thick-hard to medium

Type-7
Double Expansion Head
Range: 3 in. (76.2 mm)—10 in. (254.0 mm). Self feeding
Deposit: ¾ in. (19.0 mm) thick-hard-medium

Type-5
Wing Arm Head
Range: 1¾ in. (44.4 mm)—13¼ in. (336.5 mm). Self feeding
Deposit: ½ in. (12.7 mm) thick-hard to medium

Type-4
Forward Swing Head
Range: 1¾ in. (44.4 mm)—4¾ in. (120.6 mm)
Deposit: ½ in. (12.7 mm) thick-soft to medium



3000 Series Motor
with Optional Heads

Complete cleaner consists of: air motor with extra set of blades; choice of cutter head with two extra sets of cutters and cutter pins; universal joint with two extra pins; two drills. If single unit head is ordered, four extra sets of cutters are furnished. If arm-type heads are ordered, one extra set of arm pins is furnished. For operating hose (not included) refer to page HH-12.

Appendix C. Dose Conversion Factors

Table 1. Inhalation dose conversion factors: dose equivalent, colon and bone marrow

Radionuclide	Dose Equiv[a] (Sv/Bq)	Colon DCF[a] (Sv/Bq)	Bone Marrow[b] DCF (Sv/Bq)
Ra-226	8.62E-10	4.73E-08	6.03E-07
Pb-214	7.84E-13	1.50E-10	3.00E-10
Bi-214	3.78E-12	1.30E-11	7.41E-12
Pb-210	2.40E-10	1.16E-07	3.16E-06
Bi-210	2.27E-11	2.50E-09	4.41E-11
Po-210	8.11E-10	5.59E-08	4.51E-07
Ra-228	7.03E-10	3.11E-07	4.70E-06
Ac-228	4.32E-12	4.70E-10	1.10E-09
Th-228	1.00E-08	1.90E-06	1.70E-06
Ra-224	7.84E-10	3.51E-08	5.89E-08
Pb-212	5.14E-12	5.19E-09	1.10E-08
Bi-212	8.11E-12	1.00E-10	2.10E-11

a. Adult w/45 yr commitment period, particle size 1 μm AMAD.

b. Adult w/26-yr commitment period, particle size 1 μm

Table 2. Ingestion dose conversion factors: dose equivalent, colon cancer and bone marrow

Radionuclide	Dose Equiv[a] (Sv/Bq)	Colon DCF[a] (Sv/Bq)	Bone Marrow[b] DCF (Sv/Bq)
Ra-226	7.27E-11	9.89E-08	8.51E-07
Pb-214	3.78E-14	1.50E-10	3.00E-11
Bi-214	2.97E-14	3.59E-11	2.60E-12
Pb-210	1.84E-10	9.03E-08	2.40E-06
Bi-210	3.51E-13	1.00E-08	2.00E-11
Po-210	6.49E-11	8.70E-08	5.19E-07
Ra-228	1.81E-10	1.90E-07	2.30E-06
Ac-228	1.16E-13	2.20E-09	1.50E-10
Th-228	9.46E-12	8.00E-08	2.00E-07
Ra-224	1.76E-11	1.40E-07	1.70E-07
Pb-212	1.59E-12	1.90E-08	6.59E-09
Bi-212	7.03E-14	4.30E-10	1.30E-11

a. Adult w/45 yr commitment period, particle size 1 µm

b. Adult w/26-yr commitment period, particle size 1 µm