Occupational Exposures to Radioactive Scale During Oil Pipe Cleaning Operations

Report

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1.0 Introduction

Radioactive Waste Management Associates has been retained by the Smith Stag law firm to evaluate the radiation and toxic exposures of the eleven pipe yard workers: Curtis Arwood, Dwayne Batiste, Darryl Boyer, Dolin Calvey, Horace Fennidy III, Cedric Guidry Sr., Cedric Guidry Jr., Jeffery Holmes, Clarence Richard, Troy Richard, and James Richardson.

The aforementioned pipe yard workers worked in pipe yards for Intracoastal Tubular Services Company (ITCO) Brown & Root and others in Louisiana. The pipe yard workers were exposed, without their knowledge, to technologically enhanced naturally occurring radioactive material (TENORM) in the course of oil field pipe de-scaling operation at the pipe yards. Workers at ITCO and Brown & Root pipe yards were exposed to radiation through inhalation of the scale dust and radon gas, incidental ingestion of radioactive dust, and to external radiation from the scale in the pipe and from the scale deposited on the ground.

There were no radiation protection programs at the ITCO and Brown & Root pipe yards. Therefore, no measurements were made at the time the work was performed, so the true radiation doses received by these workers will never be known. In this report, 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). The radiation doses received by the workers greatly increased their risk of developing cancer.

To prepare this report we reviewed court petitions, exhibits, deposition transcripts, previous work in similar cases, and medical records. Interviews with the plaintiffs or the plaintiffs' family members were also consulted as well as several articles and reference documents. We performed spreadsheet calculations, which are summarized in the tables at the end of the text. As more information becomes available, we reserve the right to supplement this report.[1]

2.0 Pipe Yard Operations

2.1 Intracoastal Tubular Services Company

Intracoastal Tubular Services Company (ITCO) 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. Trucks, each carrying about 150 to 200 joints, would then transport the used oilfield pipe to ITCO's pipe yards at various locations. Pipe was also trucked in directly from production sites in Louisiana and neighboring states, and from an additional pipe yard in Alabama.

The pipe was stacked in up to eight layers on racks, which were several feet high[2]. 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 TENORM-containing salts 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. The quantity of radioactive material in the deposits is small from a mass standpoint. Only one billionth of a gram of Ra-226

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[1] Stanley Waligora, CHP, has reviewed this report.
[2] Testimony of Milton Vercher in Grefer Case, p. 33

is equivalent to 1,000 pCi/g. The radioactive material within the pipe scale cannot be distinguished from the salts and other deposits.

ITCO 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)[3], and other pipe yards in Amelia, LA (near Morgan City, LA), Houston, TX and Flomaton, AL. 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 brine and therefore both were contaminated with scale. At ITCO, both tubing and casing was cleaned, but since the process to clean tubing and casing is very similar[4], 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 th at 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 and dust coming out of the inside of the pipe. Depending on the degree of contamination, the cleaning process removed about 0.5 – 2 lbs of scale from the inside of 30-foot pipe joints[5].

At least one stationary pipe cleaning machine and several mobile cleaning units were employed in the itco yard. 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 Fig. 2.

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 was 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 mounted on a fixed thin air pressure pipe, whereas 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[6], 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[7]. 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[8]. The larger scale fragments accumulated on the ground near the cleaning machine and had to be removed twice per week.

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[3] IT1988.
[4] Testimony of Milton Vercher in Grefer Case, p. 27
[5] Testimony of Mike Bulot in Grefer Case, p. 26
[6] Testimony of Mike Bulot in Grefer Case, p. 16
[7] Telephone conversation with Mike Bulot; corroborated by Milton Vercher, Ricky Benoit and James Armand (all telephone conversations)
[8] Testimony of Mike Bulot in Grefer Case, p. 19

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[9]. Former workers testified that some areas were covered with about 5 to 7 inches of scale[10].

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. As long as pipe was not cleaned, every heavy impact would release a certain amount of 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. Yard laborers were in charge of moving and storing pipe. Many workers performed several different jobs in the yard, either consecutively over the years, or simultaneously in the same year. The yard workers ate their lunch sitting in the scale under the pipe racks to get some shade, often without washing their hands and faces.

The workers stated that they usually came home covered with scale from head to toe[11]. 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[12]. In one incident, a worker's neighbor complained about her line-drying laundry being dirty[13] from the dust that the worker brought home on his vehicle and his clothes[14].. Workers recall coughing up visible dust and sneezing or blowing dust from their noses several hours after work.

2.2 Brown & Root

Similar to ITCO, Brown & Root Company owned and operated the yard where pipes used in the oil production industry were cleaned and inspected. Originally purchased in the mid-1950s, the Brown & Root pipe yard is located on Engineers Road in Belle Chase, Louisiana. The yard encompasses approximately 260 acres of land and is bounded by the Intracoastal Canal to the east and the Outfall Canal to the west. Pipe cleaning and inspection operations at the Brown & Root pipeyard ceased in 1991.[15]

The Brown & Root yard is divided into 6 individual working zones. Zone 5, a 78-acre, triangular shaped piece of land, is where pipe cleaning and pipe storage activities took place. Brown & Root maintained their own pipe cleaning and storage activities in this area of the yard until 1988 when Brown & Root began leasing Zone 5 to Packard Pipe Terminals, Incorporated. In addition, Brown & Root also leased a pipe threading shop and a pipe testing shop along the southern boundary of Zone 5.[16]

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[9] Testimony of Mike Bulot in Grefer Case, p. 41
[10] Deposition of Milton Vercher, 1996
[11] Testimony of Mike Bulot in Grefer Case, p. 19.
[12] Interview with Robert V. Torry and David C. Torry Jr. by Stan Waligora on October 16, 2001.
[13] Interview with Floyd Thomassie Sr. by Stan Waligora on October 16, 2001.
[14] Interview with Charles Narcisse Jr. by Stan Waligora, October 2001.
[15] Halliburton NUS Environmental Company, 1992
[16] *Ibid*

Many of the workers who worked at the ITCO pipe yards also cleaned and inspected used oil field pipe at the Brown & Root pipe yard on Engineer's Road. Generally, ITCO had 5 to 10 employees working at the Brown & Root pipe yard each day, as well as several other ITCO contract workers.[17]

Workers described the pipe cleaning activities and general environment of the Brown & Root yard as the same as the ITCO pipe yards[18]. The ground of the Brown & Root pipe yard consisted of dirt and broken shells and the yard contained both stationary and mobile cleaning machines. Rattlers and wire brushes were used to clean used, TENORM contaminated pipes at the Brown & Root yard[19]. Conditions at the pipe yard were very dusty, and workers would often go home covered in dust after cleaning pipe and/or performing general labor in the Brown & Root pipe yard[20]. Racks of contaminated pipes lined the entire outside perimeter of the Brown & Root yard[21]. Brown & Root did not provide personal protection equipment for its workers[22].

In October 1990, a Phase I survey was performed over the Brown & Root facility on Engineers Road. 19 areas of potential concert where identified during the survey, 4 of which were contained within Zone 5 where used oil field pipe was cleaned, inspected, and stored. Due to the elevated readings, further investigation of this area was conducted. It was found that surface soils in the area ranged from 10 to 700 μR/hr. The Louisiana Department of Environmental Quality requires that any facility with radiation levels exceeding 50 μR/hr at any accessible point obtain a General License with the LDEQ Radiation Protection Division.[23]

In 1991, Packard Pipe obtained a general license for TENORM from the LDEQ Radiation Protection Division for Zone 5 of the Brown & Root yard. On December 10, 2001, a Phase II TENORM soil assessment was conducted at Zone 5 of the Brown & Root yard. It was found that TENORM-impacted soils ranged from 0.5 to 1 foot below the ground surface. It was estimated that approximately 4,681 barrels of TENORM-contaminated soil would need to be excavated in order to remediate the yard to acceptable LDEQ standards.[24]

Remedial actions began at the Brown & Root yard on April 15, 2002 and were completed by April 23, 2002. Soils were excavated to twice the background radiation levels in the area and a total of 1,170 barrels of TENORM-contaminated soil and 3,690 barrels of nonhazardous oilfield wastes (NOW) contaminated soils were excavated from the site. Excavated soils were disposed of at Newpark facilities. On July 17, 2002, TENORM levels at the Brown & Root yard were measured to be less than twice background levels, as required by LDEQ, and on August 19, 2002, LDEQ granted Brown & Root release from the TENORM general license requirement.[25]

It is unclear to us why Halliburton did not inform Brown & Root of the presence of TENORM in the process equipment before March 1987. Drilling companies had reported radioactivity in oil and brine as early as the 1930's, the USGS reported radioactivity in Kansas oil fields[26] in the 1950's and the American Petroleum Institute (API) issued a report in 1982 that analyzed the potential impact of the inclusion of radionuclides into the CERCLA process on the petroleum industry. The

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[17] Deposition of Curtis Arwood, 14 October 2009
[18] *Ibid*
[19] Deposition of Horace Fennidy, III, 1 October 2009
[20] Deposition of Darryl Boyer, 2 October 2009
[21] Deposition of Darrell Calvey, 16 October 2009
[22] Deposition of Curtis Arwood, 14 October 2009
[23] Halliburton NUS Environmental Company, 1992
[24] Tetra Tech EM Inc., 2002
[25] *Ibid*
[26] United States Geological Survey (USGS), 1953

report described in detail where specific radionuclides were prevalent: Uranium in crude oil, radium in brine, and radon in both oil and brine[27]. The report concluded, “the regulation of radionuclides could impose a severe burden on API member companies”.

3.0 Radiation Pathways

The pipe yard workers were occupationally exposed to radiation while working at the ITCO, Brown & Root, and additional Louisiana pipe cleaning yards. For the time workers spent working in these yards, they were primarily exposed to radiation via inhalation of radioactive particulates, inhalation of radon and thoron, ingestion of radioactive particulates, and direct gamma radiation.

We calculate the radiation dose rate due to inhalation and ingestion of radioactive particulates by first calculating the amount of radioactivity that a person inhaled or ingested per unit time, and then by employing standard dose conversion factors (DCFs) recommended by the International Commission on Radiological Protection (ICRP). These DCFs convert an amount of a specific inhaled or ingested radionuclide into the resulting inhalation or ingestion dose. DCFs derived from ICRP 30 for the inhalation and ingestion of radioactive materials for a member of the public are summarized and presented in the Federal Guidance Report No. 11 (FGR 11)[28]. The DCFs from FGR 11 are used to calculate the total effective radiation doses received by the pipe yard workers to determine whether their occupational radiation exposures exceeded the legal limit to nuclear workers, even though the pipe yard workers were not nuclear workers. Alternatively, age-dependent DCFs from ICRP 72[29] (specific for members of the public) were also used to calculate doses from the inhalation and ingestion of radioactive materials. These age-dependent DCFs have been compiled into a database and put on the CD-ROM, ICRPDOSE2[30]. For this report, the appropriate DCFs were extracted from the database and used in our dose calculations.

In addition to being age-dependent, ICRP 72 DCFs are specific to effected organ and/or tissue types (i.e., if a worker was diagnosed with bladder cancer, ICRP 72 DCFs specific to the bladder were used). We do not use ICRP 72 DCFs specific for the skin to calculate the radiation dose the pipe yard workers received to their skin, but employ methods used by Flood[31] and Pressyanov[32]. These methods are discussed in greater detail in section 4.6 of this report. We employ alternative methods for calculating radiation doses to the skin since ICRP 72 DCFs assume all alpha and beta radiation must be inhaled or ingested to cause a radiation dose, however, alpha and beta radiation are more hazardous to the skin via dermal exposure.

The ICRP 72 DCFs were scaled in one-year increments of the commitment period to which each of the pipe yard workers were exposed to radiation. A commitment period is the time period between when a person is diagnosed with cancer and the time he was first exposed to radioactive materials. For example, if a pipe yard worker began working in 1973 and he was diagnosed with cancer in 1987, in 1973 he had a commitment period of 15 years, in 1974 a commitment period of 14 years, in 1975 a commitment period of 13 years, and so on.

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[27] American Petroleum Institute, 1982
[28] US EPA, 1993a
[29] ICRP, 1996
[30] ICRP, 1998b
[31] Flood JR, 1988
[32] Pressyanov DS, 1991

The ICRP 30 and ICRP 72 DCFs used to calculate the inhalation and ingestion doses to the pipe yard workers in this report can be found in Appendix A.

We calculate external radiation doses to the pipe yard workers by employing DCFs derived from Federal Guidance Report No. 12 (FGR 12). FGR 12 provides both effective and organ specific DCFs for external radiation from contaminated surfaces of varying thicknesses. DCFs for surfaces contaminated to thicknesses of 1 cm, 5cm, 15 cm, and infinite depths are available.

3.1 Dose Rate from Inhalation of Radioactive Particulates

We calculate the radiation dose rate due to inhalation of radioactive particulates by first calculating the amount of radioactivity that a worker inhaled per unit time, and then employing standard dose conversion factors (DCF) recommended by the International Commission on Radiological Protection (ICRP)[33]. These DCFs convert an amount of a specific inhaled radionuclide into the resulting inhalation dose.

Different DCFs exist for different exposure assumptions. For our calculations, we assume that the respirable scale dust is relatively insoluble, and that the particles have a diameter of 1 μm. 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, times the radioactive concentration of the dust, times the ventilation rate (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 decay chains (mrem/pCi)

Because the ITCO and Brown & Root yards are 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[34], and 53 mg/m^3 at another pipe yard[35]. Both measurements were taken while pipe was being cleaned, but presumably at different distances from the cleaning machine. To the best of our knowledge, particulate air concentrations were never measured at the Brown & Root yard.

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[33] International Commission on Radiological Protection (ICRP), 2001.
[34] ITCOEX 925
[35] Radiation Technical Services of Baton Rouge, 1993

Because of these uncertainties, we use an air particulate concentration range, as opposed to a single value. We expect that this range includes the "true" average air particulate concentration to which the pipe cleaners were exposed. In the vicinity of the pipe cleaning process, we use a respirable dust concentration of C = 10 mg/m^3 as a lower bound and a concentration of C = 30 mg/m^3 as an upper bound. This range includes the air particulate measurement carried out at ITCO, but it is below the measurement obtained at another pipe yard of 53 mg/m^3.

Based on the testimony of former ITCO and Brown & Root workers, the visible dust cloud emanating from the pipe cleaning machine reached at least 50 yards downwind[36].

For locations away from the pipe cleaning machine, but still within the pipe yard, we use 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 resuspension of scale particulates in the yard due to activities that mechanically moved scale. Such activities include movement of trucks and forklifts, road building, rack building and shoveling scale from ground into potholes. Workers walking around, as well as wind activity, would further re-suspend particulates. We estimate that particulate concentration due to resuspension is the same as particulate concentration at a construction site[37], 0.6 mg/m^3. The air particulate concentration in the pipe yard away from the pipe cleaning machine therefore ranges from 1.6 - 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 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[38], Chevron[39, 40] and Reed[41] (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[42] of V = 1.5 m^3/h for the times the workers worked in the pipe yards. When performing less strenuous work, such as office work or work inside one of the pipe yards' auxillary buildings, we apply a reduced ventilation rate of 0.925 m^3/h[43].

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 Brown & Root and ITCO pipe yards and/or their families.

3.2 Inhalation of Radon and Thoron

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[36] Telephone conversations with M. Bulot and R. Benoit.
[37] United States Department of Energy (US DOE), 1983
[38] United States Environmental Protection Agency (US EPA), 1987
[39] NORM Study Team, Chevron USA, Inc., 1990
[40] Scott ML, 1986
[41] Reed G, Holland B, and A McArthur, 1991
[42] ICRP, 1994
[43] Yu, C, et al, 1993

The inhalation dose due to emanation of radon and thoron from the ground is calculated in detail in App. B. Radon and thoron, decay products of radium-226 and radium-224, respectively, emanate from scale deposited on the ground or present in oil pipe. These radioactive inert gases can be inhaled, and their short-lived decay products cause a radiation dose to the lungs and other sites. The calculation of the inhalation dose rate is similar to that of the inhalation dose rate for particulates:

$DR_{inh} = R * V * DCF_{inh}$

Where:

DR_{inh}	Inhalation dose rate (mrem/time)
R	Radon or Thoron concentration in air (pCi/m^3)
V	Ventilation rate (m^3/time)
DCF_{inh}	Dose conversion factor for inhalation for Rn-222 and Ra-220 and its α-emitting progeny (mrem/pCi)

The most important parameter in this calculation is the radon / thoron air concentration. As shown in detail in App. B, this concentration can be calculated with an emanation factor, two different formulas and site-specific physical and meteorological information. Our calculations are based on the RESRAD model developed by DOE contractors[44].

The emanation of radon and thoron from the soil depends both on the thickness of the scale, and on the activity of Ra-226 and Ra-228 in the scale. For the latter, we again take 6,000 and 2,000 pCi/g, respectively. For the thickness of the scale, we use a lower and an upper bound, which results in the calculation of a dose range. For the lower bound, we use a scale thickness layer of 1 cm, whereas for the upper bound, we use a thickness of 5 cm.

Using these two thicknesses, we first calculate a range of the radon and thoron fluxes, which in turn serve as an input to calculate the radon and thoron air concentration ranges. We obtain a radon flux of J_o (radon) = 47.3 – 236.2 pCi/m^2-s and a thoron flux of 47,377 – 133,213 pCi/m^2-s.

With an average wind speed of 3.6 m/s[45], the resulting radon and thoron air concentration ranges are 328.1 – 1,640 pCi/m^3 and 302,032 – 849,241 pCi/m^3, respectively.

The dose conversion factors for the radon and thoron progeny (Pb-212) were taken from UNSCEAR[46] and ICRP 72[47].

Radon, thoron and inhalation of particulates are important for determining the risk of cancer and the TEDE dose.

3.3 Dose Rate from Incidental Soil Ingestion

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

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[44] Tennery VJ, et al., 1978
[45] National Weather Service, 2001
[46] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1988
[47] ICRP, 1996

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 decay chains (mrem/pCi).

For incidental soil ingestion, we bound the likely ingestion rate and with a minimum and maximum ingestion rate and a central point. The upper bound is the incidental soil ingestion rate for outdoor yard work of 480 mg/d as given by EPA[48]. 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. The EPA also considers a soil ingestion rate of 20 mg/hr or 200 mg/d. For our calculations we use this as a median value. Finally, for a lower bound, we take the standard adult incidental dust ingestion rate, 50 mg/d[49]. We assume all the ingested material to be pipe scale.

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 the pipe yard workers, which was determined from interviews and the type of job(s) they 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.

3.4 Dose Rate from External Radiation

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

External radiation is directly incurred 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

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[48] US EPA, 1997, Table 4-15.
[49] US EPA, 1997, Table 4-16.

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 decay chains (mrem*g/h-pCi)

The resulting effective dose is calculated by multiplying the dose rate with the exposure time.

To calculate the external radiation dose that the pipe yard workers received directly from pipe (as opposed to scale deposited on the ground), we use pipe measurements from other yards, and make adjustments to reflect the average scale activity and pipe size in the ITCO yard. We arrive at a contact dose rate of 0.923 mrem/h for one joint (App. C).

As the pipe joints entered the cleaning machines, they were stored horizontally in rows, one next to the other. External radiation from a line source, such as a long pipe joint, decreases as an inverse function of distance[50]. In addition, the nearest joint partially shields the radiation from the joints further away. For the combined dose of 10 joints (the first next to a worker, and the other 9 horizontally behind at increasing distances), we arrive at a dose rate of 1.5 mrem/h (App. C). We further multiply this dose rate by 0.5, because only half of the stored or handled pipe was heavily contaminated with scale, whereas the other half had already been cleaned. The resulting dose rate is 0.75 mrem/h.

Workers informed us that in absence of a lunchroom at Brown & Root, they ate lunch on the ground under the pipe racks to shield themselves from the sun. Their heads would be very close to the radioactive pipe. This additional exposure is also not included in our calculations.

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 0.22 (the other 78 % of the volume is steel and air). This results in a dose rate of 2.50 mrem/h.

Because the driver is shielded from the load with about 3 mm of either steel or glass, this dose is reduced by 22 or 20 %, respectively. Because on average, every second pipe joint that was transported was clean, the dose is once more multiplied by 0.5. The resulting dose rate to truck drivers is 0.98-1.00 mrem/h.

We apply this dose rate for drivers only while they are actually driving, but not while loading and unloading, which is better represented by the line source calculation described above.

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[50] Cember H, 1996

4.0 Specific Dosimetry

The workers at the ITCO and Brown & Root pipe yards held several different positions while working at the yards. Many workers carried out similar jobs. To simplify our exposure assessment, we calculate a dose rate for five types of exposure situations, which combined describe the individual exposures for the workers included in this report. Based on a personal interview or plaintiff deposition, we then assign each worker the corresponding amount of exposure time for each type of exposure. We differentiate the workers' exposure into the following exposure types:

A.) Physical work in pipe yard near descaling process
B.) Physical work in Inspection Units
C.) Physical work in pipe yard away from descaling process
D.) Trucking of pipe
E.) Work inside of auxiliary buildings (office buildings, warehouses, etc.) adjacent to pipe yard

For each of the exposure types A-E, we calculate a total effective dose equivalent (TEDE) rate in mrem/h, using the methodology described in the previous chapter. Detailed calculations are presented in Appendices A (inhalation and ingestion of particulates), B (inhalation of radon and thoron gas), and C (direct gamma radiation). Table 1 shows all dose rate results.

Some workers were subjected to the same type of exposure during their entire work time at ITCO and Brown & Root, whereas others were subjected to two or more types of exposure.

Due to the assumption that no pipe with readings greater than 50 μR/h reached the main yard after 1989, and the fact that Brown & Root did obtain a general TENORM license from LDEQ in 1991, the dose rate calculated for each exposure type is different for the years after 1989 (starting with 1990).

To calculate the radioactivity of scale that correlates to a dose rate reading of 50 μR/h, we employ the program MicroShield[51], v8.02, which is used to calculate radiation doses received by workers external exposed to sources of radiation.

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

As inputs to MicroShield, we assume an outer pipe diameter of 4 inches (10.16 cm), a scale thickness of 0.2 cm, and a pipe wall thickness of 0.91 cm, as suggested by the US EPA[52]. We assume that each contaminated pipe is 30 feet long, and that radiation measurements would have been taken at the center of the pipe, on contact with the outer pipe wall. From MicroShield, we obtain a Ra-226 concentration in scale of 1,313.5 pCi/g and a Ra-228 concentration in scale of 437.8 pCi/g that correspond with a dose rate of 50 μR/h.

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[51] Grove Software Incorporated, 2008
[52] US EPA, 1993c

4.1 Physical Work in Pipe Yard near Descaling Process

Near the pipe cleaning machines, workers were exposed to a concentration of 10 – 30 mg/m^3 of scale dust in the air. With a ventilation rate of 1.5 m^3/h, a scale activity of 6,000 and 2,000 pCi/g scale for Ra-226 and Ra-228, respectively, we obtain an hourly dose rate of 12.79 – 38.36 mrem/h (Table 1). Detailed calculations are presented in App. A. The dose corresponds to committed effective dose equivalents.

The incidental soil ingestion dose rate is calculated per day. The ingestion of 50 – 480 mg/d of scale leads to an effective dose of 2.7 – 26.10 mrem/d. As seen in interviews with workers, most spent 40 – 60 h/w at work. If we take an average of 50 h/w, and 5 d/w, we obtain an average number of 10 work hours per day. The dose rate from incidental soil ingestion can then be expressed as 0.27 – 2.61 mrem/h (App. A).

The inhalation of radon and thoron leads to a dose that is much lower than that from the inhalation of airborne particulates. The hourly inhalation dose in the pipe yard rate from these two radioactive gases is 0.10 – 0.36 mrem/h (App. B).

The groundshine dose rate from the contaminated soil (1 – 5 cm of scale) is 2.02 – 5.90 mrem/h (App. C).

The dose rate from the exposure to 10 pipe joints in a horizontal plane (one at contact, and 9 at increasing distances) is 1.50 mrem/h. If we assume that half of the pipe that the workers were exposed to was contaminated with TENORM, whereas the other half had already been cleaned, we apply an average dose rate of 0.75 mrem/h.

The total effective dose rate for workers in the pipe yard near the cleaning process is **15.94 – 47.98 mrem/h** (Table 1). This is much higher than the allowable dose rate to workers at nuclear power plants.

For exposures after 1989 (i.e. starting in the year 1990), we assume that only pipe with readings of up to 50 μR/h were cleaned in the main yard. As discussed in App. A, this reduces the inhalation dose rate to 2.80 – 8.40 mrem/h. The external radiation dose rate from a line of 10 pipe joints is 0.04 mrem/h (App. C). The dose rate from incidental soil ingestion becomes 0.06 – 0.57 mrem/h. The pathways of inhalation of radon/thoron and groundshine from previously deposited scale remain unchanged. The resulting total dose rate for Exposure Type A after 1989 (Type A_{90}) is **5.03 – 15.27 mrem/h**.

4.2 Physical Work in Inspection Units

The air in the entire inspection units was very dusty, even at locations not in the immediate vicinity of the pipe cleaning process, although the pipe cleaner was probably exposed to the highest dust levels. For the entire building, we therefore apply the same scale dust concentration of 10 – 30 mg/m^3 and the resulting inhalation dose rate of 12.79 – 38.36 mrem/h that we used in the pipe yard. We also apply the same incidental soil ingestion dose rate of 0.27 – 2.61 mrem/h and the dose rate due to external radiation from pipe of 0.75 mrem/h (Table 1).

Scale did not accumulate as much on the floor in the inspection units as it did on the soil in the pipe yard, because the wooden walkways and the concrete pads in the units were periodically cleaned[53] (scale was brushed under adjacent pipe racks). Scale dust that settled onto the shell

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[53] Telephone conversation with J. Bailey

part of the floor mixed into the shells, i.e. it did not form a continuous layer on top of it. We neglect groundshine in the inspection units because, even though there would have been radiation coming off the shell floors, it was far less than out in the pipe yard. Workers in the inspection unit were exposed to direct radiation from the radiography machines. As discussed earlier, we apply a dose range of 170 – 568 mrem/y. To make it compatible with the other radiation exposures, we apply 2,500 working hours per year, as was the case for most workers, and obtain an hourly dose rate of 0.07 – 0.23 mrem/h.

Because the inspection units were adjacent to the pipe yards and the pipe racks, where the ground was covered with scale, and because the wall to the pipe yard was permanently open, the workers in the inspection units were exposed to the same levels of radon and thoron, as were the yard workers. This additional dose rate is 0.10 – 0.36 mrem/h.

The total dose rate that a worker received while working in the inspection unit is **13.98– 42.31 mrem/h** (Table 1).

The changes for this exposure type after 1989 are similar to those for exposure type A. The inhalation dose rate decreased to 2.80 – 8.40 mrem/h, the incidental soil ingestion decreased to 0.06 – 0.57 mrem/h, and direct gamma radiation from used pipes decreased to 0.04 mrem/h. The pathways of inhalation of radon/thoron, incidental soil ingestion and external radiation from the radiography machines remained unchanged. The total dose rate for exposure type B after 1989 is **3.07 – 9.59 mrem/h**.

4.3 Physical Work in Pipe Yard at Distance from Descaling Process

For work away from the descaling operation, we use the dose rates for inhalation of radon and thoron, external radiation and incidental soil ingestion for work near the pipe cleaning machine. These dose rates are 0.10 – 0.36 mrem/h for radon, 2.02 – 5.90 mrem/h for groundshine, 0.75 mrem/h for external radiation from the pipe itself, and 0.27 – 2.61 mrem/h for incidental soil ingestion (Table 1).

The same dose rate can be used because the radon and thoron air concentration is constant throughout the entire area, and groundshine was calculated with an average layer of 1 – 5 cm of scale in the entire pipe yard. Also, the amount of pipe handling would be similar among workers, regardless of their distance from the pipe cleaning machine.

Therefore, the only difference between this type of exposure and that for a pipe cleaner is the applied scale dust concentration in air. For locations away from the pipe cleaning machines, we use a concentration of 1.6 – 3.6 mg/m^3, with a resulting inhalation dose of 2.05 – 4.60 mrem/h.

The total dose rate for exposure away from the descaling operation is **5.19 – 14.22 mrem/h** (Table 1).

As was assumed for exposure type A (see above), the inhalation and incidental ingestion doses from the pipe cleaning process and the external radiation dose from the pipe decreased for years after 1989 for exposure type C (C_{90}). These changes are documented in detail in Appendices A and C. The inhalation dose rate at a distance from pipe cleaning processes decreases to 0.45 – 1.01 mrem/h, the incidental soil ingestion dose rate decreases to 0.06-0.57, and the dose rate due to external radiation from pipes decreases to 0.04 mrem/h. (Table 1).

The pathways of inhalation of radon/thoron and groundshine remain unchanged for the years after 1989. The total dose rate for exposure type C_{90} is therefore **2.67 – 7.88 mrem/h**.

4.4 Trucking of Pipe

While driving a truckload of pipe, drivers were exposed to external radiation from their load. We calculate this exposure for truck drivers separately from other exposures that drivers were confronted with while working for ITCO. While loading/unloading the truck, we apply the exposure types A and C calculated above for physical work in the pipe yard near and away from cleaning machines, respectively.

The dose rate from a truckload of pipe with a 1-cm-layer of scale, shielded with 3 mm of steel or glass (as would be the case in a driver's cabin), is 1.95 – 2.00 mrem/h (App. C). Because only half of the transported pipe was heavily contaminated with TENORM, whereas the other half was cleaned, we apply an average dose rate of **0.98 - 1.00 mrem/h** (Table 1).

As shown in App. C, the external dose rate for pipe truck drivers in the years after 1989 (exposure type D_{90}) is reduced to **0.23 – 0.24 mrem/h**.

4.5 Work Inside the Auxiliary Buildings

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

Because work in auxiliary buildings is usually not very physical, we apply a ventilation rate of 22.2 m^3/d or 0.925 m^3/h. The resulting inhalation dose is 0.47 mrem/h for particulates, and 0.06 – 0.22 mrem/h for radon and thoron.

The total dose rate for exposure type E is **0.54 – 0.69 mrem/h** (Table 1).

This exposure type remains unchanged for the years after 1989, as the pipe yard was still covered with a layer of radioactive scale from earlier years.

4.6 Doses to the Skin

Some of the pipe yard workers suffered from basal cell skin carcinoma. To calculate the doses to skin we used two different methodologies to account for both beta and alpha exposures. This is discussed in detail in Appendix D. The first methodology, based on an article by JR Flood[54], calculates an hourly dose due to the beta daughter radionuclides of Ra-226 and Ra-228 and the area of the impacted part of skin. Since the lip is the thinnest skin on the face, and therefore most vulnerable to alpha and beta radiation exposure, we only calculate the skin dose for those

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[54] Flood JR, 1988

plaintiffs diagnosed with skin cancer. We take the surface area of the lip to be 10 cm^2. The final total beta dose rate range to skin we calculate is **0.03 – 0.08 rem/y**.

To calculate the dose to the skin due to alpha radiation we employed the methodology outlined in an article[55] by D.S. Pressyanov's. In this article a range of skin doses is given for the face, neck, and hands. For the cheek where the skin is thinner, we calculated a range of yearly doses for the pipe yard workers and find that the alpha yearly skin dose rate ranges from **17.2 – 50.0 rem/y**. This is discussed in some detail in Appendix G.

4.7 Total Effective Dose Equivalent (TEDE)

The total effective dose equivalent (TEDE) consists of the sum of all exposures through inhalation, ingestion and external radiation. The TEDE dose is calculated using DCF's from ICRP30, in order to compare the TEDE dose to the allowable dose to nuclear industry workers. In Tables 2 and 3, we calculate the TEDE that the pipe yard workers received from the ITCO and Brown & Root operations by multiplying the total number of hours each worker was exposed during his work in the pipe yards by the dose per hour for the respective exposure type. Doses from his three exposure types (n) were added:

$$TotalDose(mrem) = \sum_{i=1}^{n} ExposureType_i(mrem/h) \times ExposureTime_i(h)$$

According to the Committee Examining Radiation Risks of Internal Emitters (CERRIE)[56], 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 [57]. 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. A more detailed discussion on the uncertainties of exposures to internal emitting radionuclides can be found in Section 6.2.3 of this report.

The ITCO and Brown & Root pipe yard workers were exposed to alpha-emitting radionuclides taken internally by inhalation and ingestion. Therefore, we multiply the upper bounding radiation dose calculated for the plaintiffs by a factor of 10, to account for the uncertainty in dose rate due to internal alpha emitters, following CERRIE's findings.

4.8 Likelihood that Cancers Were Caused Solely by Radiation

We use NIOSH's Interactive RadioEpidemiological Program (IREP), version 5.5.2[58] to calculate the likelihood that the pipe yard workers' 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

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[55] Pressyanov DS, 1991
[56] CERRIE, 2004
[57] Preston, DL, et al., 2003
[58] NIOSH and SENES Oak Ridge Inc., 2009a

radioepidemiological tables developed by the National Institutes of Health (NIH) in 1985 and more recently updated with Japanese atomic bomb survivor data. These tables act as a reference tool to provide the probability of causation estimates for individuals with cancer that were exposed to ionizing radiation. The purpose of this program is to calculate the probability of causation that occupational radiation exposure received while working at a DOE facility or elsewhere within the nuclear weapons industry caused a specific type of cancer[59].

IREP is primarily based upon risk coefficients for cancer incidence gathered from the Japanese atomic bomb survivor studies. The risk coefficients have been adjusted to account for random and systemic errors in the atomic bomb survivor dosimetry as well as for the low dose and low dose-rate situations that are more common to American workers exposed while on the job. The probability of causation, or assigned share, for this risk is calculated as "the cancer risk attributable to radiation exposure divided by the sum of the baseline cancer risk (the risk to the general public) plus the cancer risk attributable to the radiation exposure". 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, than the worker is deemed eligible for compensation. The upper 99-percent confidence level is used to minimize the possibility of denying compensation to employees with cancer likely caused by occupational radiation exposure. The following equation is utilized in IREP to determine the probability of causation or assigned share.[60, 61]

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

Where:

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

In the event of multiple primary cancers, a probability of causation for multiple primary cancers model is used. This was calculated from the following equation provided in IREP:

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

Where:

PC_{Total}	Total probability of causation
PC_{Skin}	Probability of causation for skin cancer
$PC_{Bladder}$	Probability of causation for bladder cancer

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

[60] *Ibid*

[61] Federal Register, 2002

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

Calculated doses from internal exposure using ICRP 72 derived DCFs and from external exposure using FGR 12 derived DCFs were entered into IREP. To enter the doses that resulted from internal radiation exposures, we employed a triangular distribution for internal radiation doses, using the low, medium, and high radiation doses the pipe yard workers received during the time they worked at the ITCO and Brown & Root pipe yards. For external radiation doses, we use a uniform distribution, using the low and high radiation doses the workers received during their time of employment with ITCO and Brown & Root. In IREP, the appropriate cancers were selected, along with the plaintiffs' years of birth and years of diagnoses.

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

4.8.1 Radiation Exposure Compensation Act

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

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

4.9 Underestimates in the Exposure Assessment

The following pathways were either underestimated or not accounted for in the exposure types:

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

Drinking water from coolers located near cleaning machines[64].

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[62] US Department of Justice, 2009

[63] Cardis E, et al., 2005

[64] Testimony of M. Vercher in Grefer case, p. 30.

Chewing tobacco while at work.

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

Elevated external radiation from potholes filled with scale.

Calculations for dose rate from radiography machines assume shielding, even though there was probably little or no shielding at Brown & Root.

Density of pipe scale is 2.6 g/cm^3. For ground up scale, we used the density 1.5 g/cm^3, the same as for normal soil. This is probably an underestimate, and as a consequence, we underestimate the radon and thoron emanation rate, which both depend on scale density.

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

Direct contact of workers' families with contaminated clothes.

Washing of contaminated vehicles (by workers or their family members, done at home).

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

If these factors were considered, the dose for the workers and visitors would be higher.

5.0 Plaintiff Profiles and Radiation Dose Calculations

5.1 Cancer Plaintiffs

5.1.1 Dwayne Batiste

Mr. Batiste was born February 28, 1960. He was diagnosed with rectosigmoid colon cancer on October 18, 2000[65]. He died on November 11, 2009 due to Stage 4 colon cancer.

Mr. Batiste worked approximately 2 years as a pipe cleaner at the ITCO and Brown & Root pipe yards, from 1985-1986. He spent his time in the pipe yards, both near and at a distance from the pipe cleaning process. The conditions in the pipe yards were very dusty. At night he would go home covered in dust. He did not wear a TLD badge or sufficient protective equipment.

Mr. Batiste's primary work was as a pipe cleaner. He cleaned both the internal and external surfaces of used contaminated oil field pipe. Based on Mr. Batiste's deposition, in our calculations we assign 90% of his time at work close to the pipe cleaning operations and 10% of his time at work at a distance from the pipe cleaning operations during his 2 years. From testimony and other statements we estimate that he spent about 50 hours per week at ITCO and Brown & Root.

Based on Mr. Batiste's work history, we calculate that he received a TEDE dose that ranged between 74.31 and 1,931 rem and a total dose to his colon that ranged between 14.30 and 74.23 rem. NIOSH IREP calculated Mr. Batiste's probability of causation to be 26.71% at the 99th percentile (Table 2).[66] Therefore, it is likely that radiation was a substantial and contributing factor to Mr. Batiste's cancer diagnosis.

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[65] Itcow18845

[66] Batiste, Dwayne_Calculations

5.1.2 Dolin Calvey

Mr. Calvey was born December 17, 1917. He was diagnosed with pancreatic cancer in 1997. Mr. Calvey also suffered from hypertension and coronary artery disease. Mr. Calvey did not smoke.

Mr. Calvey worked approximately 35 years as a pipe cleaner, general laborer, and warehouseman, from 1953-1988. He spent his time in the ITCO warehouse and in the ITCO and Brown & Root pipe yards, both near and at a distance from the pipe cleaning process. The conditions in the pipe yards were very dusty. He did not wear a TLD badge or sufficient protective equipment.

Mr. Calvey's primary occupation between 1953 and the mid-1970s was a pipe cleaner and general laborer. After the mid-1970s, Mr. Calvey was transferred to work in the ITCO warehouse as a warehouseman. Therefore, we assume Mr. Calvey spent 50% of his time between 1953 and 1975 near the pipe cleaning machines and 50% of his time between 1953 and 1975 at a distance from the pipe cleaning machine. We assumed he only worked inside the ITCO warehouse from 1975 until 1988. From testimony and other statements we estimate that he spent about 50 hours per week at ITCO.

Based on Mr. Calvey's work history, we calculate that he received a TEDE dose that ranged between 591 and 13,846 rem and a total dose to his pancreas that ranged between 154 and 647 rem. NIOSH IREP calculated Mr. Calvey's probability of causation to be 68.28% at the 99th percentile (Table 2).[67] Therefore, it is more likley than not that Mr. Calvey's cancer was caused by his occupational exposure to radiation.

5.1.3 Cedric Guidry Sr.

Mr. Guidry was born on March 16, 1932. He was diagnosed with skin cancer of the lip in 1992[68] and with bladder cancer on January 17, 2001[69]. Mr. Guidry also suffered from COPD, hypertension coronary artery disease, and diabetes. Mr. Guidry smoked 1.5 to 2 packs of cigarettes a day for approximately 57 years. He quit smoking in the year 2000.

Mr. Guidry worked approximately 13 years as a pipe cleaner, general laborer, and truck driver, between 1967 and 1983. He spent his time in the ITCO pipe yards, both near and at a distance from the pipe cleaning process. The conditions in the pipe yards were very dusty. He did not wear a TLD badge or sufficient protective equipment.

Based on Mr. Guidry's work history, we believe he spent approximately 20% of his time working near the pipe cleaning machines, 20% of his time working at a distance from the pipe cleaning machines, and 60% of his total time working as a truck driver. From testimony and other statements we estimate that he spent about 50 hours per week at ITCO and Brown & Root.

Based on Mr. Guidry's work history, we calculate that he received a TEDE dose that ranged between 99.78 and 2,095 rem and a total dose to his bladder that ranged between 35.71 and 111.0 rem. In addition, we calculated that Mr. Guidry received a total skin beta dose that ranged between 0.24 and 0.69 rem and a total alpha dose to the skin that ranged between 143.0 and 414.1 rem. NIOSH IREP calculated Mr. Guidry's probability of causation to be 92.88% at the 99th

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[67] Calvey, Dolin_Calculations
[68] Bailey01850, bailey01851, bailey01853
[69] Bailey01783

percentile for the development of both of his cancer types (Table 2). [70] Therefore, it is more likely than not that Mr. Guidry's cancers were caused by his occupational exposure to radiation.

5.1.4 Clarence Richard

Mr. Richard was born July 11, 1922. He was diagnosed with nasopharyngeal cancer in 1997[71]. He died on May 10, 1997.

Mr. Richard worked approximately 13 years as a laborer, from 1980-1992. He spent his time in the pipe yards, both near and at a distance from the pipe cleaning process. The conditions in the pipe yards were very dusty. At night he would go home covered in dust. He did not wear a TLD badge or sufficient protective equipment.

Mr. Richard's primary work was as a general laborer. He did all types of work in the pipe yard. Based on our interviews, in our calculations we assign 50% of his time at work close to and at a distance from the pipe cleaning operations during his 13 years. From testimony and other statements we estimate that he spent about 50 hours per week at ITCO and Brown & Root.

Based on Mr. Richard's work history, we calculate that he received a TEDE dose that ranged between 283.8 and 6,563 rem and a total dose to his nasopharyx that ranged between 723.6 and 18,895 rem. NIOSH IREP calculated Mr. Richard's probability of causation to be 98.80% at the 99th percentile (Table 2).[72] Therefore, it is more likely than not that Mr. Richard's cancer was caused by his occupational exposure to radiation.

5.1.5 James Richardson

Mr. Richardson was born June 28, 1947. Mr. Richardson was diagnosed with basal cell carcinoma on his left eyebrow in October 1999, which was removed at that time. He was later diagnosed with thyroid cancer in February 2004, and had a total thyoidectomy in March 2004.

Mr. Richardson worked approximately 28 years as a pipe thread inspector from 1980-2008. He inspected used oil field production equipment both onshore and offshore, and a portion of his onshore work occurred in the ITCO and Brown & Root pipe yards in Louisiana. The conditions in the pipe yards were very dusty. At night he would go home covered in dust. He did not wear a TLD badge or sufficient protective equipment.

Based on Mr. Richardson's deposition, in our calculations we assign 12.5% of his time at work near the pipe cleaning machines and 12.5% of his time at work at a distance from the pipe cleaning machines at the ITCO and Brown & Root pipe yards. These assigned work times are based on the assumption that Mr. Richardson spent 50% of his work time onshore, and 50% of that time onshore in the ITCO and Brown & Root pipe yards. Although Mr. Richardson did not work in pipe yards 100% of the time he worked, he did inspect used, contaminated oil field pipe the entire time he worked, and we therefore also assign that he was exposed to direct gamma radiation emanating from the pipes he inspected100% of the total time he worked. From testimony and other statements we estimate that he spent about 50 hours per week at ITCO and Brown & Root.

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[70] Guidry, Cedric Sr._Calculations
[71] 000009511
[72] Richard, Clarence_Calculations

Based on Mr. Richardson's work history, we calculate that he received a TEDE dose that ranged between 112.6 and 2,076 rem and a total dose to his thyroid that ranged between 50.26 and 142.6 rem. NIOSH IREP calculated Mr. Richard's probability of causation to be 69.14% at the 99th percentile (Table 2).[73] Therefore, it is more likely than not that Mr. Richard's cancer was caused by his occupational exposure to radiation. Since Mr. Richardson was not diagnosed with cancer of the lip, we do not calculate the probability of causation of his skin cancer.

5.2 Non-Cancer Plaintiffs

5.2.1 Curtis Arwood

Mr. Curtis Arwood was exposed without his knowledge, to naturally occurring radioactive material (TENORM) in the course of oil field pipe de-scaling operation at Intracoastal Tubular Services Co. (ITCO) in Louisiana. Mr. Arwood worked at the Brown & Root yard and at ITCO's yards 3 and 4 in Harvey, Louisiana.

Curtis Arwood worked for ITCO approximately 6 ½ years as a pipe cleaner and inspector, from 1980 to 1986, when he was laid off. He worked in the south yard, cleaning and inspecting pipe. He cleaned pipe about 90 % of his work time. He spent about 10 hours per day at the plant. He worked as a supervisor for part of his employment, but he essentially did the same job as the workers that were under him. He never had to do paperwork.

Mr. Arwood developed dermatitis and respiratory problems during his employment at ITCO and currently has bronchitis. Additionally, he suffered a heart attack. The radiation dose received by Mr. Arwood greatly increased his risk of developing these ailments d cleaning chemicals contributed to his dermatitis.

Based on Mr. Arwood's work history, we calculate that he received a TEDE dose that ranged between 226.0 and 5,873 rem (Table 3)[74]. According to the Nuclear Regulatory Commission (NRC), maximum allowable doses for workers in industries regulated by the NRC are 5 rem/yr. If nuclear workers were to be exposed to the maximum allowable doses for 6.5 years, the comparable dose would be 32.5 rem. We acknowledge that Mr. Arwood was not a nuclear worker, but we use the regulated doses for purpose of comparison. As seen above, the total effective dose received by Mr. Arwood greatly exceeds the NRC allowable dose to nuclear workers.

In addition, Mr. Arwood received a skin dose due to α and β emitting radionuclides. Our calculated skin dose ranged between 732.0 rems and 2,186 rems. The NRC guideline[75] for skin irradiation to prevent deterministic effects (changes in skin function or appearance) is 50 rem/y.

The particulate concentrations near the cleaning machines ranged between 10 and 30 mg/m^3. In contrast OSHA recommends a limit of 5 mg/m^3 for respirable dust[76]. In addition to dust, Mr. Arwood was also exposed to the cleaning chemical Varsol. The health impact of Varsol and nuisance dust is discussed in much greater detail below in Section 8.1 and 8.2.

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[73] Richardson, James_Calculations

[74] Arwood, Curtis_Calculations

[75] Code of Federal Regulations (CFR), 10(20):1201(a)(2)(ii).

[76] 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.

In our opinion, the excess dust, radiation and chemical conditions at the ITCO and Brown & Root yards were substantial and contributing factors to Mr. Arwood's skin rash and heart attack.

5.2.2 Darryl Boyer

Mr. Darryl Boyer was exposed without his knowledge, to naturally occurring radioactive material (TENORM) in the course of oil field pipe de-scaling operation at Intracoastal Tubular Services Co. (ITCO) in Louisiana. ITCO conducted oilfield pipe scale cleaning operations from the 1940's until 1993 at the Harvey and Brown & Root pipeyards. Workers and visitors at ITCO and Brown & Root were exposed to radiation through inhalation of the scale dust, incidental ingestion of radioactive dust, and to external radiation from the scale in the pipe and from the scale deposited on the ground.

Mr. Boyer worked for ITCO for 4 years from June of 1978 to 1981 as a laborer, switchman, hookman, and also loading and unloading pipe on and off of trucks.

Mr. Boyer's heart problems, high blood pressure, anemia and excess dryness of skin could be due to his exposure to radiation in the Brown & Root and ITCO pipe yards.

Numerous references cite a relationship between Mr. Boyer's health effects and conditions at the ITCO and Brown & Root pipeyards. The sources for the risk estimates (with measured health impact) are discussed in detail in sections 8.1 and 8.2 below.

Based on Mr. Boyers's work history, we calculate that he received a TEDE dose that ranged between 100.2 and 2,381 rem (Table 3)[77]. According to the Nuclear Regulatory Commission (NRC), the maximum allowable dose for workers in industries regulated by the NRC is 5 rem/yr. If nuclear workers were to be exposed to the maximum allowable doses for 4 years, the comparable dose would be 20 rem. We acknowledge that Mr. Boyer was not a nuclear worker, but we use the regulated doses for purpose of comparison. As seen above, the total effective dose received by Mr. Boyer greatly exceeds the NRC allowable dose to nuclear workers.

In addition, Mr. Boyer received a skin dose due to α and β emitting radionuclides. Our calculated skin dose ranged between 159.1 rems and 460.9 rems. The NRC guideline[78] for skin irradiation to prevent deterministic effects (changes in skin function or appearance) is 50 rem/y.

The particulate concentrations near the cleaning machines ranged between 10 and mg/m^3. In contrast OSHA recommends a limit of 5 mg/m^3 for respirable dust[79]. In addition to dust, Mr. Boyer was also exposed to the cleaning chemical Varsol. The health impact of Varsol and nuisance dust is discussed in much greater detail below in Section 8.1 and 8.2.

In our opinion, the excess dust, radiation, and chemical conditions at the ITCO and Brown&Root yards were substantial and contributing factors to Mr. Boyer's skin rash and heart attack.

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[77] Boyer, Darryl_Calculations

[78] Code of Federal Regulations (CFR), 10(20):1201(a)(2)(ii).

[79] 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.

Along with heart problems, Mr. Boyer also suffers from high blood pressure, diabetes, gastrointestinal bleeding, hepatitis B, heart problems, peripheral neuropathy, hypotension, anemia, hyperglycemia, cellulitis (finger), excess dryness of skin (xerosis), renal cystscellulitis, hepatitis B, diabetes and osteomyelitis of the hand.

5.2.3 Horace Fennidy III

Mr. Horace Fennidy was exposed without his knowledge, to naturally occurring radioactive material (TENORM) in the course of oil field pipe de-scaling operation at Intracoastal Tubular Services Co. (ITCO) in Louisiana. Brown & Root and ITCO conducted oilfield pipe scale cleaning operations from the 1940's until 1993. Workers and visitors at ITCO and Brown & Root were exposed to radiation through inhalation of the scale dust, incidental ingestion of radioactive dust, and to external radiation from the scale in the pipe and from the scale deposited on the ground.

Mr. Fennidy worked at ITCO and Brown & Root[80] for approximately 5 years between 1980 to 1986 as a pipe cleaner, inspector, and pipe repairman. For three of those years he was a supervisor of pipe cleaning and inspection. He worked in the inspection buildings during his entire time at ITCO. He cleaned and inspected pipe. When he was cleaning, he worked on approximately 900-1000 joints a day of tubing. While inspecting, he had a dosimeter badge, which he handed in every month. However, he was never informed about the results.

Mr. Fennidy suffers chronic sinusitis and chronic bronchitis. He had sinus surgery five years ago and his sinus problems continue. Horace Fennidy has also developed the blood platelet disorder, thrombocytopenia. The radiation dose received by Mr. Fennidy greatly increased his risk of developing sinusitis and bronchitis.

Mr. Fennidy's bronchitis, for which respirable dust is a known risk factor, is directly related to the dust exposure in the ITCO and Brown & Root pipe yard. The particulate concentrations near the cleaning machines ranged between 10 and mg/m^3. In contrast OSHA recommends a limit of 5 mg/m^3 for respirable dust[81].

His blood platelet disorder, thrombocytopenia, may also be related to his exposure to radiation. Mr. Fennidy also has sinusitis, for which he had surgery five years ago.

Numerous references cite a relationship between Mr. Fennidy's health effects and dusty conditions at the ITCO and Brown & Root pipeyards. This is discussed in detail below in sections 8.1 and 8.2.

Based on Mr. Fennidy's work history, we calculate that he received a TEDE dose that ranged between 168.5 rem and 4,965 rem (Table 3)[82]. According to the Nuclear Regulatory Commission (NRC), the maximum allowable dose for workers in industries regulated by the NRC is 5 rem/yr. If nuclear workers were to be exposed to the maximum allowable doses for 5 years, the comparable dose would be 25 rem. We acknowledge that Mr. Fennidy was not a nuclear worker, but we use the regulated doses for purpose of comparison. As seen above, the total effective dose received by Mr. Fennidy greatly exceeds the NRC allowable dose to nuclear workers.

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[80] Fennidy Deposition, p. 193.

[81] 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.

[82] Fennidy, Horrace_Calculations

In our opinion, the excess dust and radiation and chemical conditions at the ITCO and Brown & Root yards were substantial and contributing factors to Mr. Fennidy's bronchitis and blood platelet problems.

5.2.4 Cedric Guidry Jr.

Cedric Guidry Jr. was exposed without his knowledge, to naturally occurring radioactive material (TENORM) in the course of oil field pipe de-scaling operation at Intracoastal Tubular Services Co. (ITCO) in Louisiana. ITCO conducted oilfield pipe scale cleaning operations from the 1940's until 1993. Workers and visitors at ITCO were exposed to radiation through inhalation of the scale dust, incidental ingestion of radioactive dust, and to external radiation from the scale in the pipe and from the scale deposited on the ground. ITCO workers were also subject to dusty conditions and to hazardous chemicals, such as Varsol, in the process of cleaning pipes.

Mr. Guidry worked for ITCO for approximately 2 years between 1983 and 1984 as a yard hand, general laborer, and truck driver, primarily loading and unloading pipe. He drove pipe from one area in the yard to another, but not to the oil fields. He stated that ITCO maintained pipe-cleaning processes in the pipe yard where he worked, even after 1987. He worked between 40 and 60 hours per week.

Mr. Guidry suffers from dermatitis and chronic cough, as well as chest and neck pain. The radiation dose received by Mr. Guidry greatly increased his risk of developing a dermatitis and chronic cough. Dusty working conditions and hazardous chemicals were contributory causes.

High doses of localized radiation can result in dermatitis[83]. The NRC guideline[84] for skin irradiation to prevent deterministic effects (changes in skin function or appearance) is 50 rem/y. Based on Mr. Guidry's work history, we calculate that he received a TEDE dose that ranged between 43.24 rem and 1,006 rem (Table 3)[85]. According to the Nuclear Regulatory Commission (NRC), the maximum allowable dose for workers in industries regulated by the NRC is 5 rem/yr. If nuclear workers were to be exposed to the maximum allowable doses for 2 years, the comparable dose would be 10 rem. We acknowledge that Mr. Guidry was not a nuclear worker, but we use the regulated doses for purpose of comparison. As seen above, the total effective dose received by Mr. Guidry greatly exceeds the NRC allowable dose to nuclear workers.

In addition, Mr. Guidry received a skin dose due to α and β emitting radionuclides. Our calculated skin dose ranged between 74.04 rems and 214.5 rems. The NRC guideline[86] for skin irradiation to prevent deterministic effects (changes in skin function or appearance) is 50 rem/y.

The particulate concentrations near the cleaning machines ranged between 10 and mg/m^3. In contrast OSHA recommends a limit of 5 mg/m^3 for respirable dust[87]. In addition to dust, Mr.

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[83] Alaska Department of Labor and Workforce Deployment, Labor Standards and Safety Division, Physical Agent Data Sheet (PADS) – Ionizing Radiation, available at http://www.labor.state.ak.us/lss/pads/ionizing.htm#Health%20Effects, accessed June, 2002.

[84] Code of Federal Regulations (CFR), 10(20):1201(a)(2)(ii).

[85] Guidry, Cedric Jr._Calculations

[86] Code of Federal Regulations (CFR), 10(20):1201(a)(2)(ii).

[87] 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.

Guidry was also exposed to the cleaning chemical Varsol. The health impact of Varsol and nuisance dust is discussed in much greater detail below in Section 8.1 and 8.2.

In our opinion, the excess dust, radiation, and chemical conditions at the ITCO and Brown & Root yards were substantial and contributing factors to Mr. Guidry chronic cough, and heart disease.

5.2.5 Jeffery Holmes

Mr. Jeffery Holmes was exposed without his knowledge, to naturally occurring radioactive material (TENORM) in the course of oil field pipe de-scaling operation at Intracoastal Tubular Services Co. (ITCO) at the Harvey and Brown & Root yards in Louisiana. ITCO conducted oilfield pipe scale cleaning operations from the 1940's until 1993. Workers and visitors at ITCO were exposed to radiation through inhalation of the scale dust, incidental ingestion of radioactive dust, and to external radiation from the scale in the pipe and from the scale deposited on the ground.

Mr. Holmes worked at Brown & Root and ITCO as a pipe cleaner for 13 years, from 1980 through 1992. He worked in the pipe yard. He also was a supervisor, but he did not have to do any paperwork. He always worked with the crew. He remembers working from 8am to 6pm typically. He also recalls coughing up dust every night.

Mr. Holmes suffers from sinus problems, dizziness, shortness of breath and cough. The radiation dose received by Mr. Holmes greatly increased his risk of developing sinus problems and a cough.

Mr. Holmes' asthma and high blood pressure, for which respirable dust and radiation are known risk factors, are directly related to the dust exposure and radioactive materials in the ITCO and Brown & Root pipe yards.

Numerous references cite a relationship between Mr. Holmes' health effects and dusty conditions at the ITCO and Brown & Root pipeyards. This is discussed in detail in sections 8.1 and 8.2 of this report.

The particulate concentrations near the cleaning machines ranged between 10 and mg/m^3. In contrast OSHA recommends a limit of 5 mg/m^3 for respirable dust[88]. In addition to dust, Mr. Holmes was also exposed to the cleaning chemical Varsol. The health impact of Varsol and nuisance dust is discussed in much greater detail below in Section 8.1 and 8.2.

Based on Mr. Holmes's work history, we calculate that he received a TEDE dose that ranged between 264.0 rem and 6,104 rem (Table 3)[89]. According to the Nuclear Regulatory Commission (NRC), the maximum allowable dose for workers in industries regulated by the NRC is 5 rem/yr. If nuclear workers were to be exposed to the maximum allowable doses for 13 years, the comparable dose would be 65 rem. We acknowledge that Mr. Holmes was not a nuclear worker, but we use the regulated doses for purpose of comparison. As seen above, the total effective dose received by Mr. Holmes greatly exceeds the NRC allowable dose to nuclear workers.

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[88] 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.

[89] Holmes, Jeffery_Calculations

In our opinion, the excess dust, radiation, and chemical conditions at the ITCO and Brown & Root yards were substantial and contributing factors to Mr. Holmes' asthma and high blood pressure.

5.2.6 Troy Richard

Mr. Troy Richard was exposed without his knowledge, to naturally occurring radioactive material (TENORM) in the course of oil field pipe de-scaling operation at Intracoastal Tubular Services Co. (ITCO) in Louisiana. ITCO conducted oilfield pipe scale cleaning operations from the 1940's until 1993. Workers and visitors at ITCO were exposed to radiation through inhalation of the scale dust, incidental ingestion of radioactive dust, and to external radiation from the scale in the pipe and from the scale deposited on the ground.

Mr. Richard worked in the Peters Road yard at ITCO and also at Brown & Root for approximately 5 years, between 1980 to 1986. He was a yard operator; his job included cleaning, testing, moving, transporting, loading and unloading of pipe.

He spent 6 to 8 hours per day near pipe cleaning, estimating that between 400 and 800 joints a day were cleaned. The rest of his work time, he transported, tested, greased and degreased pipe. He handled pipe scale waste from 10 to 12 hours daily. Per week, he worked anywhere between 40 and 60 hours.

During most of his life, i.e. long before he started working for ITCO, Mr. T. Richard ate vegetables that his father (Clarence Richard) grew in the Tom Hicks yard. As a child, he was also exposed to his father's dusty work clothes.

Mr. Richard suffers from dyspnea and asthma. He also sometimes experiences severe numbness in his arms and hands. Additionally he suffers from depression and anxiety. The radiation dose received by Mr. Richard greatly increased his risk of developing these ailments.

Mr. Richard's asthma, neurological problems and ischemia, for which respirable dust and hazardous chemicals are known risk factors, are directly related to the dust exposure and working conditions in the Brown & Root and ITCO pipe yards. The particulate concentrations near the cleaning machines ranged between 10 and mg/m^3. In contrast OSHA recommends a limit of 5 mg/m^3 for respirable dust[90]. In addition to dust, Mr. Richard was also exposed to the cleaning chemical Varsol. The health impact of Varsol and nuisance dust is discussed in much greater detail below in Section 8.1 and 8.2.

Numerous references cite a relationship between Mr. Richard's health effects and dusty conditions at the ITCO and Brown & Root pipeyards. These are discussed in detail in section 8.1 and 8.2 below.

Based on Mr. Richard's work history, we calculate that he received a TEDE dose that ranged between 108.1 rem and 2,514 rem (Table 3)[91]. According to the Nuclear Regulatory Commission (NRC), the maximum allowable dose for workers in industries regulated by the NRC is 5 rem/yr. If nuclear workers were to be exposed to the maximum allowable doses for 5 years, the comparable dose would be 25 rem. We acknowledge that Mr. Richard was not a nuclear worker,

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[90] 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.

[91] Richard, Troy_Calculations

but we use the regulated doses for purpose of comparison. As seen above, the total effective dose received by Mr. Richard greatly exceeds the NRC allowable dose to nuclear workers.

In our opinion, the excess dust, radiation, and chemical conditions at the ITCO and Brown & Root yards were substantial and contributing factors to Mr. Richard's asthma neurological problems and ischemic heart disease.

6.0 Radiation Health Effects

6.1 Principle Effects of Radiation

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

There are many important factors bearing upon understanding of the effects of radiation dose. These include the total dose, the rate at which the dose was delivered, the dose pattern (e.g. intervals between exposure), and the nature of the radiation contributing to the dose. For example, gamma rays can penetrate through the body and deposit only a fraction of their energy. Interactions are thinly distributed over relatively remote cells and organs. On the other hand, alpha-emitting radionuclides, deposited internally, deliver a highly localized radiation dose with a total range of approximately 20 μm (0.0008 inches). Effects are relatively much more likely with alpha particle irradiation. The ICRP accounts for this high energy transfer of alpha particles with a quality factor of 20 in converting rads to rems; for gamma radiation, a rad equals a rem. Another important factor is the stage of cell division. The cell is more susceptible to damage at the last stage of division. Children could be more susceptible because cells are reproducing more rapidly while growing and more cells are in the susceptible stage. This is the same reason why radiation therapy has greater effect on cancerous cells that are multiplying more rapidly. Other factors affecting radiation effects include sex, age at exposure, time of conception (relative to irradiation), location of exposed genes, and genetic susceptibility. The ICRP[92] recently published a treatise on the possible genetic inherited susceptibility to cancer that could modify the effects of radiation exposure. The path and organ dose due to the internal deposition of radionuclides is highly variable. The attendant physical and chemical characteristics result in variable deposition and retention patterns at specific locations in the body. Certain organs and cells can be much more affected than others.

6.1.1 Genetic Effects

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

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[92] ICRP, 1998a

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

Virtually any identified birth defect has genetic alterations that could be a consequence of radiation damage. All mutations are expected to have some harmful effect. Genetic problems are generally classified to three categories: single gene disorders, chromosomal aberrations, and multifactorial disorders. Single gene disorders usually are more drastic and are immediately manifest in offspring. Major anomalies might include hydrocephalus (fluid in the cerebral ventricles of the brain) and achondroplasia (bone deformities and dwarfing).

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

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

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

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

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

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

6.1.2 DNA Damage

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

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

Ionizing radiation can cause different kinds of damage. The complexity of the damage increases with an increase in the radiation Linear Energy Transfer (LET). Ionizing radiation deposits energy in cells as tracks of ion pairs. The intensity and density of ionizations is a function of the LET of the radiation. Typical low-LET x-ray and gamma radiation can cause about 70 ionizations across an 8 μm cell diameter cell nucleus. A high-LEt alpha particle, such as from Ra-226, will cause over 23,000 ionizations within the nucleus of a single cell[93]. This damage causes mutations and chromosomal changes. Radiation damage transforms cells to a stage in the development of metaplasia that can lead to neoplasia or cancer.

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

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

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

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

6.1.3 Radiation Induced Cancer

It is known that radiation dose can lead to the induction of cancer. For over 60 years, the International Commission on Radiation Protection, a body of experts in this field, has produced a series of documents providing the progressive knowledge of radiation effects to enable proper radiation protection. In the United States, since 1931 the National Council on Radiation Protection and Measurements has published similar reports, and continues to do so. In 1959, the Federal Radiation Council was formed to advise the President on radiation matters affecting

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[93] UNSCEAR, 2000

health for all Federal agencies and for cooperative State Programs. With the formation of the US EPA in 1970, that program became the responsibility of the US EPA. Since the mid 1980s the US EPA has provided a related series of documents to assist Federal and State agencies in their implementation of radiation protection programs. The US EPA has recently (Sept., 1999) updated their published cancer risk coefficients. A successive series of reports by the Committee on the Biological Effects of Ionizing Radiations (BEIR) of the National Research Council have continued to update the knowledge on the health effects of radiation. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has similarly been issuing successive reports on radiation effects since 1955.

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

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

Tumorigenesis is a multi-stage process. First the chromosomal DNA in a normal target is damaged. With the failure to correctly repair that damage, a specific neoplasia initiating mutation can appear. This promotes growth to metaplasia followed by conversion to a malignant phenotype leading to the tumor. According to the National Academy of Sciences, radiation is not only an initiator of cancer, but also a promoter.[94]

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

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

It is unanimously agreed that leukemia and virtually all forms all forms of solid cancers in humans can be induced by ionizing radiation.[95] Lymphoma is a group of diseases that involve lymphoid tissue. Multiple myeloma is a malignancy of bone marrow with abnormal plasma cells.

6.1.4 Radiation Protection Standards

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

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[94] National Research Council, 1990

[95] Gofman JW, 1981

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

6.2 Radiation Risk Analysis for Cancer

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

6.2.1 Cancer Dose

The cancer dose is the radiation dose that on average leads to one fatal cancer in an irradiated population. The cancer dose depends on age, gender, and cancers included. There is a range of risk estimates in the literature, all of which lead to different cancer doses. In this report, we discuss risk estimates from BEIR V[96], Gofman[97], and Pierce[98], all of which ultimately use data from Japanese bomb survivors in Hiroshima and Nagasaki. However, we employ the IREP program for calculating the likelihood that radiation was responsible for the pipe yard workers' cancers. IREP calls this likelihood the assigned share. Combining all radiation pathways, we determine whether it is more likely than not that the pipe yard workers' cancers were caused due to his radiation exposure.

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

6.2.1.1 Excess Lifetime Risk to Develop Fatal Cancer

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

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

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

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[96] National Research Council, 1990
[97] Gofman JW, 1981
[98] Pierce DA, et al., 1996

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

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

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

This likelihood can range between 0 (no relationship between cancer and radiation) to 1 (cancer certainly caused by radiation). It is a measure of the probability that a worker's cancer was effectively caused by the radiation dose he received. In previous reports, we employed risk models from BEIR V, Gofman[99] and Peirce[100]. Like IREP, all are based on Japanese bomb survivor studies. In this report we only employ IREP, which incorporates the latest Japanese bomb survivor data. A more recent study shows that NHL and has been associated with radiation[101].

6.2.2 The Linear-No-Threshold Hypothesis and Bystander Effects

Extensive research has been done in an attempt to quantify the health effects from inhalation, ingestion, and external exposure to radionuclides. The consensus of the international scientific community has accepted the linear no-threshold hypothesis, which posits that dose-effect relationships derived from experiments with high doses of radiation can be scaled linearly to calculate effects from low doses. It also states that there is no "safe" threshold of radiation, that each additional exposure, no matter how small, increases a person's risk of cancer. The hypothesis is based on the understanding that radiation-induced cancer is caused by mistakes in the genetic code produced when radiation comes in contact with DNA. For every additional radioactive disintegration, there will be an increased probability that a cancer-causing DNA mutation will occur. The linear no-threshold hypothesis is also based on epidemiological evidence of Japanese bomb survivors[102]. A significant increased incidence of cancers occurred down to a dose of 5 rems, and an increased incidence occurred down to the lowest doses.

Bystander Effect. Japanese bomb survivors were subjected to external gamma and neutron radiation, but not to internal exposure due to ingestion and inhalation of radionuclides. However, recent studies suggest that the theory of a proportional dose-response mechanism without threshold significantly underestimates the effects of low-dose radiation. Whereas at high doses, mutagenic effects do seem to be proportional to the radiation received, low doses have shown a different relationship. In one study, the mutagenic effect in a cell culture in which only 10 % of all cells were penetrated with one α-particle was found to be almost the same as when all cells were exposed, due to a strong bystander effect[103]. 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.[104] This effect has been

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[99] Gofman JW, 1981
[100] Pierce DA, et al., 1996
[101] Berrington A, et al., 2001
[102] Pierce DA, et al., 1996
[103] Zhou H, et al., 2001
[104] Lorimore A, Coates PJ, and EG Wright, 2003

observed with both alpha- and gamma- radiation.[105] The bystander effect is thought to be caused by proteins excreted from cells in response to radiation. The bystander effect does not follow a linear dose-response relationship; culture from cells irradiated with low doses causes more mutations in non-irradiated cells than culture from cells irradiated with high doses.[106]

This recent research shows that the linear no-threshold hypothesis may not be sufficiently conservative, as at low doses the effect per dose unit may be significantly greater than at high doses. Therefore, the use of the linear no-threshold hypothesis may significantly underestimate doses from relatively low levels of radiation, particularly in certain circumstances. Unfortunately there is not sufficient data from human studies to prove or disprove the significance of the bystander effect in real-life situations.[107]

6.2.3 Risk Uncertainties for Internal Radiation

According to the Committee Examining Radiation Risks of Internal Emitters (CERRIE)[108], the risk due to exposure by radionuclides taken internally may be as much as 10 times higher. CERRIE was established by the Environment Minister of Great Britain in 2001 for the express purpose of investigating internal risks and consisted of scientists with a broad range of views on the subject. The pipe yard workers were exposed to radionuclides taken internally by inhalation and ingestion, in addition to direct gamma external radiation.

Radiation risks are predominantly determined by epidemiological studies, particularly the study of Japanese bomb survivors.[109] Residents of Hiroshima and Nagasaki were exposed primarily to an instant of external gamma radiation and neutrons. From that epidemiological study, that is still ongoing, international committees like the International Commission on Radiological Protection (ICRP) have extrapolated the bomb survivor results to radionuclides taken internally. But radionuclides that emit beta and alpha short range radiation over long time periods present several issues that have not been studied in detail.

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

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

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

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

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

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

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[105] Little JB, 2003
[106] Lorimore A, Coates PJ, and EG Wright, 2003
[107] Brenner DJ, et al., 2003
[108] CERRIE, 2004
[109] Preston DL, et al., 2003

investigated these issues, especially (2) above, concluded that the dose due to internal emitters, may be 10 times higher, as discussed in Section 4.7 above.

Genomic instability relates to the damage to genomic DNA that results in "detrimental effects in the progeny of the irradiated cell, many cell divisions after the initial insult."[110] There is some evidence that low doses of radiation can lead to much greater frequency of mutations down the road than induced by the direct action of radiation.

Bystander effects are damage to cells that are not directly along a radiation track, but to adjacent cells. Bystander effects have been seen in laboratory experiments and are not linearly related to radiation dose. The data are sparse for whole animals.[111]

Minisatellite mutations are characterized by very high mutation rates and were first observed among the barn swallow breeding close to the Chernobyl reactor. Compared to barn swallows in Italy and the Ukraine, the mutation rates were ten times higher.[112]

The second event theory or SET propounds that a second radiation hit, within a specific time window after the first, enhances the mutagenic effectiveness of radiation. According to SET, this might be the case for Sr-90/Y-90 and certain Pu radionuclides.[113] The CERRIE committee recommended additional studies of the phenomena.

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

7.0 Rules and Regulations

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

The first regulations were promulgated in 1966, and took effect on May 1, 1967. All radioactive materials, not just source and special nuclear materials, were regulated by the Division of Radiation Control. While the term TENORM was not specifically defined in the regulations, Ra-226 was specifically regulated. Exemption limits were specified, but these were far below the levels present in the Brown & Root and ITCO yards. Though the Division never enforced the Ra-226 regulations, general licenses were issued and carried over until February 1989 when the State issued a "Declaration of Emergency"[114] and specifically enacted regulations for TENORM material. Whether the regulations were enforced before 1989 or not, ITCO and Brown & Root were required to satisfy radiation regulations such as the posting of radioactive areas, protecting worker safety (also regulated by OSHA) and controlling soil contamination, specifically, maintaining total radium concentrations less than 5 pCi/g in potential residential areas and 15 pCi/g in industrial areas. The soil contamination limits for operating facilities was relaxed to 200

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[110] CERRIE, 2004
[111] *Ibid*
[112] *Ibid*
[113] *Ibid*
[114] Louisiana Register, 1989

pCi/g in more recent regulations, but the soil contamination limit for decommissioned sites released for unrestricted use remained the same.

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

Our calculations assume that Brown & Root and ITCO adhered to these regulations beginning September 1989 (even though the regulations were repealed and re-promulgated only in 1992). According to the regulations, licenses are differentiated into general and specific licenses. For a general license, a licensee must fulfill certain requirements in order to be allowed to process TENORM. The licensee has to comply with these conditions, but does not have to apply for a license. In contrast, specific licenses can only be obtained through an application process. Section 1408 requires that licensees notify the Office of Environmental Services by filing TENORM Form RPD-36 with the Office of Environmental Services, Permits Division. Section 1410 pertains to pipe yards, granting a general license to "*receive, process, process, and clean tubular goods or equipment which are contaminated with scale or residue but do not exceed 50 microroentgens per hour*". For the decontamination of pipe that exceeds 50 µR/h, a specific license is required. We do not know whether ITCO or Brown & Root held a specific license.

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

Notification of DEQ within 90 days of the effective date of the regulations that facilities (ITCO and Brown & Root) intend to receive equipment contaminated with scale or residue that does not exceed 50 µR/h.

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

Program is submitted to ensure worker protection

Program is submitted to control soil contamination

Program is submitted to prevent release of TENORM beyond site boundary

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

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

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

For most of these conditions, we have no knowledge whether ITCO and/or Brown & Root complied. However, we do know that they did not comply with condition 2, as entire truckloads of pipe were screened at once, rather than individual joints. Noncompliance with a necessary

condition for the general license is equivalent to violating the license (and, by extension, Louisiana State law).
We have not seen documents that show compliance with any of the other conditions. All programs had to be submitted to DEQ, Office of Environmental Services, Permits Division, for approval.

State regulations also prohibited the transfer of radioactive material to non-licensed recipients (§340). Since ITCO and Brown & Root were general licensees under §1410, they were only allowed to transfer material with radioactivity <50 μR/h. It is not clear whether each pipe or entire loads were surveyed, or none at all, leaving the surveying entirely up to ITCO and Brown & Root. If they surveyed by load as opposed to by joint, then it was inevitable that some hot joints (>50 μR/h) were shipped to ITCO and Brown & Root. For each hot pipe that was undetected ITCO and Brown & Root, both companies violated State law, for the receipt, storage and processing of such pipes. As we were told by a former ITCO worker[115], many pieces of equipment (joints, vessels, drums etc) stored in the lower yard exceeded 50 μR/h.

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

ITCO and Brown & Root workers were not considered nuclear workers. The external radiation requirements of 50 μR/h (if enforced) ensured that ITCO workers received an external radiation dose of less than 100 mrem/y, the allowable dose for a member of the public. But ITCO and Brown & Root workers received a much greater dose from inhalation of radioactive particulates that were not seriously considered when regulations were drafted.

8.0 Non-Radiological Exposures

8.1 Respirable Particulates

The Occupational Health and Safety Administration's (OSHA) regulation standards in 29 CFR for "Particulates not otherwise regulated" (PNOR) in Table Z-1, and for "inert and nuisance dust" in Table Z-3, are 5 mg/m^3 for respirable dust. As seen in this report, we calculated the air particulate concentrations near the pipe-cleaning machine to be 10 – 30 mg/m^3, or 2-6 times above this limit. Respirable dust includes particles that are small enough to penetrate the nose and upper respiratory system and deep into the lungs. These particles are often small enough to make it past the body's clearance mechanisms of cilia and mucous. Dust is respirable at diameters below 10 μm, with those under 2 μm being the most likely to be retained.[116]

During his April 1987 visit, L. Booher noted that levels of "nuisance dust" were exceeded at the ITCO yard. A similar situation likely existed at the Brown & Root 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.

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[115] Telephone conversation with Mike Bulot, 30 December 2002
[116] US Department of the Interior, 1987

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

This directly applies to the work situation at ITCO and Brown & Root regarding the general connection between inhalation of particulates and adverse health effects. The major difference is that in epidemiological studies, the subjects are usually exposed to much lower particulate concentrations than the former Brown & Root and ITCO 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 assume a scale dust concentration of 10-30 mg/m^3 near the pipe cleaning machines, and of 1.6 – 3.6 mg/m^3 in other parts of the pipe yards.

Numerous references cite a relationship between health effects and dusty conditions at the ITCO and Brown & Root pipeyards. The sources for the risk estimates (with measured health outcome in parenthesis) are:

Cardiopulmonary disease (mortality): Pope et al. 2002
COPD (hospital admissions): Samet et al. 2000
Bronchitis and Asthma (morbidity): Kuenzli et al. 1997
Cough/phlegm and dyspnea (morbidity): Zemp et al. 1999
Myocardial infarction (onset): Peters et al. 2001
Sinusitis (hospital admissions): Gordian et al. 1996

In addition to the studies cited above, the book by Dr. John Gofman collects dose-response studies and quantitatively demonstrates the relationship between radiation and ischemic heart disease.[117]

8.2 Varsol Exposure

Many of the pipe yard workers were exposed to the chemical Varsol, a degreasing agent used to clean pipe threads, while working at the ITCO and Brown & Root pipe yards. Varsol is a trade name for Stoddard solvent. Stoddard solvent is a distillation fraction of crude petroleum that contains at least 200 products, many of which are gasoline range hydrocarbons. The mixture is generally composed of 30-50 percent straight-chain and branch-chain paraffins, 30-40 percent naphthenes, and 10-20 percent aromatic hydrocarbons.[118, 119]

Varsol is 4-percent 1,2,4-trimethylbenzene and 0.1-percent ethylbenzene, both of which are known to be toxic for inhalation, ingestion and dermal contact.[120] It is colorless, insoluble in water, volatile, and smells like kerosene or gasoline. Stoddard solvent is used as a dry-cleaning solvent and a metal degreaser. It is also used industrially as a thinning agent in paints, coatings and waxes and as a solvent in printing ink, photocopier toner, adhesives, rubber products, waxes,

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[117] Gofman, 1999
[118] Agency for Toxic Substances and Disease Registry (ATSDR), 2000
[119] ATSDR, 1995
[120] ExxonMobil

polishes, and pesticides.[121, 122] Varsol was used at Brown & Root and ITCO to clean the grease covered pipe ends and thread protectors.

Inhalation is the primary route of exposure to Stoddard solvent due to its high volatility, although dermal absorption can be enhanced by cuts or abrasions on the skin and through prolonged dermal contact with the liquid. Stoddard solvent enters the bloodstream quickly following inhalation. It is then absorbed by tissues throughout the body, and may enter the brain. It is primarily stored in fat due to its lipophilicity. Its transport throughout the body following dermal absorption is not known, although it is thought to be similar to that following inhalation. Due to Stoddard solvent's similarity to other refined petroleum solvents, metabolism is likely to occur in the liver and excretion would occur through the respiratory tract and kidneys. Acute exposure can lead to irritation of the respiratory tract and neurologic effects. Stoddard solvent is a moderate skin irritant and exposure can lead to dermatitis, lesions, and defatting of the skin.[123, 124]

Due to the complexity of Stoddard solvent's composition, the International Agency for Research on Cancer (IARC) has not evaluated the carcinogenic potential. Epidemiologic studies of painters and dry-cleaning workers, who were exposed to Stoddard solvent as well as other mixed petroleum products, have not yielded consistent findings. Some studies have found increased incidences of respiratory tract, bladder, and kidney cancers. Exposure has been associated with neuropsychiatric disorders, hepatotoxicity (toxicity of the liver), kidney damage, and changed in blood-forming capacity.[125, 126]

NIOSH recommends that workers exposed to refined petroleum products have medical surveillance examinations for blood count, urinalysis, and testing of the liver, nervous system, and kidneys. The Occupational Safety and Health Administration (OSHA) has established a time-weighted average standard for Stoddard solvent of 2,900 mg/m^3 in air for a 8-hour workday during a 40-hour workweek. NIOSH recommends an exposure limit of 350 mg/m^3 for a 10-hour workday, with a ceiling level of 1,800 mg/m^3. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a threshold limit value time-weighted average of 525 mg/m^3 for an 8-hour workday.[127, 128] In addition, work with Varsol should only be conducted in a well ventilated area and impervious (non-cloth) gloves should be utilized to limit dermal absorption. It is recommended that respiratory protection be worn if airborne concentrations are unknown or exceed the recommended exposure limit.[129] The odor threshold for Stoddard solvent is less than 2 mg/m^3, although after six minutes it can no longer be detected due to olfactory sense fatigue.[130] Visitors at Brown & Root and ITCO recall smelling Varsol. We have not seen evidence that Brown & Root and ITCO monitored the air for Varsol concentrations.

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[121] ATSDR, 2000
[122] ATSDR, 1995
[123] ATSDR, 2000
[124] ATSDR, 1995
[125] ATSDR, 2000
[126] ATSDR, 1995
[127] ATSDR, 2000
[128] ATSDR, 1995
[129] ExxonMobil
[130] ATSDR, 1995

9.0 Tables and Figures

Table 1. TEDE Dose Rates for different work situations (exposure types) at ITCO

Radiation Pathway	Type A (mrem/h)	Type B (mrem/h)	Type C (mrem/h)	Type D (mrem/h)	Type E (mrem/h)
Inhalation of particulates through 1989	12.79 - 38.36	12.79 – 38.36	2.05 - 4.60		0.47
inhalation of particulates in after 1989	2.80 - 8.40	2.80 - 8.40	0.45 - 1.01		0.47
Inhalation of radon/thoron	0.10 - 0.36	0.10 - 0.36	0.10 - 0.36		0.06
Incidental soil ingestion through 1989	0.27 - 2.61	0.27 - 2.61	0.27 - 2.61		
incidental soil ingestion after 1989	0.06 - 0.57	0.06 - 0.57	0.06 - 0.57		
Groundshine	2.02 - 5.90		2.02 - 5.90		
Ext. radiation (pipe) through 1989	0.75	0.75	0.75	0.98 - 1.00	
Ext. radiation (pipe) after 1989	0.04	0.04	0.04	0.23 - 0.24	
Pipe Radiography for Inspection		0.07 – 0.23			
Total Dose Rate through 1989	**15.94 – 47.98**	**13.98 – 42.31**	**5.19 – 14.22**	**0.98 – 1.00**	**0.54 – 0.69**
Total Dose Rate after 1989	**5.03 – 15.27**	**3.07 – 9.59**	**2.67 – 7.88**	**0.23 – 0.24**	**0.54 – 0.69**

<u>Description of Exposure Types:</u>

A: Physical work in pipe yards near descaling process
B: Physical work in inspection units
C: Physical work in pipe yards at distance from descaling process
D: Trucking of pipe
E: Work in auxiliary buildings

Table 2. Exposure type, Time and Doses Received at ITCO and Brown & Root for Workers Diagnosed with Cancer

Name	Cancer Type	Radiation Exposure Type and Percentage of Time Worked						TEDE Radiation Dose (rem)	Cancer Organ Radiation Dose (rem)	IREP Probability of Causation
		Type	% time	Type	% time	Type	% time			
Batiste, Dwayne	Colon	A	90%	C	10%			74.3 - 1,931	14.3 - 74.2	26.71%
Calvey, Dolin	Pancreas	A	50%*	C	50%*	E	100%*	591.0 - 13,846	153.8 - 647.4	68.28%
Guidry, Cedric Sr.	Skin, Bladder	A	20%	C	20%	D	60%	99.78 - 2,095	143.2/35.71 - 414.8/111.0	92.88%
Richard, Clarence	Nasopharynx	A	50%	A	50%			283.8 - 6,593	723.6 - 18,895	98.80%
Richardson, James	Thyroid, skin cancer	A	12.5%	C	12.5%			112.6 - 2,076	50.26 - 142.6	69.14%

* Dolin Calvey worked as a “Type A” and “Type C” worker from 1953 to 1974, and as a “Type E” worker from 1975 to 1988.

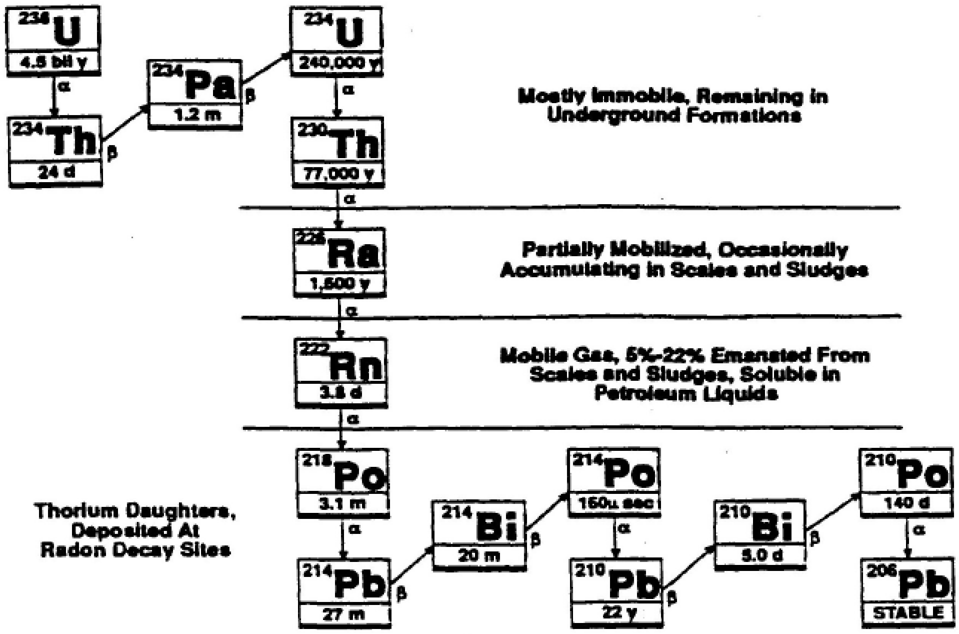
Table 3. Exposure Type, Time and Dose received at ITCO and Brown & Root for Workers Diagnosed with Non-Cancerous Health Problems

Name	Illnesses	Radiation Exposure Type and Percentage of Time Worked						TEDE Radiation Dose (rem)	Additional Potential Causes of Illnesses
		Type	% time	Type	% time	Type	% time		
Arwood, Curtis	Dermatitis, Myocardial Infarction, Bronchitis	A	90%	C	10%			226.0 – 5,873 (732.0 – 2,186)[a]	α,β Skin radiation Respirable Particulates, VARSOL
Boyer, Darryl	Asthma, Bronchitis	A	50%	C	50%			100.2 – 2,381	Respirable Particulates, VARSOL
Fennidy, Horrace	Chronic Sinusitis, Chronic Bronchitis	A	100%*	B	100%*			168.5 – 4,965	Respirable Particulates, VARSOL
Guidry, Cedric Jr.	Dermatitis, Chronic Cough	A	40%	C	40%	D	20%	43.24 – 1,006 (74.04 – 214.5)[a]	α,β Skin radiation Respirable Particulates, VARSOL
Holmes, Jeffery	Sinus Problems, Dizziness, Shortness of Breath, Cough	A	50%	C	50%			264.0 – 6,104	Respirable Particulates, VARSOL
Richard, Troy	Dyspnea, Asthma, Severe Numbness in Arms and Hands	A	40%	C	40%	D	20%	108.1 – 2,514	Respirable Particulates, VARSOL

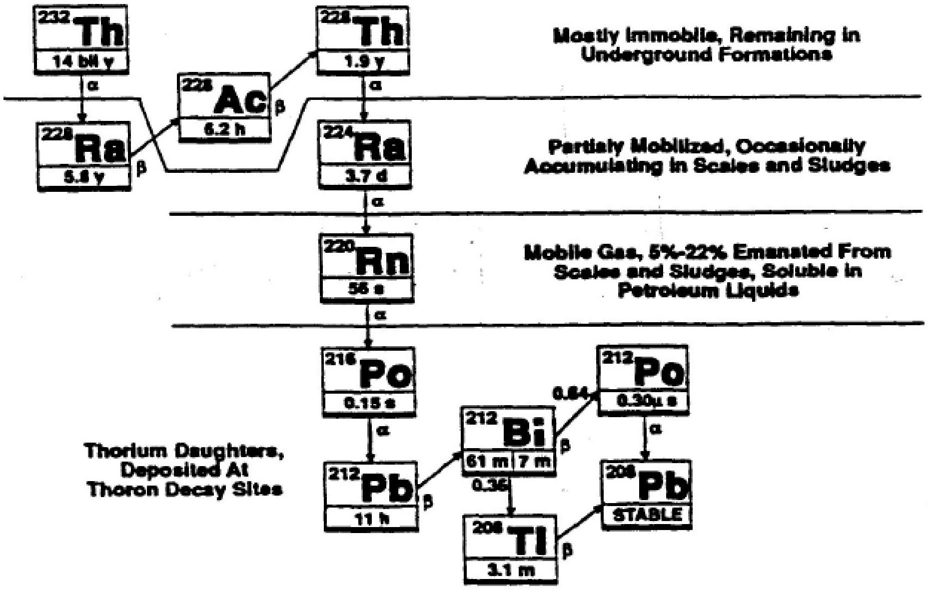
* Horrace Fennidy worked as a “Type A” worker in 1980 and as a “Type B” worker from 1981 to 1986.

[a] – radiation to skin due to α,β radiation

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

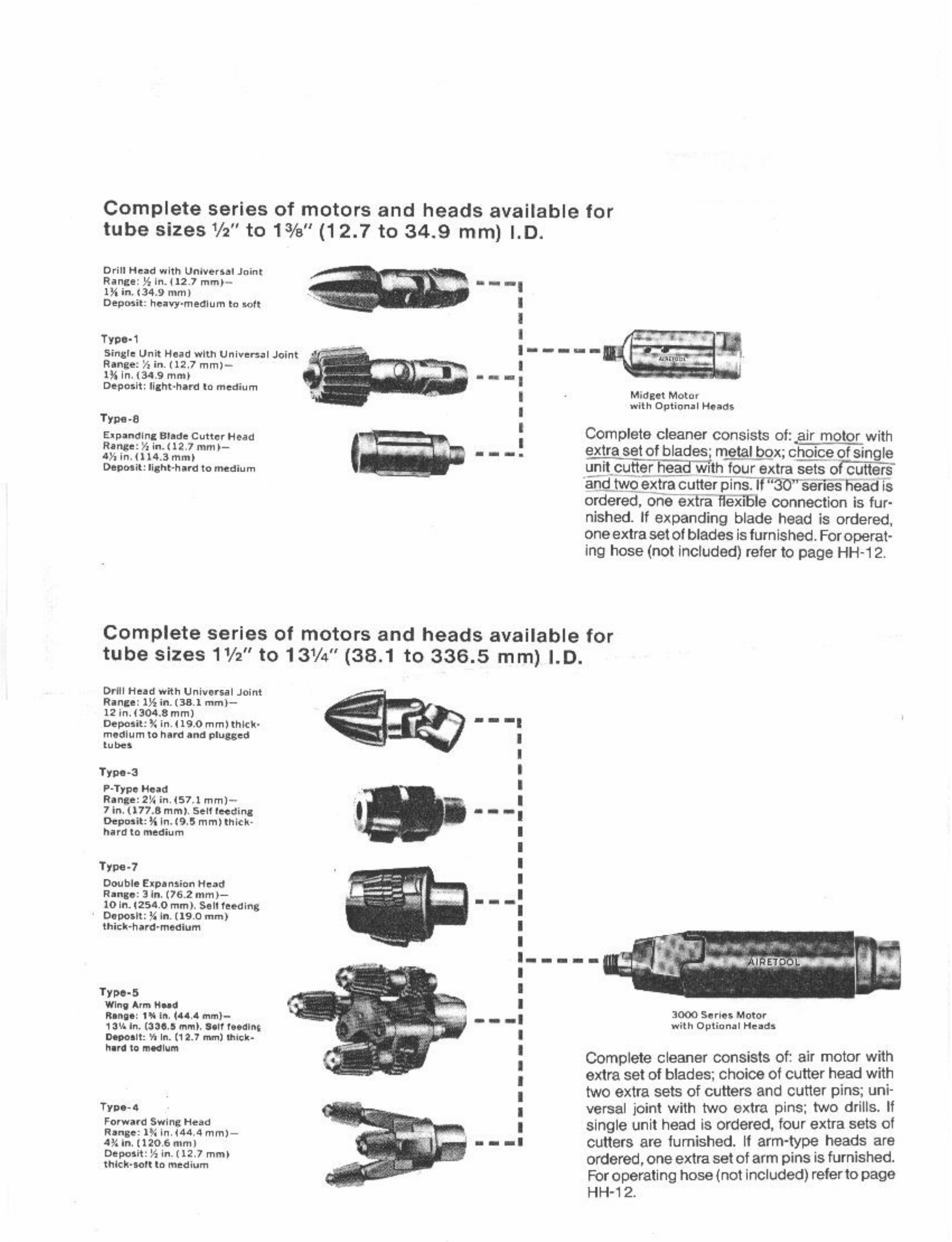


Uranium-238 Decay Series



Thorium-232 Decay Series

Fig. 2. Air Rattlers for Straight Tubes



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

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

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.

Figure 2. Air rattlers for straight tubes.

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