Occupational Exposures to Benny Goirl, Pipeyard Worker

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Report Prepared by

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Stanley Waligora, CHP
Environmental Dimensions, Inc.
1901 Candelaria Road NW
Albuquerque, NM 87107

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Marvin Resnikoff, Ph.D.
RWMA
18 The Square, Suite 26
Bellows Falls, VT 05101

Benny Goirl

1. Introduction

Benny Goirl worked as a pipeyard worker for Brown & Root for a span of five years, in 1971 and again from 1979 to 1982. He spent half of his time as a crane operator, moving pipes around the pipeyard from one area to another and the other half of his time as a pipe cleaner, operating and loading the pipe cleaning machines, and was exposed, without his knowledge, to naturally occurring radioactive material (NORM) 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. He worked between 45 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. Goirl suffers two types of cancer, throat/larynx and prostate cancer. The radiation dose received by Mr. Goirl, more likely than not, caused his cancer.

After calculating Mr. Goirl's radiation dose to specific organs, such as the larynx and bladder, we employed NIOSH's Interactive RadioEpidemiological Program (IREP), version 5.7[1] to calculate the likelihood that the plaintiffs' cancers were caused by radiation, rather than by something else. This program was developed by NIOSH to apply the National Cancer Institute's (NCI) risk models directly to data about exposure for a specific employee. IREP is based upon radioepidemiological tables developed by the National Institutes of Health (NIH) in 1985 and more recently updated with Japanese atomic bomb survivor data. These tables act as a reference tool to provide the probability of causation estimates for individuals with cancer that were exposed to ionizing radiation. The purpose of this program is to calculate the probability of causation that occupational radiation exposure received while working at a DOE facility or elsewhere within the nuclear weapons industry caused a specific type of cancer[2].

IREP is primarily based upon risk coefficients for cancer incidence gathered from the Japanese atomic bomb survivor studies. The risk coefficients have been adjusted to account for random and systemic errors in the atomic bomb survivor dosimetry as well as for the low dose and low dose-rate situations that are more common to American workers exposed while on the job. The probability of causation, or assigned share, for this risk is calculated as "the cancer risk attributable to radiation exposure divided by the sum of the baseline cancer risk (the risk to the general public) plus the cancer risk attributable to the radiation exposure". That is this is the fraction of cancers observed in a large heterogeneous group with similar exposure histories that

[1] NIOSH and SENES Oak Ridge Inc., 2009
[2] *Ibid*.

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.

To prepare this report we reviewed, deposition transcripts, exhibits, previous work in similar cases, and medical records as well as several articles and reference documents. Interviews with Mr. Goirl were also conducted. We employed standard methodology used by health physicists to calculate Mr. Goirl's radiation dose. To calculate direct gamma dose rates in the pipe yard, we used the standard software, MicroShield Version 8.02[3], by Grove Software, Incorporated. MicroShield is a program used to estimate dose rates due to a specific external radiation source.

2. 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, 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[4]. 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, primarily barium sulfate, 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.

[3] Grove Software Incorporated, 2008
[4] Testimony of Milton Vercher in Grefer Case, p. 33.

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 was in contact with radium-contaminated water or brine which plated out on piles, scale. At the pipeyards, both tubing and casing were cleaned, but since the process to clean tubing and casing is very similar[5], we refer to both as simply "pipe". 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 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[6].

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[7], 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. Goirl recall a dense cloud of dust during pipe cleaning[8]. 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[9]. 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[10]. Former workers testified that some areas were covered with about 5 to 7 inches of scale[11].

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.

[5] Testimony of Milton Vercher in Grefer Case, p. 27.
[6] Testimony of Mike Bulot in Grefer Case, p. 26.
[7] Testimony of Mike Bulot in Grefer Case, p. 16.
[8] Telephone conversation with Mike Bulot; corroborated by Milton Vercher, Ricky Benoit and James Armand (all telephone conversations)
[9] Testimony of Mike Bulot in Grefer Case, p. 19.
[10] Testimony of Mike Bulot in Grefer Case, p. 41.
[11] Vercher Deposition, Civil District Court, Parish of Orleans, State of Louisiana, No. 95-15159 (26 January 1996).

Workers and Mr. Goirl stated that they usually came home covered with scale from head to toe[12]. 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[13]. In one incident, a worker's neighbor complained about her line-drying laundry being dirty[14] from the dust that the worker brought home on his vehicle and his clothes[15]. 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[16,17], discussed later in the report.

During his April 1987 visit, Lindsay Booher Exxon's Industrial Hygienist, noted that levels of "nuisance dust" were exceeded at the ITCO yard. This means that the workers' health were endangered in two separate ways by the very high dust concentrations they were exposed to at work: the sheer amount of it, and the radionuclides within this dust. A report by Lindsay Booher[18] 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.

The correlation between exposure to respirable particulates and increased morbidity and mortality is well documented. In the following, we present the findings of some key studies.

Health effects for which statistically significant associations with exposure to PM_{10} were found include overall mortality, mortality due to cardiopulmonary and cardiovascular diseases and lung cancer, and morbidity due to chronic obstructive pulmonary disease (COPD), bronchitis, asthma, dyspnea, breathlessness, cough, production of phlegm and pneumonia.

Epidemiological work conducted over several decades has suggested that long-term residence in cities with elevated ambient levels of air pollution from combustion sources is associated with

[12] Testimony of Mike Bulot in Grefer Case, p. 19.
[13] Interview with Robert V. Torry and David C. Torry Jr. by Stan Waligora on October 16, 2001.
[14] Interview with Floyd Thomassie Sr. by Stan Waligora on October 16, 2001.
[15] Interview with Charles Narcisse Jr. by Stan Waligora, October 2001.
[16] ITCOEX 925
[17] 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).
[18] 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).

increased mortality. Subsequently, two prospective cohort studies, the Six Cities Study[19] and the American Cancer Society (ACS) Study[20] estimated that annual average all-cause mortality, increased in association with an increase in $PM_{2.5}$ (all particles less than 2.5 μm in median aerodynamic diameter). The findings of these studies were recently confirmed in a large-scale reanalysis[21].

As part of the Six Cities Study, Dockery and colleagues had prospectively followed a cohort of 8,111 adult subjects in Northeastern and Midwestern United States for 14 to 16 years beginning in the mid-1970s. The authors found that higher ambient levels of fine particles ($PM_{2.5}$) were associated with a 26% increase in mortality from all causes, when comparing the most polluted to the least polluted city, which had a difference in $PM_{2.5}$ concentration of 18.6 $\mu g/m^3$ and a PM_{10} concentration of 28.3 $\mu g/m^3$. This approximately translates to a 9% increase in mortality for an increase in $PM_{2.5}$ of 10 $\mu g/m^3$. The same increase in fine particles was associated with a 13% increase in mortality from cardiopulmonary disease.

In the much larger ACS Study, Pope and colleagues followed 552,138 adult subjects in 154 US cities beginning in 1982 and ending in 1989. It was again found that higher ambient levels of fine particles were associated with increased mortality from all causes and from cardiopulmonary disease in the 50 cities for which fine particle data were available (sampled from 1979 to 1983). In a recent follow-up of the same cohort study[22], the authors calculated an increased risk for all-cause, cardiopulmonary and lung cancer mortality of 4%, 6% and 8%, respectively, for each increase in fine particulate air pollution of 10 $\mu g/m^3$ after adjusting for a range of other risk factors, including smoking.

An extensive study about mortality and morbidity in the United States researched the association between PM_{10} and hospital admissions due to specific illnesses in 14 U.S. Cities[23]. The authors calculated an average increase in hospital admissions of 1%, 2% and 2% for cardiovascular diseases (CVD), pneumonia and chronic obstructive pulmonary disease (COPD), respectively. Another study did not measure COPD as a diagnosed disease, but did find impaired lung function among workers who are exposed to high levels of dust. Prevalence rates of airway obstruction, (defined as the percent of the ratio of the forced expiratory volume/s (FEV_1) and the forced vital capacity (FVC) below the expected ratio based on age), were higher among workers exposed to both mineral and organic dust[24].

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[19] Dockery DW, *et al*, *An Association Between Air Pollution and Mortality in Six U.S. Cities*, New England Journal of Medicine, 329:1753-9 (1993).
[20] Pope CA, *et al*, *Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults*, Journal of the American Medical Association, 151:669-74 (1995).
[21] Krewski D, et al, *Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality,* Health Effects Institute (HEI) (July, 2000).
[22] Pope CA, et al.
[23] Samet JM, *et al*, *The National Morbidity, Mortality, and Air Pollution Study. Part II: Morbidity and Mortality from Air Pollution in the United States*, Health Effects Institute (HEI), Research Report 94 (II) (June 2000).
[24] Kennedy SM and PA Demers*, Occupational Airways Disease from Chronic Low Level Exposure to Mineral Dusts, Organic Dusts, and Mixed Exposures*: Occupational Chronic Obstructive Pulmonary Disease, Seminars Respiratory Critical Care Medicine, 20(6):541-9 (1999).

Another short-term study shows a significant correlation between PM_{10} and the onset of myocardial infarction (heart attack)[25]. An increase in 24-h-PM_{10} was associated with an increased onset of myocardial infarction of 22%.

A cross-sectional study of schoolchildren living in ten different communities in Switzerland found statistically significant correlations between long-term exposure to PM_{10} and symptom rates of chronic cough, nocturnal dry cough and bronchitis[26]. The correlation was strongest for children who had asthmatic or cough symptoms. A similar study involving adults[27] calculated statistically significant correlations between an increase of the annual mean concentration of PM_{10} of 10 $\mu g/m^3$, and the prevalence of chronic cough or phlegm production (ERR 0.27, 95% CI: 0.11-0.65), breathlessness (ERR 32.8, 95% CI: 0.14-0.55) and dyspnea on exertion (ERR 0.32, 95% CI: 0.18-0.46). These correlations were controlled for smoking.

In a study to assess the impact of particulate air pollution on health effects and resulting health costs in Switzerland, the authors calculated the causal correlation between PM_{10} and a series of health outcome variables, using available epidemiological data[28]. An increase in ambient PM_{10} concentration of 10 $\mu g/m^3$ was associated with a statistically significant increase of 4.4% in total mortality; 25% in total bronchitis prevalence in adults; 12.8% cough/phlegm in adults; 1.47% in hospital admissions for respiratory diseases; 0.9 % in admissions for cardiovascular diseases; and 5.3% in days with asthma attacks among asthmatics. According to the authors, conservative assumptions were used throughout this study, and therefore the true effects were likely to be even larger.

A study undertaken among residents in and around Anchorage examined the correlation between PM_{10} concentrations and the number of daily outpatient visits for respiratory disease including asthma, bronchitis and upper respiratory illness[29]. The latter category included sinusitis and rhinitis, two diseases that exist among the former ITCO workers. An increase of 10 $\mu g/m^3$ was associated with an increase in hospital visits due to upper respiratory illness of 1.2%.

All these epidemiological studies directly apply to the work situation at the pipeyards regarding the general connection between inhalation of particulates and adverse health effects. The major difference is that in epidemiological studies, the subjects are usually exposed to much lower particulate concentrations than pipeyard workers. Under "normal" circumstances, it is very rare that someone is exposed to particulate concentrations of more than 0.1 mg/m^3. In contrast, we apply a scale dust concentration of 10-30 mg/m^3 near the pipe cleaning machines, and of 1.6-3.6 mg/m^3 in other parts of the pipe yards. That is, we reduce the dust concentration by a factor of 10 away from the pipecleaning machines, and factor in 0.6 mg/m^3 due to resuspension of scale that had been deposited on the ground of the pipeyard. Mr. Goirl reported a very dusty environment and that his work environment was constantly dusty and covered in scale material.

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[25] Peters A, Dockery DW, Muller JE, *et al*, *Increased Particulate Air Pollution and the Triggering of Myocardial Infarction*, Circulation, 103:2810-15 (2001).
[26] Braun-Fahrlaender C, *et al*, *Respiratory Health and Long-term Exposure to Air Pollutants in Swiss Schoolchildren*, American Journal of Respiratory Care Medicine, 155:1042-49(1997).
[27] Zemp E, Elsässer S, Schindler C, et al, *Long-Term Ambient Air Pollution and Respiratory Symptoms in Adults (SAPALDIA Study*), American Journal of Respiratory Care Medicine, 159:1257-66 (1999).
[28] Kuenzli N, et al, *Air Pollution in Switzerland-Quantification of Health Effects Using Epidemiologic Data*, Schweizerische Medizinische Wochenschrift (Swiss Medical Weekly), 127(34):1361-70 (23 August 1997).
[29] Gordian ME, Ozkaynak H, Xue Jianping, *et al*, *Particulate Air Pollution and Respiratory Disease in Anchorage, Alaska*, Environmental Health Perspectives, 104:290-7 (1996).

3. 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)[30]. 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 is relatively insoluble, and that the particles have a particle size distribution of 1 μm AMAD. Dose conversion factors for inhalation are presented in App. A.

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 ITCO 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[31], and 53 mg/m^3 at another pipe yard[32]. Both measurements were taken while pipe was being cleaned, but

[30] 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.
[31] ITCOEX 925
[32] 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).

presumably at different distances from the cleaning machine (the exact locations of the measurements were not given).

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.

Based on testimony of former ITCO workers, the visible dust cloud emanating from the pipe cleaning machine reached at least 50 yards downwind[33].

For locations away from the pipe cleaning machine, but still within the pipe yard, we apply a concentration range directly due to pipe cleaning operations that is ten times smaller, i.e. of 1 – 3 mg/m^3. To this, we add re-suspension of scale particulates in the yard due to activities that mechanically and non-mechanically disrupted scale. Such activities include movement of trucks and forklifts, road building, rack building, shoveling scale from ground into potholes, workers walking, as well as wind activity. We estimate that particulate concentration due to re-suspension is the same as particulate concentration at a construction site[34], 0.6 mg/m^3. The air particulate concentration in the pipe yard away from the pipe cleaning machine therefore ranges from 1.6 to 3.6 mg/m^3. A detailed discussion of our calculations and estimates of the concentration range of respirable particulates is presented in App. A.

To calculate the radioactivity (A) in the dust, we use 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[35], Chevron[36] [37] and Reed[38] (for details, see App. A).

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[39] 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:

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

[34] United States Department of Energy, *Pathway Analysis and Radiation Dose Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites*, Oak Ridge National Laboratory. DOE ORO-832 (1983).

[35] 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).

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

[37] PGREF 101884

[38] 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).

[39] 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).

$Dose_{inh}$ (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:

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

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)
DCFing. 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 = 240 mg/d as a lower bound and IR = 480 mg/d as the upper bound. The upper bound is the incidental soil ingestion rate for outdoor yard work as given by EPA[40]. 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

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

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.

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)

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. Goirl spent 50-percent of his time moving pipes within the pipe cleaning area and 50% of his time at the pipeyard performing machine operated cleaning. Mr. Goirl stated that the crane used to move pipes was not enclosed and that he was subject to dust and scale in the air whether he was in the crane or cleaning pipes.

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 scale thickness of 0.2 cm, and a pipe wall thickness of 0.551 cm, as suggested by the US EPA[41]. 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. For Mr. Goirl's prostate exposure to a horizontal pipe rack while cleaning, we calculate a contact dose rate of 2.5518mrem/h and for Mr. Goirl's larynx exposure to a horizontal pipe rack while cleaning we calculate a contact dose rate of 2.3902 mrem/hr.

4. Radiation Dose Rate to Mr. Goirl

Mr.Goirl worked as a pipeyard worker for Brown & Root in 1971 and again from 1979 to 1982. He spent half of his time as a crane lift operator, moving pipes around the pipeyard from one area to another and the other half of his time as a pipe cleaner. It can be assumed that Mr. Goirl was exposed to contaminated pipes 50% of the time.

Mr. Goirl received a gamma dose from the scale that was present on the ground at pipeyards, and from scale located in the pipes while cleaning. Mr. Goirl was exposed to alpha radiation from inhalation of scale particles and incidental ingestion of scale particles in the pipeyard.

The dose calculations for Mr. Goirl's prostate cancer appear in the spreadsheet, Goirl B_calcs(prostate).xml. The dose calculations for Mr. Goirl's throat cancer appear in the spreadsheet, Goirl B_calcs(throat). Given the radiation doses to the layrnx and to the prostate, we used dose conversion factors to calculate the 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)[42], 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 [43]. 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.

His total minimum committed radiation dose to the larynx was calculated to be 72.6 rems while the total maximum radiation dose is calculated as 287.3 rems. Employing IREP, we determined that the likelihood that his throat cancer was caused by his occupational radioactive exposures was 93.9%. His total minimum committed radiation dose to the prostate was calculated to be 25.9 rems while the total maximum radiation dose is calculated as 105.0 rems. Using IREP, we determined that the likelihood that his prostate cancer was caused by his radioactive exposures was 40.84%. The dose commitment period for throat cancer is 28 years and less, since Mr. Goirl contracted throat cancer 28 years after he began working for Brown & Root. His prostate cancer was diagnosed later, 41 years after he started working for Brown & Root.Since these two cancers

[41] US EPA, 1993b
[42] CERRIE, 2004
[43] Preston, DL, et al., 2003

are independent, the likelihood that both cancers were caused by radiation is 96.4%, indicating that more likely than not his two cancers were caused by radiation.

Tables

Table 1. Inhalation dose conversion factors:, throat and prostate

Radionuclide	Throat DCF[a] (mr/pCi)	Prostate DCF[b] (mr/pCi)
Ra-226	2.48E-02	1.03E-04
Pb-214	1.04E-04	4.81E-07
Bi-214	8.14E-04	2.44E-08
Pb-210	4.07E-04	4.07E-04
Bi-210	4.81E-04	1.63E-07
Po-210	1.44E-02	1.74E-04
Ra-228	1.89E-02	1.81E-03
Ac-228	1.67E-04	5.55E-07
Th-228	4.07E-01	7.03E-04
Ra-224	4.44E-03	1.30E-05
Pb-212	4.07E-05	1.22E-05
Bi-212	9.25E-04	7.03E-08

a. Adult w/ 28 yr commitment period, particle size 1 µm

b. Adult w/41-yr commitment period, particle size 1 µm

Table 2. Ingestion dose conversion factors: throat and prostate

Radionuclide	Throat DCF[a] (mr/pCi)	Prostate DCF[b] (mr/pCi)
Ra-226	1.43E-04	1.47E-04
Pb-214	3.52E-08	4.07E-08
Bi-214	2.96E-09	3.70E-09
Pb-210	3.13E-04	3.17E-04
Bi-210	7.40E-08	7.4E-08
Po-210	2.04-04	2.04E-04
Ra-228	5.48E-04	7.40E-04
Ac-228	2.55E-09	9.99E-08
Th-228	1.15E-05	3.22E-05
Ra-224	4.07E-05	3.70E-05
Pb-212	7.77E-06	7.77E-06
Bi-212	2.59E-08	3.00E-08

a. Adult w/ 28 yr commitment period, particle size 1 µm

b. Adult w/41-yr commitment period, particle size 1 µm

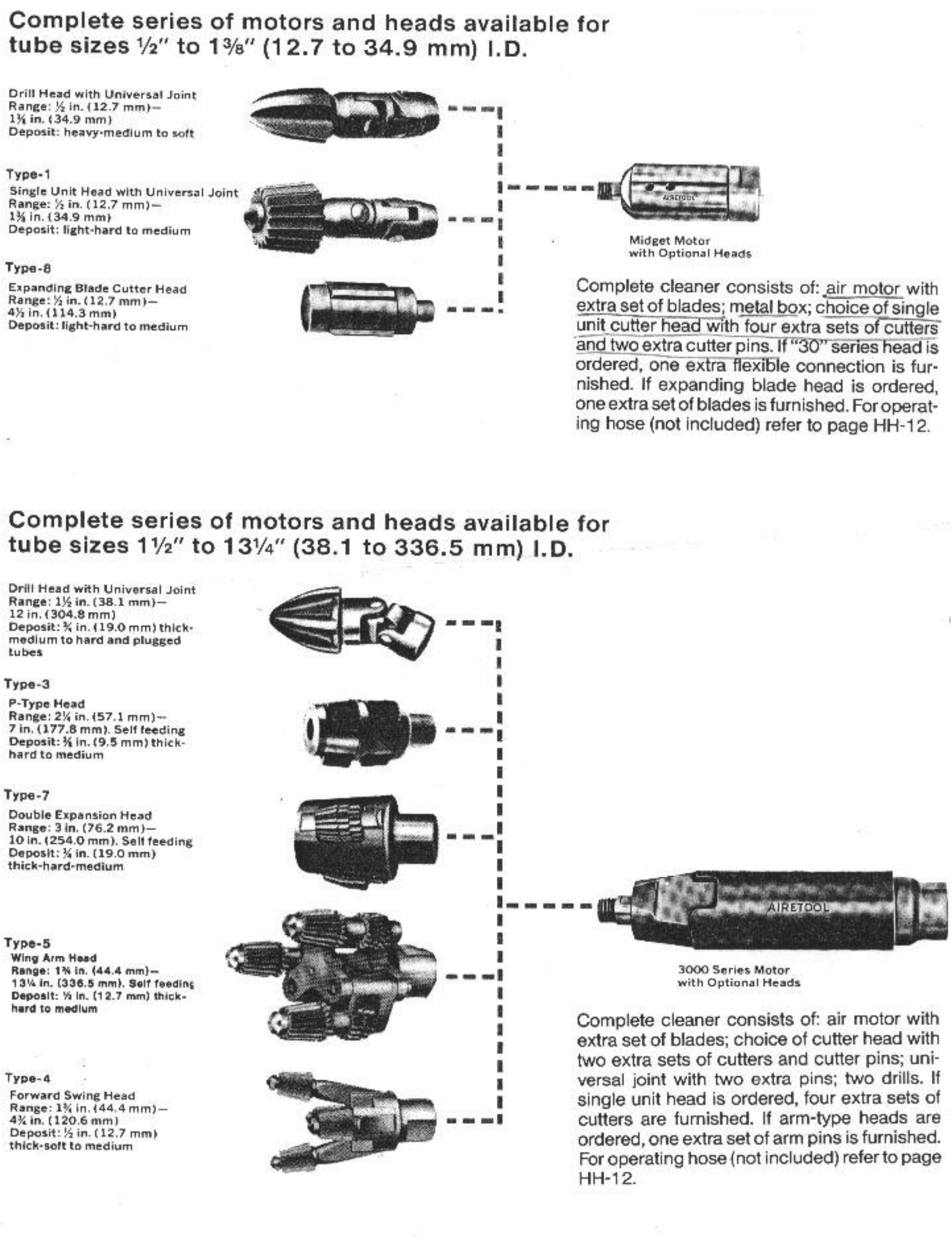

Figure 2. Air rattlers for straight tubes.

Appendix B. Rattlers used to clean pipes at pipeyards

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