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A RISK ASSESSMENT OF THE USE AND REUSE OF NORM-CONTAMINATED WASTE

Prepared by

Rogers & Associates Engineering Corporation
P.O. Box 330
Salt Lake City, Utah 84110-0330
(801) 263-1600

under contract with
Sandy Cohen & Associates, Inc.
1311 Dolley Madison Blvd., Rte. 123
McLean, VA 22101

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William E. Russo
Work Assignment Manager

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Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Figures

Figures (Continued)

Tables

Tables (Continued)

Tables (Continued)

Executive Summary

The Environmental Protection Agency (EPA) has had a continuing interest in addressing potential radiation exposures from the use and management of Naturally Occurring Radioactive Materials (NORM). Draft standards and recently promulgated regulations address several areas of concern, including emissions from several NORM sources such as elemental phosphorus plants and the disposal of phosphogypsum, and guidance on the disposal of drinking water treatment residues. The EPA, in May 1991, released a draft risk assessment characterizing generation and disposal practices of wastes which contain diffuse levels of NORM (EPA91).

In order to minimize wastes, alternative uses of NORM-contaminated oil production equipment and phosphogypsum are currently being developed and practiced. An investigation into the recycling and reuse of these materials is needed to evaluate risks and exposures to the public. The overall objective of this report is to present a risk assessment of the products associated with reprocessing and reuse of NORM-contaminated oil production equipment and phosphogypsum. Current reuse and recycling practices are summarized along with any associated requirements and regulation for transportation and reuse of NORM-contaminated material.

The oil and gas production industry produces approximately 700,000 m^3 of waste (sludge, scale, and equipment) annually (EPA91). It is estimated that ten to thirty percent of this waste contains naturally-occurring radioactive material (NORM) (EPA91). The production of oil and gas can concentrate the NORM. NORM waste from oil and gas production contains about 10 to 100,000 pCi of radium per gram of waste (EPA91). A median value of 360 pCi (API89) radium per gram of scale is used in the risk assessment. Lower radium concentrations (50 pCi/g) occur in sludges from oil and gas production, but neither sludge nor the equipment containing sludge are reused (API89).

The yearly phosphogypsum production has averaged nearly 40 million MT since 1984 (EPA91). The total phosphate waste volume generated in the U.S. from 1910 to 1981 has been estimated at 7.7 billion MT (EPA91). An average of eight percent of the mined phosphate rock (approximately 3.2 million MT) are processed annually in thermal plants for the production of elemental phosphorous (EPA91). Since the thermal process yields about 0.07 MT (EPA91) of elemental phosphorous per MT of phosphate rock, approximately 3.0 million MT of slag are generated yearly by U.S. thermal plants. The annual average slag generation rate is estimated to be 600 thousand MT per plant.

Alternative uses of NORM-contaminated oil and gas production equipment and phosphogypsum reviewed in this document are based on actual practices. Before the accumulation of NORM in oil and elemental phosphorous production equipment was fully recognized, contaminated equipment, such as tubing, was occasionally released to the public for alternative uses (FUE92). The uses included: load-supporting beams in house construction, plumbing for culinary water, fencing material, for playground equipment in school yards, awning supports, and practice welding material in classrooms (FUE92).

Since its discovery, greater precautions have been taken to evaluate and remove NORM contamination from used oil and phosphate-production equipment before its release for reuse (ZAL92). Loads of scrap metal being transported are often surveyed for hidden radioactive sources and for NORM (MIN92, BER92). Piping and equipment are generally cleaned before release or before being sent to a smelter. Additionally, pollution control devices such as filters and bubblers are emplaced in the smelter stacks to reduce airborne emissions (ROW92). Selection among these alternatives depends in part on the quantity of NORM remaining in the equipment.

Alternatives for the use of phosphogypsum have included use as a soil conditioner for agriculture, as a base for secondary road construction, as a concrete additive, and in research and development activities (RAE92). Recent revisions to the NESHAP for phosphogypsum reuse limit the average radium-226 concentration in phosphogypsum for agricultural use to no greater than 10 pCi/g. Additionally, the use of phosphogypsum in research and development is permitted. However, no facility may purchase or process more than 700 pounds of phosphogypsum. Other uses of phosphogypsum are now prohibited without prior EPA approval (FR92).

Risks resulting from exposures in the various scenarios are estimated. The PATHRAE methodology is used to determine the risks of human exposure to various contaminant pathways. The MICROSHIELD code is used to determine direct gamma exposure rates for scenarios too complex for the PATHRAE methodology. PRESTO-PILCPG is used to determine exposures from atmospheric resuspension pathways. COMPLY is utilized to determine exposures from stack releases. VARSKIN is used to determine acute dermal exposures from direct contact with NORM scale.

Risks resulting from the reuse and recycling of NORM are found to be significant in several cases. For the scenarios involving past practices of unrestricted general release, overall risks range from 1.7E-08 for a teacher supervising a playground to 1.2E-05 for a child playing on a NORM-contaminated jungle gym (for median NORM concentrations). In the scenarios where NORM-contaminated equipment is reprocessed, risks are comparable where the amount of scale transported via the dominant exposure pathways and exposure times are larger (9.0E-09 for a truck driver and 2.0E-04 for a smelter yard worker where no special NORM capturing slag agents are added).

The risks from the use of phosphogypsum are significantly affected by inhalation of radon. Risk to the farmer of land where phosphogypsum was used as fertilizer is 6.8E-06 (with 3.1E-06 resulting from radon inhalation). Risk to the reclaimer of land where phosphogypsum was used as an additive to concrete for road construction is 1.4E-04 with 8.1E-05 resulting from radon inhalation.

The risk assessments are calculated to provide insight into the potential health impacts associated with the reuse and recycling of NORM wastes; to determine whether a more vigorous analysis or more detailed characterization is justified; and to help evaluate the need for future regulatory action.

1. Introduction

Natural radioactivity occurring at trace concentrations in oil and gas formations, ore bodies, and water supplies can accumulate during production or purification. Since the radioactivity is generally low and of natural origin, its accumulation and significance were not noted and studied until recently (MAR87). This report presents analyses of the radiological impacts from the reuse of equipment containing naturally-occurring radioactive materials (NORM) from oil and gas production facilities and from phosphate fertilizer production plants. Additional concerns result from past general reuses of NORM-contaminated equipment and wastes without knowledge of their NORM concentrations.

NORM concentrations in oil and gas production equipment and phosphogypsum vary from background levels to levels exceeding 100,000 pCi/g (EPA91), suggesting a similarly broad range of risks from alternative uses for the contaminated equipment. When elevated occurrences are found, the equipment use should be handled in a way that protects against significant radiation exposure. Although detailed regulations restrict the uses of radioactive materials regulated under the atomic energy act (10 CFR 61, 40 CFR 192), there is no specific federal guidance on the reuse of wastes and contaminated equipment containing NORM with elevated radionuclide concentrations. Due to the lack of specific federal guidance, NRC Regulatory Guide 1.86, providing direction for implementation of the requirements of 10 CFR 50, is often applied for guidance in NORM-contaminated equipment release and reuse.

Specifically, 10 CFR 50 presents requirements for termination of an operating license for a nuclear reactor, including decontamination of the facility and equipment. Residual radioactive contamination levels are specified for release of areas, equipment, and materials for unrestricted reuse. These levels are expressed as dpm per 100 cm^2 area. If contaminated tubing and pipes are to be used for culinary water plumbing, then the national primary drinking water regulations and maximum allowable radionuclide water concentrations specified in 40 CFR 141 are also applicable. Table 1-1 presents a summary of the applicable regulation from 10 CFR 50 and 40 CFR 141.

Table 1-1. Application of 10 CFR 50 and 40 CFR 141 to NORM contaminated equipment reuse.

Citation & Title	Limit	
10 CFR 50, Domestic Licensing of Production and Utilization Facilities/NRC Regulatory Guide 1.86	Avg: Max:	100 dpm/100 cm^2 [a] 300 dpm/100 cm^2
40 CFR 141, National Primary Drinking Water Regulations	Pb-210 Ra-226 Ra-228 Po-210 Th-228	4 mrem/y 20 pCi/l 20 pCi/l 15 pCi/l 15 pCi/l

[a] Limit applies to overall exposure reading from NORM (approx. 45 pCi/100 cm^2).

The Part N subcommittee of the National Conference of Radiation Control Program Directors has been working since 1983 to develop model state regulations (Part N of suggested State Regulations for control of Radiation) for the control of NORM (CPD87). These model regulations are intended to help individual states develop regulations in a uniform way such that the regulations are consistent from state to state and with Federal regulations.

The NORM Ad Hoc Committee, consisting of representatives from the Environmental Protection Agency Alabama, Arkansas, Louisiana, Mississippi, Oklahoma and Texas, met June of 1990 and informally adopted interim guidance on the release of NORM-contaminated equipment. It is recommended that equipment contaminated below 50 μR/hr should be released for general reuse. Additionally, equipment contaminated above 50 μR/hr should be cleaned to levels below 50 μR/hr before release (AHC90). It should be noted that the Environmental Protection Agency does not agree with these proposed standards (EPA92a). Additionally, both Mississippi and Texas have since proposed different regulations.

Louisiana is the only state at this writing that has regulations specifically concerning NORM and NORM-contaminated equipment. The State of Louisiana licenses the operators of cleaning and refurbishing shops which handle oil production equipment. NORM-contaminated scale is now regulated to protect the cleaning operators and the general public. Transfer of oil production equipment and land must be preceded by a release survey to insure that NORM is not released to the general public for unrestricted use.

Other states are applying broad ionizing radiation regulations to NORM guidance. The State of Michigan, in Rule 2410, restricts any employer from possessing, using, or transferring sources of ionizing radiation in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter a whole body dose in excess 1.25 rem. Additionally, Rule 2410 restricts airborne contaminants (R2410).

The U.S. Department of Transportation (DOT) also does not specifically regulate NORM, but it does regulate the transportation of radioactive material. The DOT regulations, applicable to the transport of low-level radioactive waste, are found in Title 49 of the U.S. Code of Federal Regulations Parts 171, 172, 173, and 177. Paragraph 173.403(y) specifically defines regulated radioactive material as "*any material having a specific activity greater than 0.002 microcuries per gram*" (49 CFR 173). Since the radionuclides of the Ra-226 decay chain are the principal elements in NORM, the applicability of the 49 CFR 173 limit can be determined as follows:

$$C_{Ra-226} = 3\ C_{Ra-228} \tag{1-1}$$

where

C_{Ra-226} = concentration of Ra-226 in scale (pCi/g)

C_{Ra-228} = concentration of Ra-228 in scale (pCi/g)

Applying this relationship and the five principal nuclides (including daughters) being considered (see Table 2-3) gives:

$$3\ C_{Ra-226} + 2\ C_{Ra-228} = 2{,}000\ pCi/g \tag{1-2}$$

Solving equations 1-1 and 1-2 simultaneously gives a limiting <u>total</u> radium (Ra-226 and Ra-228) of 726 pCi/g. NORM-contaminated equipment with total radium concentrations greater than this limit are then required to follow DOT regulations for the transportation of low-level radioactive waste before being shipped. Additionally, paragraph 173.441(b3) restricts radiation levels at any point 2 meters from the outer lateral surfaces of a transport vehicle to a maximum of 10 mR/hr (49 CFR 173).

This report analyzes the risks associated with the reuse and handling of oil and gas production equipment and phosphate scale equipment contaminated with NORM (cleaned or undisturbed) and phosphogypsum. Reuse alternatives analyzed include: 1) storage of equipment on site; 2) use of phosphogypsum as a soil conditioner, a road construction base, and as a concrete additive; 3) unrestricted release of contaminated equipment to the general public; and 4) smelting of equipment for the fabrication of new products. The exposures from both median and 90 percentile NORM concentrations are evaluated separately to better estimate their range. For the reuse alternatives, radiation exposures are considered from radon gas inhalation, external gamma-ray exposure, contaminant ingestion and dust inhalation. Scenarios analyzed are based on current industrial methods and actual practices where possible. Using the NORM concentrations and the risk involved in each exposure pathway an evaluation can be made as to the risks from reuse practices.

Risks from exposures during cleaning and reprocessing of contaminated oil and gas production and phosphate ore equipment are also analyzed. Exposure pathways during cleaning and recycling of NORM-contaminated equipment are identified from point of generation to the final release of the recycled product. Potential worker risks and radionuclide concentrations and dilutions are evaluated for each process. Additionally, alternative cleaning methods and exposure reduction procedures currently being utilized in the steel industry are reviewed.

As a safeguard against unknowingly receiving radioactive sources and other materials, many steel mills and scrap yards are installing alarmed detection systems (ZAL92). Some of these alarm systems are being tripped by NORM-contaminated equipment being received for reprocessing (ZAL92). Minimum detectable NORM concentrations, loading distributions and volumes are analyzed as part of this risk assessment. Additionally, these limiting concentrations and volumes are compared with applicable DOT regulations.

This report presents a waste and use characterization and risk assessment for NORM generated in oil and gas production and fertilizer production. The general methodology presented here can be used to evaluate similar scenarios and situations. Chapter 2 presents an overview of the industry, the characterization of physical and radiological properties of the waste and the waste generation rates. Chapter 3 presents the reuse practices which determine the pathways of exposure. Additionally, current radiation detection methods and alarm settings are presented. The risk assessment methods, presented in Chapter 4, document the exposure scenarios.

Chapter 5 gives the results of the risk assessments. The risk assessments are calculated to provide insight into the potential health impacts associated with the reuse and recycling of NORM waste; to determine whether a more vigorous analysis or more detailed characterization is justified; and to help evaluate the need for future regulatory action. Chapter 6 provides a summary and conclusions.

2. NORM in Production Wastes

This chapter discusses the production of NORM wastes in the oil, gas and phosphate industries. The wastes are characterized and median and high radionuclide concentrations are estimated. Source terms used in the risk assessments of Chapter 4 and 5 are presented and justified.

2.1 OIL AND GAS PRODUCTION WASTES

Both uranium and thorium and their decay products are known to be present in varying concentrations in underground geological formations from which oil and gas are produced (BEL60, JOH73, PIE55). The presence of these naturally occurring radionuclides in petroleum reservoirs has been recognized since the early 1930's and has been used as one of the methods for finding hydrocarbons beneath the earth's surface (MAR87). Uranium and thorium are insoluble and, as oil and gas are brought to the surface, they remain mostly in place in the underground reservoir (EPA91). However, radium and the radium daughters are slightly soluble, and under some conditions may become mobilized by the liquid phases in the formation (EPA91). When brought to the surface with liquid production streams, radium and its daughters may remain dissolved at dilute levels, or they may precipitate because of chemical changes and reduced pressure and temperature (EPA91). Since radium concentrations in the original formation are highly variable, the concentrations that precipitate out on the surfaces of oil and gas production and processing equipment are also variable and may exhibit elevated radioactivity levels. Scales and sludges that accumulate in surface equipment may vary from background levels of NORM (~1 pCi/g) to elevated levels as high as hundreds of thousands of picocuries per gram depending on the radioactivity and chemistry of the geologic formation from which oil and gas are produced and on the characteristics of the production process (EPA91, RAE92).

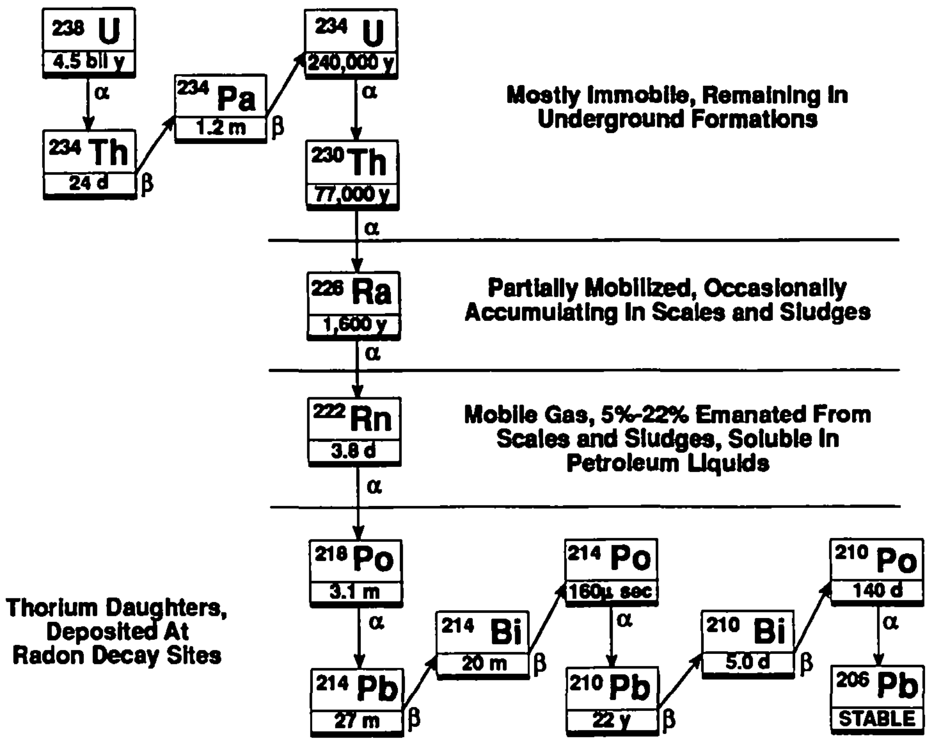
The initial production of oil and gas from a reservoir is usually dry (EPA91). However, as the natural pressure within the petroleum bearing formation falls, groundwater present in the reservoir will also be brought to the surface with the oil and gas. This formation water contains dissolved mineral salts, a very small proportion of which may be radioactive because of the presence of uranium and thorium and their decay products in the underground formation. Thus, the amount of surface NORM material from a producing field generally increases with the increases in the amount of water pumped from the formation (EPA91).

Deposits in production equipment are generally in the form of scale, loose material, and oily sludge. The scale in these chemical matrices is very hard and relatively insoluble. It may vary in thickness from a few millimeters to more than 3 cm (RAE92). Some accumulations have been known to completely block the flow in pipes as large as 4 inches in diameter (EPA91).

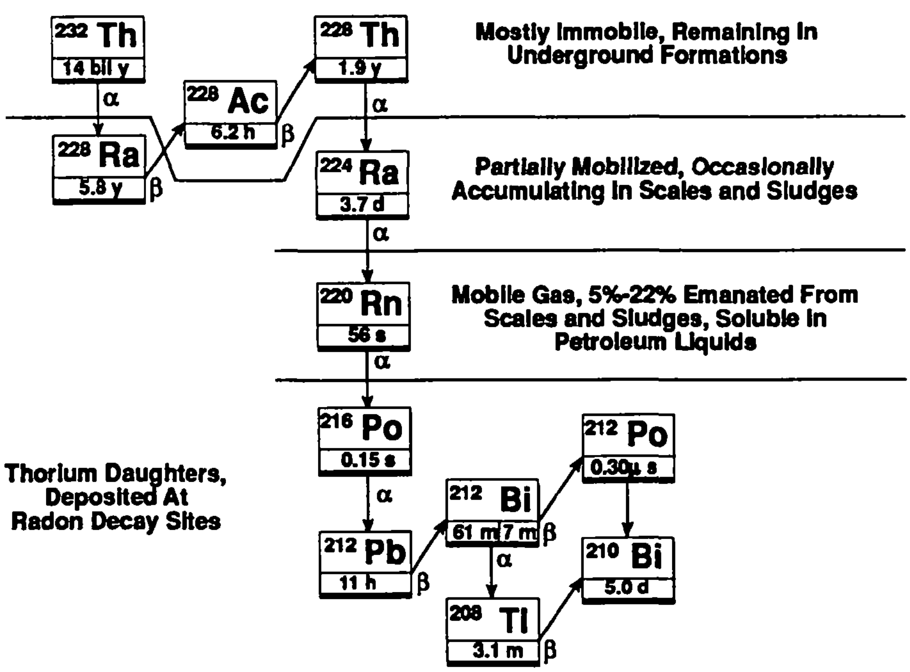
The NORM accumulated in production equipment scales typically contains radium coprecipitated in barium sulfate ($BaSO_4$) (EPA91). Sludges are dominated by silicates or carbonates, but also incorporate trace radium by coprecipitation. Ra-226 is generally present in scales and sludges in higher concentrations than Ra-228 (EPA91). The nominal activity ratio appears to be about three times as much Ra-226 as Ra-228 (EPA91). Typically, Ra-226 is in equilibrium with its decay products, but Ra-228 is not in equilibrium with its decay products. Reduced concentrations of Ra-228 daughters are due to the occurrence in the thorium series decay chain of two radium nuclides (Ra-228 and Ra-224) separated by Th-228 with a 1.9-year half-life. Thus radium mobilized from the formation initially becomes depleted in Ra-224 (half-life = 3.6 days) until more is generated by Ra-228 decay through Th-228 (Figure 2-1). For the sake of simplicity, the term radium is used in this report to refer to the combination of Ra-226 and Ra-228.

2.1.1 Oil and Gas Scale and Sludge Production Rates

The volume of NORM scale and sludge that is produced annually is uncertain, but recent estimates suggest that as many as one-third of domestic oil and gas wells may produce some radium-contaminated scale (MCA88, EPA91). The geological location of the oil reserve and the type of production operation strongly influences the prevalence of NORM accumulations. A review of surveys conducted in 13 of the major oil producing states revealed that the number of facilities reporting NORM in production wells ranged from 90 percent in Mississippi to none or only a few in Colorado, South Dakota, and Wyoming (MCA88). However, 20 to 100 percent



Uranium-238 Decay Series



Thorium-232 Decay Series

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Figure 2-1. Principal nuclides, decay modes, and mobilities of the Uranium-238 and Thorium-232 decay chains.

of the facilities in every state identified NORM in heater/treaters. A separate estimate based on Mississippi data indicates that one-half of the wells do produce scale and ten percent of these have scale with elevated NORM concentrations (BLI88).

In a recent assessment of the characteristics of diffuse NORM for the EPA (EPA91), it was determined that approximately 620,000 oil and gas production wells operate in the United States. Additionally, an average of 30 percent of these wells were projected to be operated by equipment contaminated with NORM scale and sludge. The average total annual volume of NORM scale and sludge waste generated in the U.S. can be estimated as 230,000 m^3 or approximately 1.23 m^3/contaminated well (EPA91, RAE92).

In a related study performed for the State of Texas (RAE88), the volume of NORM scale waste was estimated to be between six percent - ten percent of the total NORM waste volume generated per well. Total waste evaluated included sludge, scale, tubing, pipes, and valves.

2.1.2 Radionuclide Concentrations

Elevated NORM concentrations in oil and gas production equipment result when Ra-226 and Ra-228 and their decay products co-precipitate with mineral scales, such as $BaSO_4$, that form deposits on the insides of field production equipment. Concentrations of NORM radionuclides in scale and sludge of petroleum production equipment can vary from background (about 1 pCi/g) to hundreds of thousands of picocuries per gram (EPA91). For example, Ra-226 concentrations as high as 160,000 pCi/g have been found in pipes at storage yards in Michigan (DNR90). Factors which can affect the magnitudes of NORM concentrations in oil and gas production equipment include the location of the production facility, the type of equipment, how long the production well has been in operation, and changes in temperature and pressure that take place during extraction of the petroleum from the underground formation (EPA91). The State of Michigan, for example, reports that the precipitates containing radium in Michigan are predominantly tank sediments rather than pipe scale as found in Louisiana (DNR90).

The American Petroleum Institute (API) has conducted an industry-wide survey of external gamma radiation exposure levels associated with NORM in oil production and gas processing equipment (API89). Over 36,000 individual observations were made in 20 states and two offshore areas by participating petroleum companies using similar equipment and data collection protocols. Radiation exposure levels were measured in units of µR/hr. Background radiation levels were also measured and reported for each site in order to differentiate the background effects from contamination effects. The survey showed, as illustrated in Figures 2-2 and 2-3, that the geographic areas with the highest equipment readings (2-33 µR/hr) were northern Texas and the gulf coast crescent from southern Louisiana and Mississippi to the Florida panhandle. Very low levels of NORM activity (0-2 µR/hr) were measured in equipment from California, Utah, Wyoming, Colorado, and northern Kansas. Assuming 33 percent (EPA91) of the oil wells produce NORM-contaminated scale, and that an average of 2 tons of scale precipitate for every 3,000 barrels of oil produced (EPA91), median and 90 percentile (calculated as median × GSD^t with $t = 1.2817$) NORM scale concentrations can be calculated for each state surveyed. Table 2-1 presents the median and 90 percentile scale concentrations as well as the total NORM activity for the main oil producing states in the United States.

The American Petroleum Institute study also determined that the highest concentrations of radium (Ra-226 and Ra-228) occurred in the wellhead piping and in production piping near the wellhead (API89). The concentration of radium deposited in separators is about a factor of ten less than that found in wellhead systems. Additionally, there is a further reduction of up to an order of magnitude in the radium concentrations in heater/treaters and in sludge holding tanks. Concentrations of radium in scale deposited in production tubing near wellheads can range to up to tens of thousands of picocuries per gram (EPA91, API89). The concentrations in more granular deposits, found in separators, range from one to about one thousand picocuries per gram (API89). Higher concentrations are associated with hard scale deposits associated with precipitation from the water phase. Radium concentrations in sludge deposits in heater/treaters and tanks are generally around 50 pCi/g (API89).

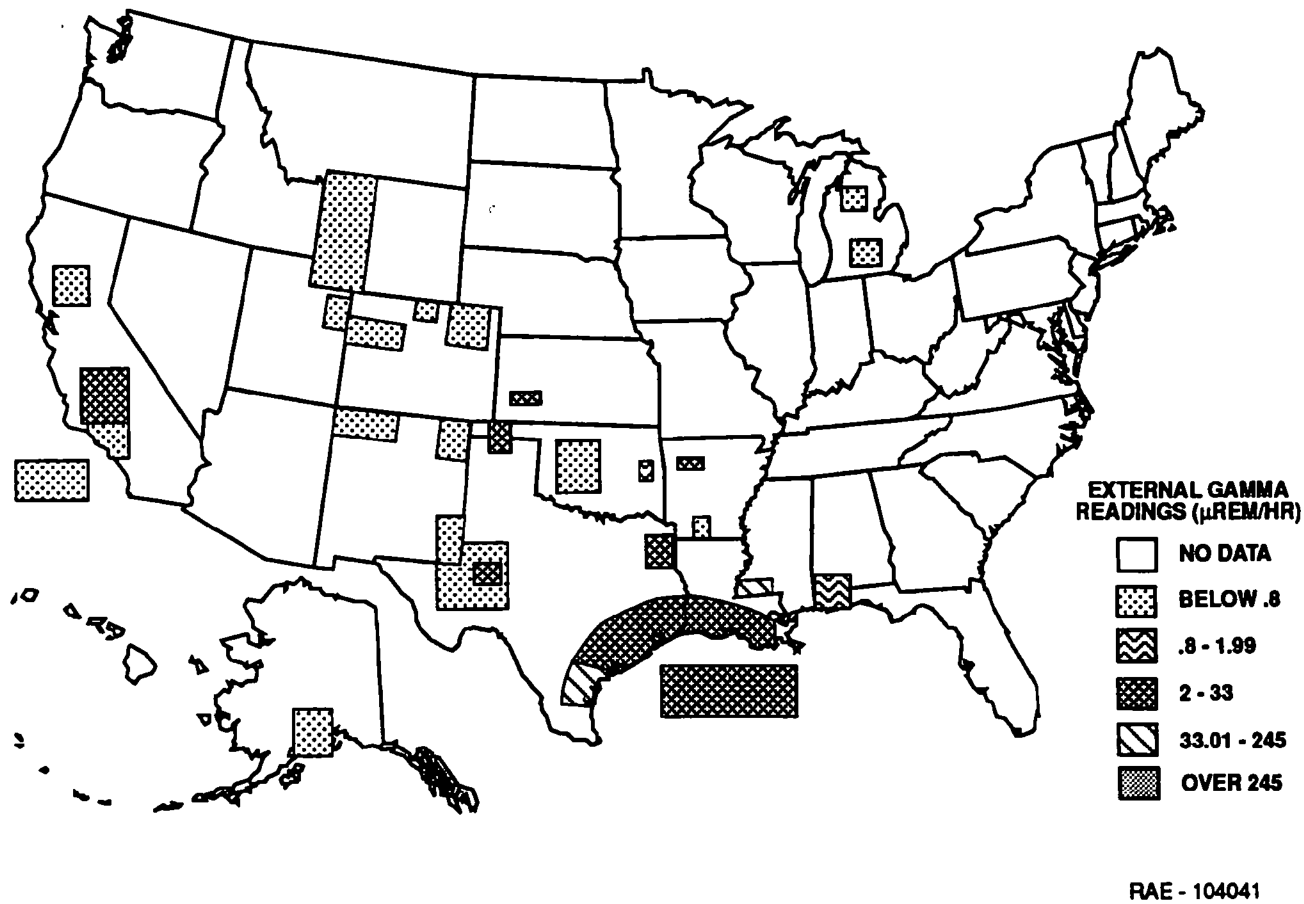

Figure 2-2. Median of differences of external readings over local background for NORM contaminated gas production equipment (API89).

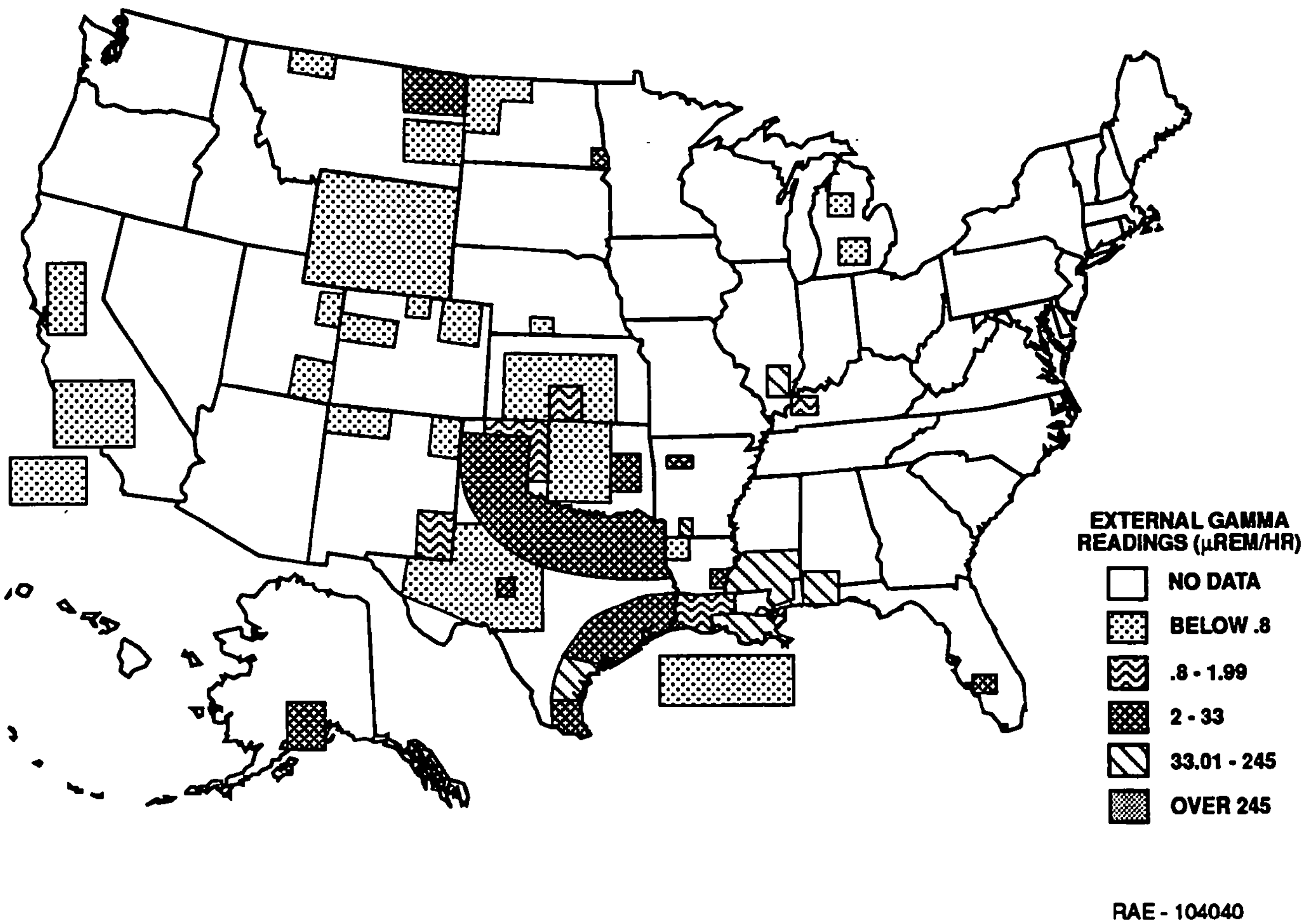

Figure 2-3. Median of differences of external readings over local background for NORM contaminated oil production equipment (API89).

Table 2-1. Median and 90 percentile gamma radiation levels and NORM concentrations based on (API89) survey data.

State	Gamma Radiation: Mean Difference Above Background (μR/hr)[a]	Gamma Radiation: 90 Percentile Difference Above Background (μR/hr)[a]	Oil Produced (1000 barrels/yr)[b]	Total Scale Produced (tons/year)[c]	NORM Contaminated Scale Produced (tons/yr)[d]	Mean Scale Concentration of Above Background Readings (pCi/g)[e]	90 Percentile Scale Concentration of Above Background Readings (pCi/g)[e]	Mean Activity of NORM Scale Produced (Ci/yr)[f]
Alaska	1.0E+01	8.5E+01	7.2E+05	4.8E+05	1.6E+05	4.1E+02	3.5E+03	5.9E+01
Alabama	5.9E+01	2.4E+02	2.6E+04	1.8E+04	5.9E+03	2.4E+03	9.9E+03	1.3E+01
Arkansas	2.0E+00	4.4E+00	1.5E+04	1.0E+04	3.3E+03	8.2E+01	1.8E+02	2.5E-01
California	1.0E+01	5.1E+01	4.0E+05	2.7E+05	8.9E+04	4.1E+02	2.1E+03	3.3E+01
Colorado	8.5E+00	1.7E+01	3.3E+04	2.2E+04	7.4E+03	3.5E+02	6.7E+02	2.3E+00
Florida	5.9E+01	2.4E+02	9.4E+03	6.2E+03	2.1E+03	2.4E+03	9.9E+03	4.5E+00
Illinois	2.3E+01	2.2E+02	2.4E+04	1.6E+04	5.3E+03	9.4E+02	8.9E+03	4.5E+00
Kansas	1.1E+01	1.1E+02	6.8E+04	4.5E+04	1.5E+04	4.3E+02	4.4E+03	5.9E+00
Kentucky	1.2E+01	6.8E+01	6.8E+03	4.6E+03	1.5E+03	4.9E+02	2.8E+03	6.7E-01
Louisiana	1.2E+01	8.1E+01	5.4E+05	3.6E+05	1.2E+05	4.8E+02	3.3E+03	5.2E+01
Michigan	2.6E+00	5.0E+00	3.0E+04	2.0E+04	6.7E+03	1.1E+02	2.0E+02	6.5E-01
Mississippi	4.6E+00	3.8E+02	2.9E+04	1.9E+04	6.4E+03	1.9E+02	1.6E+04	1.1E+00
Montana	3.7E+01	4.3E+01	2.6E+04	1.7E+04	5.7E+03	1.5E+03	1.7E+03	7.8E+00
North Dakota	9.0E+00	1.7E+01	4.4E+04	3.0E+04	9.8E+03	3.7E+02	7.1E+02	3.3E+00
Nebraska	5.4E+00	1.1E+01	6.1E+03	4.1E+03	1.4E+03	2.2E+02	4.5E+02	2.7E-01
New Mexico	4.0E+00	1.9E+01	8.7E+04	5.8E+04	1.9E+04	1.6E+02	7.7E+02	2.9E+00
Oklahoma	4.0E+00	3.7E+01	1.7E+05	1.1E+05	3.7E+04	1.6E+02	1.5E+03	5.5E+00
Texas	5.0E+00	3.0E+01	9.0E+05	6.0E+05	2.0E+05	2.0E+02	1.2E+03	3.7E+01
Utah	5.0E+00	9.0E+00	4.0E+04	2.7E+04	8.9E+03	2.0E+02	3.7E+02	1.7E+00
Wyoming	2.3E+00	4.3E+00	1.3E+05	9.0E+04	3.0E+04	9.4E+01	1.8E+02	2.5E+00
EFFECTIVE NATIONAL TOTAL			3.3E+06	2.2E+06	7.3E+05			
EFFECTIVE NATIONAL WEIGHTED MEAN						3.6E+02	2.4E+03	2.4E+02

a (API89).
b (EPA91).
c Based on 2 tons of scale for every 3000 barrels of oil produced (EPA91).
d Based on 1/3 of all scale is NORM contaminated (EPA91).
e Based on the correlation that the State of Louisiana is projected to have a median of 480 pCi/g (RAE92) which corresponds to median readings of 11.8 μR/hr.
f Based on pCi/g for the projected tons of NORM per year.

The API89 data for the State of Louisiana shows that approximately 60 percent of the total NORM waste is below 15 pCi/g (based on correlations developed in RAE92). Using the API89 data for the State of Louisiana, the median value of the radium (Ra-226 and Ra-228) concentration in scale is 270 pCi/g (RAE92). This value includes many measurements that are within the uncertainty of general detection limits. To characterize actual radium distributions, the values less than the 15 pCi/g uncertainty limit are removed from the distribution and a measurable biased median concentration of 480 pCi/g (RAE92) is calculated.

Due to the consistently high measurements found in Alabama, Florida, Mississippi and Illinois, the national distribution of radium in NORM-contaminated equipment is estimated to have a median of 180 pCi/g, a seventy-fifth percentile of 900 pCi/g, a ninetieth percentile of 2,000 pCi/g, and a ninety-fifth percentile near 9,000 pCi/g. Removing readings from the national distribution that are below detection limits gives the distribution found in Table 2-2. The reusable waste from oil and gas production consists of equipment that is contaminated with scale. The concentration of radium (Ra-226 and Ra-228) in scale is calculated to have a median value of 360 pCi/g. A 90 percentile value is calculated using the following equation:

$$Ra_{90\%} = Ra_{median} \times GSD^{t} \qquad \textbf{(2-1)}$$

where

$Ra_{90\%}$ = 90 percent confidence limit of radium in pCi/g

Ra_{median} = median radium concentration = 480 pCi/g

GSD = effective geometric standard deviation = 5.91

t = statistical z-score corresponding to the 90 percent confidence limit = 1.28167.

Using equation 2-1, a 90 percentile confidence limit of 2,400 pCi/g is calculated. These values will be used in this risk assessment. As noted, the Ra-226 concentration is three times that of

Table 2-2. Median and 90 percentile radium concentrations in NORM scale (RAE92) (using measurement data exceeding 15 pCi/g equivalent).

Scale Bearing Equipment	Median Concentration (pCi/g)	Geometric Standard Deviation	90.0 Percentile Concentration (pCi/g)
Oil Line Piping	4.9E+2	7.3	4.4E+3
Manifold Piping	4.1E+2	6.0	2.9E+3
Injection Well Tubing	1.2E+2	4.5	5.6E+2
Production Well Tubing	1.6E+2	4.2	7.1E+2
Water Lines	1.5E+2	5.5	9.4E+2
Meters, Screens, Filters	1.8E+2	9.0	2.1E+3
SCALE COMPOSITE	**3.6E+2**	**5.9**	**2.4E+3**

Ra-228 and is in equilibrium with its daughters. Table 2-3 gives the median and 90 percentile concentrations of NORM in oil and gas production scale.

For this report, a reference oil and gas production facility consisting of ten production wells is assumed. The equipment for reuse includes oil flow lines, water lines, injection and production well tubing, manifold piping and small diameter valves, meters, screens, and filters. This typical facility (EPA91, RAE92) is estimated to have an average life of 30 years. It is further assumed that tubing and some of the pipe in the wells will be replaced about every seven years giving a total of three replacements of the original tubing during the 30-year facility life (EPA91, RAE92). Estimated quantities of equipment containing scale for reprocessing and reuse are identified in Table 2-4. The median scale volume per well reported in Table 2-4 (1.206m^3/well) is consistent with the (EPA91) reported median (1.23m^3/well) presented in Section 2.1.1 of this report.

2.2 PHOSPHOGYPSUM

Mining of phosphate rock (phosphorite) is the fifth largest mining industry in the United States in terms of quantity of material mined (EPA84). Phosphate rock is processed to produce phosphoric acid and elemental phosphorous. The most important use of phosphate rock is the production of fertilizers, which accounts for about 80 percent of the mining of phosphorite in the United States (EPA91). Waste generated during the production of phosphoric acid and elemental phosphorous is in the form of phosphogypsum.

2.2.1 Production Process

Phosphoric acid is processed by beneficiation of phosphate ore. During beneficiation, phosphate particles are separated from the rest of the ore, creating two types of waste products, phosphatic clay and sand tailings. After beneficiation, the phosphate ore is digested (dissolved) using sulfuric acid. This produces a slurry (phosphogypsum) which is discharged from filter pans, slurried with water, and pumped to large piles (phosphogypsum stacks).

Table 2-3. Median and 90 percentile radionuclide concentrations in gas and oil production NORM scale (RAE92).

Radionuclide[a]	Median Concentration (pCi/g)	90.0 Percentile Concentration (pCi/g)
Ra-226	270	2,900
Ra-228	90	950
Radium	**360**	**3,800**
Pb-210	**270**	**2,900**
Po-210	**270**	**2,900**
Th-228	**90**	**950**

a For external exposures Po-218, Pb-214, Bi-214, and Po-214 are assumed to be in secular equilibrium with radium-226.

Table 2-4. Median NORM contaminated equipment volumes for a ten well facility (EPA91, RAE92).

Scale Bearing Equipment	Median Total Volume for Recycle As Is (m^3)	Median Scale Volume (m^3)	Median Steel Volume (m^3)	Median Total Volume for Recycle As Is (m^3/well)	Median Scale Volume (m^3/well)	Median Steel Volume (m^3/well)
Oil Line Piping & Valves	111.4	9.3	34.4	11.1	0.9	3.4
Manifold Piping & Headers	0.6	0.0	<0.1	0.1	0.0	<0.1
Injection Well Tubing	6.9	0.8	2	0.7	0.1	0.2
Production Well Tubing	8.5	1.1	3.9	0.9	0.1	0.4
Water Lines & Valves	1.4	0.8	0.4	0.1	0.1	<0.1
Meters, Screens, Filters	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITE	128.8	12.1	40.7	12.9	1.2	4

Each phosphoric acid production facility may have one or more phosphogypsum stacks. The stacks range in size from 5 to 750 acres and range in height from 3 to 60 meters (EPA91). A total of 63 stacks has been identified nationwide (EPA91). The average base area is largest for operating stacks, being nearly 230 acres. The average idle or inactive stack is smaller in size, 91 and 55 acres, respectively. The average height is approximately 20 meters (EPA89a). The production rate of phosphogypsum is estimated using the assumption that 4.5 MT of phosphogypsum are produced per MT of P_2O_5 (GUI75). The yearly phosphogypsum production averages nearly 40 million MT since 1984 (EPA91). The total phosphate waste volume generated in the U. S. from 1910 to 1981 has been estimated at 7.7 billion MT (EPA85).

An additional waste product of radiological concern that is associated with this process is phosphoric acid scale. In the production of phosphoric acid from the raw ore, the phosphogypsum must be physically separated from the phosphoric acid by a filtration process. Large stainless steel filter pans are covered with fiberglass fabric which serves to filter out the phosphogypsum while allowing the passage of acid. During this process, small quantities of scale are deposited on the surface areas of the pan and fiberglass mat.

2.2.2 Physical and Radiological Properties

Concentrations of uranium in phosphate ores in the U. S. range from 7 to 100 pCi/g (BLI88). Most of the impurities, including the primary dose-contributing nuclide, radium-226 and its radioactive daughters, are separated as phosphogypsum (EPA91).

For this risk assessment, the reference waste form is phosphogypsum, and the median and 90 percentile radionuclide concentrations, as presented in Table 2-5, are those considered to be typical of phosphogypsum wastes (BID91, HOR88). The risk estimates presented in Chapter 5 are given based on a median radium-226 concentration of 31 pCi/g (BID91) and a 90 percentile radium-226 concentration of 48.6 pCi/g (BID91). The concentration of Ra-228 is derived from the activity ratio of Ra-228 to Ra-226 in phosphate fertilizer. Activity ratios for Th-228 and Th-232 relative to Ra-226 are also those for phosphate fertilizer (BID91). The activity of U-235

Table 2-5. Phosphogypsum median and 90 percentile radionuclide concentrations.

Radionuclide	Median Concentration (pCi/g)	90.0 Percentile Concentration (pCi/g)
Ra-226	31.0	48.6
Po-210	32.2	50.5
Pb-210	43.4	68.0
Th-228	4.1	6.5
Ra-228	4.1	6.5
Th-230	5.8	9.1
Th-232	3.8	6.0
U-234	3.7	5.8
U-235	0.2	0.3
U-238	3.4	5.4

is assumed to be about five percent of the U-238 activity (BID91). Clay and sand tailings generated in the production of elemental phosphorous and phosphoric acid are not considered in this assessment since they are generally not involved in reuse.

Risks associated with the cleaning and reuse of the phosphate scale-contaminated stainless steel filter pans are considered. Median and 90 percentile radionuclide concentrations, as presented in Table 2-6, are those considered to be typical of phosphate scale (EPA91, BID91).

Table 2-6. Phosphate scale median and 90 percentile radionuclide concentrations.

Radionuclide	Median Concentration (pCi/g)	90.0 Percentile Concentration (pCi/g)
Ra-226	3.0E+3	3.6E+3
Po-210	3.1E+3	3.8E+3
Pb-210	4.2E+3	5.1E+3
Th-228	4.0E+2	4.8E+2
Ra-228	4.0E+2	4.8E+2
Th-230	5.6E+2	6.8E+2
Th-232	3.7E+2	4.5E+2
U-234	3.6E+2	4.4E+2
U-235	1.9E+1	2.3E+1
U-238	3.3E+2	4.0E+2

3. Scenarios and Exposure Pathways for Reuse

This chapter identifies the procedures involved in reprocessing NORM-contaminated equipment for general reuse. Exposure pathways are presented for individuals exposed during the reprocessing activities; for individuals exposed to uncleaned equipment; and for individuals exposed due to the reuse of phosphogypsum. The scenarios considered for the exposure pathways are summarized in Table 3-1 and discussed below. Current industrial practices are presented and used as bases for scenario characterization.

3.1 OIL AND GAS PRODUCTION EQUIPMENT

Exposure pathways for reuse and reprocessing of oil and gas production equipment are grouped into two sections. First, pathways resulting from the general unrestricted release of contaminated equipment are reviewed. Second, processes and pathways are reviewed for the recycling and reprocessing of steel from production equipment.

3.1.1 General Unrestricted Release

Before the past decade, oil and gas production equipment was routinely disposed of, recycled, reused, and released to the general public without restriction. Contaminated pipe has even been donated to schools and contractors (FUE92). The State of Mississippi found used oil and gas production tubing contaminated with elevated levels of NORM in school yard fences, playground equipment, residential and school load supporting beams, residential culinary water plumbing, and in use as practice welding equipment for school metal shops (FUE92).

Recent awareness and promulgated state guidelines assist in preventing release of contaminated equipment to the general public. However, evaluation of the public exposures from past practices and potential exposures from equipment inadvertently released need to be evaluated. Exposures resulting from the general use of uncleaned contaminated equipment are presented and analyzed in Chapters 4 and 5.

Table 3-1. Exposure scenarios for evaluation.

Scenario	NORM Source
Unrestricted Release	
Student at jungle-gym	Oil and gas equipment
Teacher at jungle-gym	Oil and gas equipment
Welding shop student	Oil and gas equipment
Welding shop teacher	Oil and gas equipment
Residential construction use	Oil and gas equipment
Reprocessing of Steel	
Scrap Steel Cleaner (Mechanical, Hydrolaser)	Oil and gas and phosphate ore equipment
Storage yard worker	Oil and gas equipment
Transport operator	Oil and gas equipment
Smelter yard worker	Oil and gas equipment
Adjacent resident to the smelter yard	Oil and gas equipment
Adjacent resident to the storage yard	Oil and gas equipment
Adjacent resident to the cleaning facility	Oil and gas equipment
Agriculture	
Agricultural worker	Phosphogypsum
On-site individual	Phosphogypsum
Member of critical population group	Phosphogypsum
Off-site individual	Phosphogypsum
Road Construction	
Construction worker	Phosphogypsum
Vehicle operator	Phosphogypsum
Member of critical population group	Phosphogypsum
Reclaimer	Phosphogypsum
Off-site individual	Phosphogypsum
Research	
Researcher	Phosphogypsum

For exposures resulting from the general use of contaminated equipment at schools and in residential construction, the following scenarios and associated pathways are considered:

- Student at Jungle-gym
  - Direct gamma
  - Dermal exposure
  - Dust inhalation

- Teacher at Jungle-gym
  - Dust inhalation

- Welding Shop Student
  - Direct gamma
  - Dust inhalation
  - Indoor radon inhalation
  - Dermal

- Welding Shop Teacher
  - Dust inhalation
  - Indoor radon inhalation
  - Contaminant ingestion

- Residential Use
  - Contaminant ingestion
  - Indoor radon inhalation
  - Direct gamma

3.1.2 Reprocessing of Scrap Steel

The steel reprocessing technology, as illustrated in Figure 3-1, consists of several stages. Generally, the scrap or waste from the oil and gas production facility is stored at the facility or at an independent storage yard for resale (ZAL92). If necessary, the dirt and scale are removed from the equipment prior to resale. Some of the equipment is then recycled through smelting into new iron products and released to the general public. Other equipment is recirculated back to the oil production facility. Several scenarios are considered for exposure from NORM in scrap steel, including cleaning, storage, transportation and smelting.

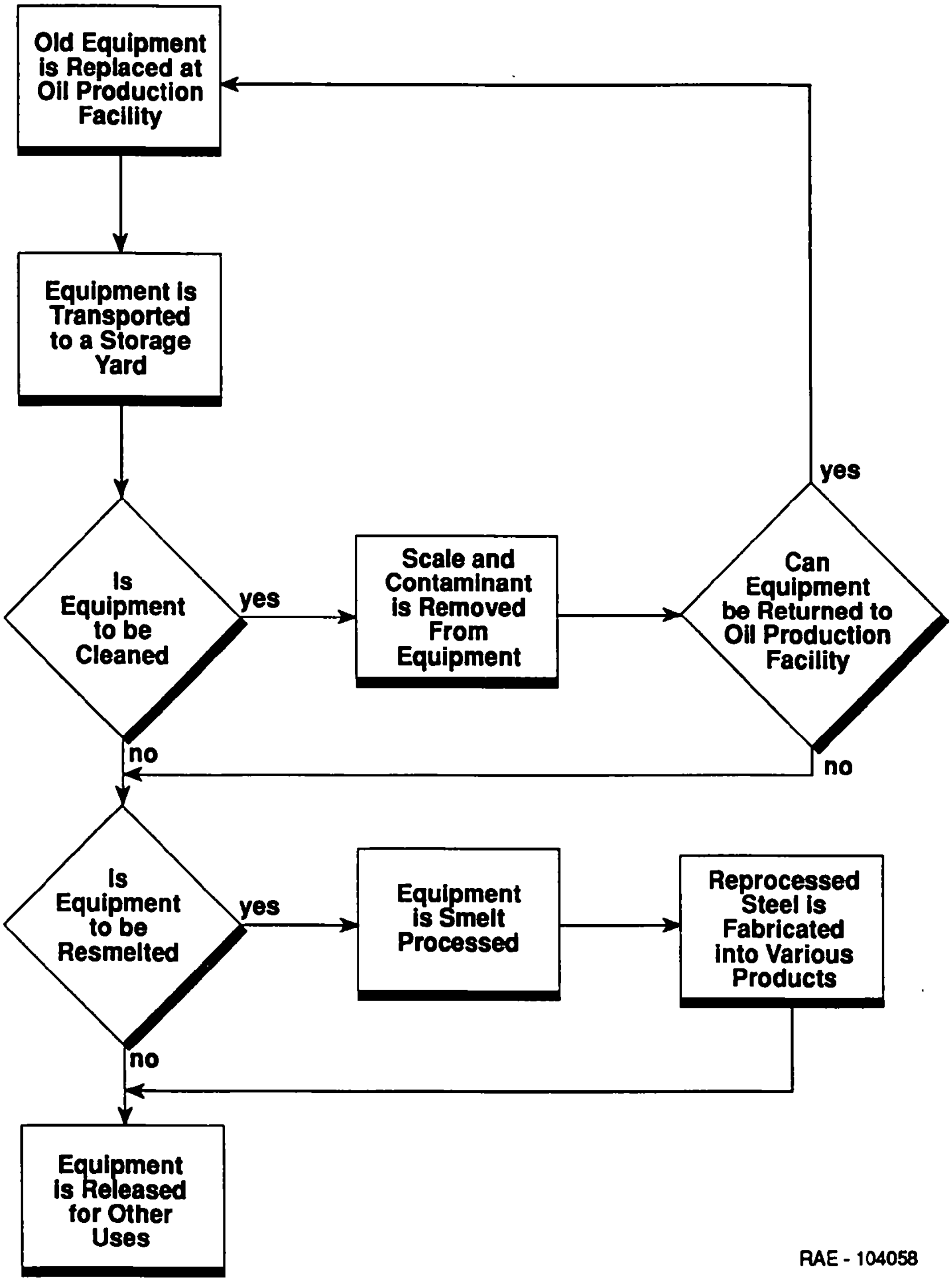

Figure 3-1. Steel Reprocessing Technology.

3.1.2.1 Pipe Cleaning

Reuse of equipment within the industry often requires the removal of NORM deposits from inside the equipment. Traditionally, this has been done using hand scrubbing (MAD79, EPA87b). Two such cleaning facilities were located near Laurel and Brookhaven, Mississippi (EPA87b). The two facilities were used to clean pipe used by the petroleum industry. Pipe taken to the contractors at these two sites was cleaned using drills to ream material from the pipes. Hand scrubbing may vary from a simple wipe with a dry or damp cloth to a scouring action with motor-powered abrasive tools and chemical additives (CHA91). While hand scrubbing is occasionally effective, worker exposures are significant. Efforts to reduce worker exposures from hand-cleaning processes include dust vacuuming and filtration systems, protective respirators and clothing, and equipment for remote handling of contaminated equipment (CHA91). These added measures have reduced worker exposures up to 90 percent of their original levels (CHA91).

Due to the difficulty and inefficiency of hand cleaning, other decontamination methods have been developed. The major systems currently being used by the industry are presented in Table 3-2. Hydrolasers and other high-pressure water cleaners are more commonly being utilized (ZAL92). Commercially available hydrolasers produce a liquid stream of up to 10,000 psi, and chemical cleaning agents can be added to the water to increase their effectiveness (MAD79). Even though the use of hydrolasers reduces dust emissions, allows for remote cleaning, and is significantly more efficient in cleaning, other waste disposal problems are inherent with such methods. Liquid wastes, for example, need to be effectively collected and solidified.

Exposures resulting from hand cleaning and remote hydro laser blasting of contaminated equipment are analyzed conservatively, in this risk assessment, with no further safety features in place. It is assumed that the following scenarios and pathways will produce limiting doses:

- <u>Pipe Cleaner - Mechanical Scrubbing</u>
  - Direct gamma
  - Dust inhalation

Table 3-2. Surface decontamination technology alternatives (CHA91).

Method	Application	Comment
Manual Abrasive Scraping	Employs dry grit blasting, scarifying drilling, vacuum cleaning, grinding, brushing, etc.	Not an effective cleaning method for dense scale deposits. Additional exposure reduction necessary to reduce airborne contamination and direct exposure to worker.
Liquid Abrasive Blasting	High volume of water recirculation of solid grits or particles (aluminum oxide or glass beads) bombards the contaminated surface and removes scale at 100 psi.	Technique is 95 percent effective with loose contamination (CHA91). Tends to inadequately remove contamination from cracks, folds, edges, welds, and from configurations that serve as contamination hideout.
Ultra High Pressure Water Decontamination (Hydroblaster/Hydrolaser)	Water particles at pressures up to 35,000 psi bombard the contaminated surface removing heavy scale coatings.	Allows for waste minimization by adapting pressure and application time. Possible to recycle contaminated water through ion-exchange treatment.
Ultrasonic Cleaning	Effective for small reusable equipment, valve parts, and precision components.	Can penetrate crevices, filter elements, etc. Limited in use since the largest size of the sounding tanks commercially available is approximately 5' x 3' x 2.5'.
Advanced Decontamination Systems	Research currently underway on: Laser decontamination, accelerator transmutation of wastes, and microwave decontamination	

- Pipe Cleaner - Hydro Laser Blasting
  - Direct gamma
  - Dust inhalation

- Adjacent Resident - Mechanical Scrubbing
  - Dust inhalation

3.1.2.2 Storage Yard

Oil-field equipment removed from service is frequently stored in oil-field equipment yards (ZAL92). Equipment is stored for possible cleaning, refurbishing, transfer to other fields, sale to other companies or other uses, and for disposal (ZAL92). As a result of the storage and the associated handling of equipment, yard employees and adjacent residents are potentially exposed to gamma emission and respirable dusts from contaminated production equipment. For exposures resulting from the storage of contaminated equipment, the following scenarios and pathways are considered:

- Storage Yard Worker
  - Direct gamma
  - Dust inhalation

- Adjacent Resident to Storage Yard
  - Direct gamma
  - Dust inhalation

3.1.2.3 Transportation

Scrap metal and oil and gas production equipment are generally transported by truck or rail (KEA92, ZAL92). The exposure pathways from the transportation of contaminated equipment for this analysis are assumed to result from truck transportation. Rail exposures are not considered since truck driver exposures are expected to be limiting. The gamma exposures during the rail transportation are minimal due to the greater exposure distances and thicker steel sidings of rail cars in comparison to truck trailers.

Since storage yards for oil and gas production equipment are generally located on site (ZAL92), it is assumed that transportation does not involve trucking any non-industry scrap metal. Since most commercial smelters accept scrap from multiple sources (ROW92), the transportation scenario conservatively assumes a storage yard destination.

- Truck Driver
  - Direct gamma

3.1.2.4 Smelting NORM-Contaminated Materials

One method of recycling used steel for other uses is to reprocess the material via smelting. Melt-refining of NORM-contaminated materials separates the NORM (contained in the scale deposits) from the steel. The NORM-contaminated scale material is primarily composed of the Alkali-earth element sulfates (principally $BaSO_4$) (EPA91). The radioactivity in the NORM comes from the presence of $RaSO_4$ in the scale deposits (EPA91). For calculations, the properties of the scale will be taken as those of $BaSO_4$. Currently, three steel mills are performing tests involving controlled melting of NORM-contaminated equipment. These are: Shaparell Steel of Texas, Segean Structured Metals of Texas, and Sheffield Steel of Oklahoma (TUR92).

A schematic diagram of a smelting furnace is shown as Figure 3-2. A typical batch-smelting operation of contaminated (recycle) steel handles approximately 50-tons of metal per batch (ROW92). The furnace is charged with the contaminated steel (approximately 9.0 wt percent, 23 percent by volume, of which is the NORM containing scales) (RAE92) and slagging material. The slagging material is typically about ten percent of the steel weight (NRC78) (5-tons in this case). The furnaces operate between 2800 and 3000^{o}F (ROW92). The flow rates of the effluent gases are 10,000 CFM for natural gas fired furnaces, and 700,000 CFM for electric arc furnaces (ROW92). A batch cycle lasts between 30 and 50 minutes (ROW92). According to Rowlan (ROW92), a typical smelting operation does include particulate emission control. In addition, it has been noted that the bulk of calcium is carried into the baghouse and collected with the

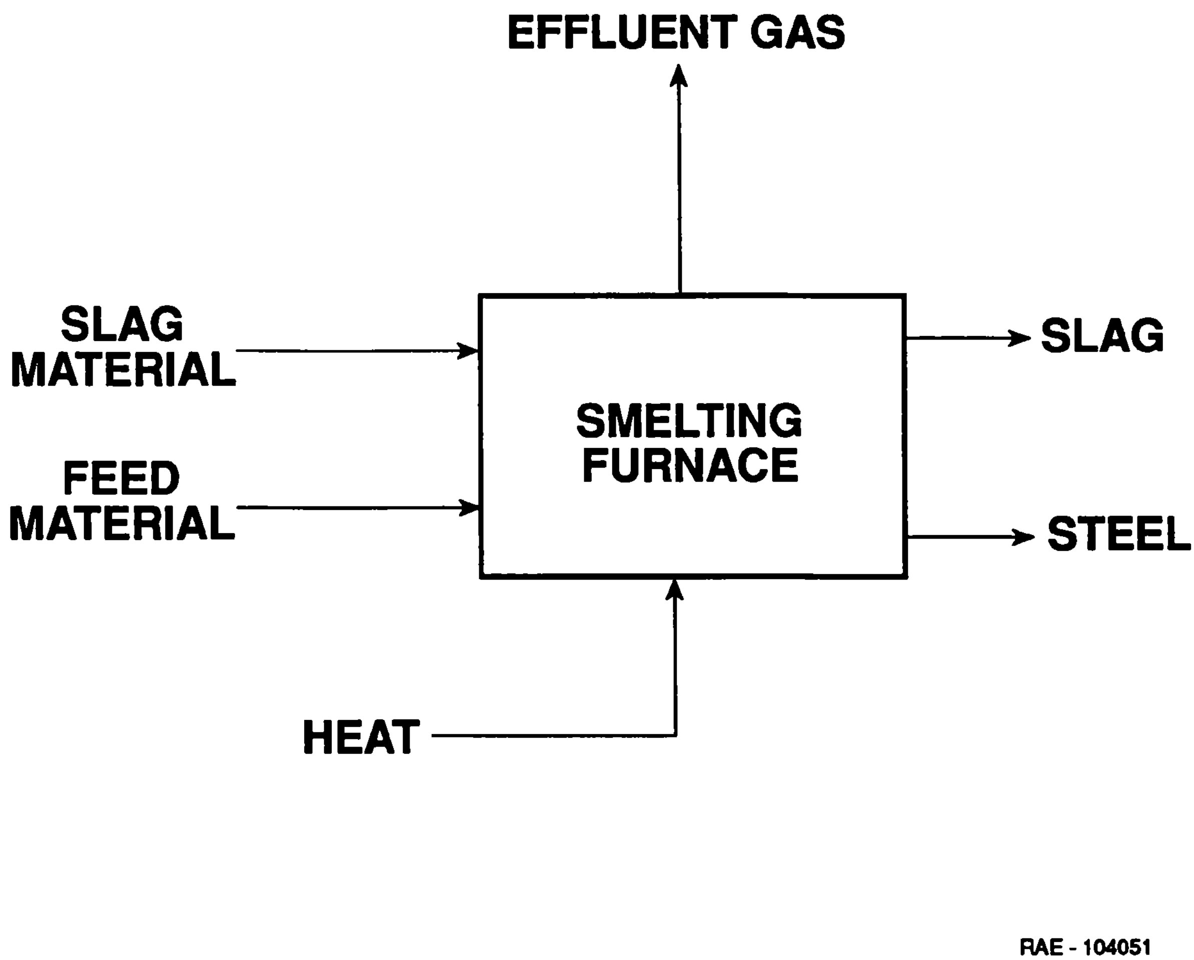

Figure 3-2. Schematic diagram of a smelting furnace.

dust (ROW92). The barium concentrations in the dust vary from 0.5 ppm to 490 ppm, but the specific value, like all the contaminants, is dependent upon the concentrations in the feed material (ROW92).

As the contaminated steel is melted, the scale deposits are volatilized. The volatilized materials are then carried out with the stack gases, or they are trapped in the slagging material and removed with the slag. Compounds which are not volatilized or which decompose to form the metal oxides, migrate into the slag layer as a result of density differences between the molten steel and the metal compounds. The percent of contaminant removed with the slag depends upon the material used for slag. According to ROW92, it is estimated that over 95 percent of the volatile material moves through the slag to the stack gas and is removed. Conversely, references MAR87, TUR92, and CEC88 indicate that slagging agents can be used to capture virtually all NORM contaminants. The steel produced from the recycling process is essentially free of contaminants (ROW92). The stack gas is generally passed through a baghouse where over 99 percent of the particulate emissions are removed (ROW92). Thus, if all the NORM were vaporized and treated in the baghouse, approximately 90 pounds of the scale deposits charged to the furnace (per 50-ton batch) could be discharged into the atmosphere with the effluent gases. The dominant management practices for the waste slag material is onsite storage in large piles.

Properties of critical compounds in the smelting of NORM-contaminated steel are given in Table 3-3 (CRC85). Although data are not readily available for the compounds of Radium, they are expected to behave similarly to the other Alkali-Earth compounds. It should also be noted that the values of slag properties will differ depending upon the type of slag used. The primary function of the slag is to provide an insulating cover on the top of the smelt (ROW92). In addition to it's primary function, the slag may be useful in removing certain impurities from the molten steel. According to Rowlan (ROW92), many different slags have been produced which are capable of entraining and removing certain contaminants.

In order to account for the NORM in a typical smelting operation, it is assumed that the equipment from a typical ten well facility will be recycled. The median activity of the scale

Table 3-3. Properties of critical compounds in the smelting of NORM contaminated steel.[a]

Material	Density (g/cc)	Melting Point (°F)	Boiling Point (°F)	Basis
Steel	7.80	2760	-----	CRC85
Slag	approx. 3.00	-----	-----	(NRC78)
$BaSO_4$	4.50	2876	2100[b]	CRC85
$CaSO_4$	2.96	2642	2179[b]	CRC85
BaO	5.72	3493	4941	CRC85
CaO	3.31	4689	5162	EPA91, RAE92
Scale	2.60			EPA91, RAE92

a Although data are not readily available for the compounds of radium, they are expected to behave similarly to the other alkali-earth compounds.

b Transition zone to monoclinic.

deposits is given as 360 pCi/g. The total recycle volume (RAE92) of steel is 40.7 m^3. The total recycle volume of scale deposits is 12.1 m^3. The density of the scale is 2.6 g/cm^3 (RAE92, EPA91). The other properties of the scale are assumed to be the properties of $BaSO_4$. The individual batch weights of the recycle smelting process are 50-tons. The amount of slag added to each batch is 5-tons. The batch cycle time is taken as 30-minutes (worst case) (ROW92). Based on these assumptions, the following case scenarios show how the NORM can be removed in the smelting process:

Case 1: All the NORM is trapped by the slag (worst case for removal in slag).

Using the densities provided in Table 3-3, the weight percent of the scales is determined to be 9.0 percent. From this value we expect that 4.5-tons of the total recycle charge to the furnace (50-tons per batch) are expected to be the scale deposits. In addition, 5-tons of slagging material is added to the furnace. Since the steel is separated from the scale deposits, 9.5-tons of the slag/scale mixture is expected to be removed. The net effect of this removal is to dilute the activity per unit weight from 360 pCi/g of radium in the scales to [360 * (4.5/9.5)] or 170 pCi/g of radium. Thus, the case of removal of the NORM in the slag dilutes the NORM activity by about a factor of two.

Case 2: All the NORM is removed in the effluent gas, no pollution control equipment is used, a gas-fired furnace is used in the smelting process, and the batch time is 30-minutes.

The amount of scale deposits is assumed to be the same as in Case 1. With a gas-fired furnace, a typical effluent discharge rate of 10,000 CFM is assumed. For the 30-minute batch time, the rate of emission of the scale deposits in the effluent stream is (9,000 lbs/30 min) 300 lbs/min. By converting this value to an activity per unit volume, the radium concentration in the exiting gas stream is calculated as follows:

$$\frac{(300\ \text{lbs/min})\ (453.6\text{g/lb})\ (360\text{pCi/g})}{(10{,}000\ \text{Ft}^3\text{/min})\ (28.32\ \text{L/Ft}^3)} = 170\ \text{pCi/L radium} \qquad \textbf{(3-1)}$$

Case 3: All the NORM is removed in the effluent gas, no pollution control equipment is used, an electric arc furnace is used in the smelting process, and the batch time is 30-minutes.

With an electric arc furnace, a typical effluent discharge rate of 700,000 CFM is used. For the 30-minute batch time, the rate of emission of the scale deposits in the effluent stream is (9,000 lbs/30 min) 300 lbs/min. By converting this value to an activity per unit volume, the concentration in the exiting gas stream is calculated is calculation as follows:

$$\frac{(300\text{lbs/min})(453.6\text{g/lb})(360\text{pCi/g})}{(700{,}000\text{Ft}^3\text{/min})(28.32\text{L/Ft}^3)} = 3\text{pCi/L radium} \qquad \textbf{(3-2)}$$

Case 4: All the NORM is removed in the effluent gas, pollution control equipment that is 99 percent effective in removing particulate emissions is used, a gas-fired furnace is used in the smelting process, and the batch time is 30-minutes.

With a gas-fired furnace, a typical effluent discharge rate of 10,000 CFM is used. For the 30-minute batch time, the rate of emission of the scale deposits in the effluent stream is (9,000 lbs/30 min) 300 lbs/min. With the pollution control equipment, the emissions of scale material are reduced to 3.0 lbs/min. By converting this value to an activity per unit volume, the concentration in the exiting gas stream is calculated as follows:

$$\frac{(3.0\text{lbs/min})(453.6\text{g/lb})(360\text{pCi/g})}{(10{,}000\text{Ft}^3\text{/min})(28.32\text{L/Ft}^3)} = 2\text{pCi/L radium} \qquad \textbf{(3-3)}$$

Case 5: All the NORM is removed in the effluent gas, pollution control equipment that is 99 percent effective in removing particulate emissions is used, an electric arc furnace is used in the smelting process, and the batch time is 30-minutes.

With an electric arc furnace a typical effluent discharge rate of 700,000 CFM is assumed. For the 30-minute batch time, the rate of emission of the scale deposits in the effluent stream is (9,000 lbs/30 min) 300 lbs/min. With the pollution control equipment, the emissions of the scale material are reduced to 3.0 lbs/min. By converting this value to an activity per unit volume, the concentration in the exiting gas stream is calculated as follows:

$$\frac{(3.0\text{lbs/min})(453.6\text{g/lb})(360\text{pCi/g})}{(700{,}000\text{Ft}^3\text{/min})(28.32\text{L/Ft}^3)} = 0.02\text{pCi/L radium} \qquad \textbf{(3-4)}$$

For the purpose of calculating exposures, Case 1 (worst slag case) is used for exposure based on removal of the NORM in the slag, and Case 2 (worst effluent case) is used for removal of the NORM in the effluent gas stream. Case 1 may be modified as needed based on the percent removal for the actual slagging compound used, and also for the amount of slag used. Case 2 may be modified to account for different variations in the smelting process and feed material. The numerator in Equation 3-1 may be modified for differences in cycle time, pollution control capabilities, weight of deposits in the recycle steel, and the average activity per unit mass of the NORM. The denominator of Equation 3-1 may be modified to account for differences in flow rate of the effluent gas stream.

For exposures resulting from the smelting of contaminated equipment, the following scenarios and pathways are considered:

- Adjacent Resident - With NORM Removal in Slag
  - Direct gamma from slag pile
- Worker in Smelter Yard - No NORM Removal in Slag
  - Dust inhalation from resuspended particles in flue gas

- Adjacent Resident - No NORM Removal in Slag
  - Dust inhalation from resuspended particles in flue gas

- Worker in Smelter Yard - With NORM Removal in Slag
  - Direct gamma from slag pile

3.1.2.5 Steel Mill and Scrap Yard Alarm Systems

Louisiana allows an item to be released for unrestricted use if survey readings are not above 50 μR/hr (ZAL92, RAE92). This value includes background and is generally equivalent to three times that of average background. Some metal scrap yards and steel mills have emplaced detectors to serve as alarms for monitoring incoming truck and train loads of scrap steel. In general, the monitors are located two feet from the side of the load (ZAL92).

Initially, these monitors were installed to detect low-level radioactive waste and sources. However, these alarm systems also have the ability to detect NORM contamination. An industry sampling of the average detection criteria for the alarm is presented in Table 3-4. As can be seen, an average limit can be taken as twice background (or approximately 16 μR/hr). Other methods of specific NORM detection are currently being developed. Methods currently being researched incorporate correlations from hand meter readings to NORM contamination (MIL90, RAE92, SCO92).

An additional alarm detection or early warning method, by which the presence and concentration of radioactive scale can be assessed, is with the use of wireline logs (SMI85). Petroleum engineers routinely utilize gamma ray logging to enable them to delineate the sand bearing strata from the natural shales (SMI85). The logging tool detects the natural gamma radiation of the strata. Consequently, internal NORM deposits can severely interfere with the interpretation of the natural strata (SMI85).

Table 3-4. Alarm screening settings for contaminant detection at steel mills, scrap yards, and landfills.

Alarm Settings	Reference
Twice to ten times background	RAE90
Twice to three times background	ZAL92
Twice background	FUE92
400 cpm above background of 400-800 cpm	MIN92
10 - 15 percent of background above background	BER92, ZAL92

Most frequently used value: 2 times background.

A correlation is used between the levels of radioactivity measured during a gamma-logging survey from the strata and scale, and the levels of radioactivity that can be expected to be observed once the tubing has been removed from operation (SMI85).

Detection and distribution limits for detecting NORM in contaminated equipment loads are presented in Chapter 5.

3.2 PHOSPHOGYPSUM

Since there are large volumes of phosphogypsum wastes being produced, use and reuses are desirable to reduce problems associated with disposal. Past commercial applications of phosphogypsum, discussed below, include: as a fertilizer and soil conditioner, backfill for road construction, and as a concrete additive (EPA91). Recent revisions to NESHAPS now restrict uses to agriculture and research (FR92). The scenarios evaluated in this assessment are based on actual past practices. In a review by the EPA of the uses and resulting risks of the phosphogypsum wastes from the FMC elemental phosphorous plant, Simplot phosphate fertilizer plant, the Monsanto elemental phosphorous plant, and the Kerr-McGee vanadium plant of Idaho, phosphogypsum slag was found in street paving and as a foundation additive (EPA90). Additionally, exposures and procedures for cleaning of stainless steel filter pans used in phosphate production are reviewed.

3.2.1 Phosphogypsum in Agriculture

Uses of phosphogypsum in agriculture include use as a source of calcium and sulfur for soils deficient in these elements, and as sediment control for soils that have been eroded and leached. For exposures resulting from the agricultural use of phosphogypsum the following pathways are considered:

- Agricultural Worker
  - Direct gamma
  - Dust inhalation

- On-site Individual
  - Ingestion of contaminated well water
  - Indoor radon inhalation
  - Direct gamma

- Member of Critical Population Group (CPG)
  - Inhalation of contaminated dust
  - Ingestion of drinking water from contaminated well
  - Ingestion of foodstuffs contaminated by well water
  - Ingestion of foodstuffs grown on fertilized soil

- Off-site Individual
  - Ingestion of river water contaminated via the groundwater pathway
  - Ingestion of river water contaminated by surface runoff.

3.2.2 Phosphogypsum in Road Construction

Past uses of phosphogypsum in road construction include its use as a secondary road base, and as a concrete additive for the road surface. Exposures resulting from the use of phosphogypsum in road construction include the following scenarios and pathways:

- Construction Worker
  - Direct gamma
  - Dust inhalation

- Person Driving on Road
  - Direct gamma

- Member of CPG
  - Direct gamma exposure
  - Ingestion of drinking water from contaminated well
  - Ingestion of foodstuffs contaminated by well water

- Reclaimer
  - Direct gamma
  - Indoor radon inhalation

- Use of contaminated well water
- Ingestion of foodstuffs grown on-site

- Off-site Individual
  - Ingestion of river water contaminated via the groundwater pathway
  - Ingestion of river water contaminated by surface runoff.

3.2.3 Phosphogypsum in Research and Development

Uses of phosphogypsum in further research and development activities is also considered in this assessment. Exposures resulting from the use of phosphogypsum in a laboratory environment include the following scenario and pathways:

- Researcher
  - Direct gamma
  - Dust inhalation
  - Indoor radon inhalation

3.2.4 Filter Pan Cleaning

The large stainless steel filter pans, which are used to separate the phosphoric acid and the phosphogypsum, are covered with fiberglass fabric which serves to filter out the phosphogypsum while allowing the passage of acid (EPA91). During this process, small quantities of phosphate scale are deposited on the surface areas of the pan and fiberglass mat. This scale can also be found deposited in ancillary piping and filtrate receiver tanks that are associated with the filtration process (EPA91). Radium concentrations in scales have been found to range from several picocuries to as high as 100,000 pCi/g (KEA88). While the concentrations of radium are quite high, the volume associated with this scale is relatively low. One estimate is that a phosphoric acid production plant will generate about 6 m^3 of scale per year (EPA91).

Due to the high cost of filter pans, averaging $20,000 each (KEA92), their reuse is highly desirable to the phosphogypsum industry. If the filter pans are to be reused, they must be cleaned similar to the contaminated oil and gas production equipment. Current industrial surface decontamination practices involve either non-chemical or chemical processes. A summary of the metal surface decontamination technologies currently in practice is presented in Table 3-2.

Due to the effectiveness, hydroblasting is currently most commonly used in the phosphogypsum industry for the cleaning of the stainless steel filter pans (KEA92). Grinding and additional abrasive cleaning are also used to augment decontamination. Hydroblasting and additional abrasive grinding generally cleans the filter pans sufficiently to allow for unconditional release to the general public or reuse in the phosphate processes (KEA92). No cost effective cleaning method, however, has been developed for the decontamination of the fiberglass mats (KEA92). Currently these are packaged in drums and returned to the phosphogypsum owner (KEA92).

Exposures resulting from the cleaning of the stainless steel filter pans includes the following scenario and pathways.

- Filter Pan Cleaner - Hydrolaser
  - Dust inhalation
  - Direct gamma

4. Risk Assessment Methodology

The purpose of this risk assessment is to analyze the radiological risks associated with alternative uses of phosphogypsum and gas and oil production wastes and equipment. Chapters 2 and 3 briefly discussed the radiological properties, current industrial practices, exposure pathways and scenarios of phosphogypsum and oil production wastes and current uses for this material. The PATHRAE, COMPLY, and PRESTO-PILCPG dose assessment models are employed to evaluate potential doses and risks for the defined exposure scenarios involving the use of these wastes. This section describes the methodology for this risk assessment, including the PATHRAE, COMPLY, and PRESTO-PILCPG dose assessment models, the exposure scenarios evaluated, and the input parameter values and assessment models used for each scenario. The input parameters and scenario characteristics are based on the current practices of the industry. The results of the risk assessment are presented in Sections 5.1 and 5.2. Risks to workers, to individuals in the critical population group (CPG), and to reclaimers are evaluated for agricultural, road construction, recycling and general public use.

4.1 COMPUTER MODELS

The computer models used to evaluate individual and population risks from uses of these wastes are described in this section. Dose calculations are performed using the PATHRAE, COMPLY, and PRESTO-PILCPG dose assessment models (EPA87a, RAE91a, EPA89c). Calculations are performed for exposure scenarios which included the use of phosphogypsum in agriculture, road construction and research. Additionally, exposures from the cleaning, recycling and general public use of NORM-contaminated equipment are analyzed. Where PATHRAE, COMPLY, or PRESTO-PILCPG do not adequately model the gamma-ray exposure scenarios (e.g., a person performing experimental analyses on wastes contained in metal drums), the MICROSHIELD computer code (GRO85) is used to augment the analyses. Additionally, the VARSKIN computer code (NRC87) is used to estimate acute dermal exposures from direct contact with NORM-contaminated scale. Lifetime risks are computed using annual dose and risk conversion factors, as illustrated in Table 4-1, from the EPA's Environmental Impact Statement for NESHAPS radionuclides (EPA89b).

Table 4-1. Dose and risk conversion factors.

I. DOSE CONVERSION FACTORS (DCF)

Nuclide	Inhalation DCF (mrem/pCi)[a]	Ingestion DCF (mrem/pCi)[a]	Direct Gamma DCF (mrem/yr per pCi/m^2)
Ra-226	8.6E-03	1.3E-03	1.7E-04
Po-210	9.4E-03	1.9E-03	8.6E-10
Pb-210	1.4E-02	5.4E-03	0
Th-228	3.4E-01	4.0E-04	3.4E-04
Ra-228	4.8E-03	1.4E-03	9.0E-05
Th-230	3.3E-01	5.5E-04	8.9E-08
Th-232	1.6E+00	2.7E-03	6.6E-08
U-234	1.3E-01	2.8E-04	8.0E-08
U-235	1.2E-01	2.5E-04	6.4E-08
U-238	1.2E-01	2.7E-04	1.7E-05

(a) 50-year committed dose equivalent from one year of intake (uptake).

II. RISK CONVERSION FACTORS[b]

Nuclide	Inhalation Risk per pCi Inhaled	Ingestion Risk per pCi Ingested	Direct Gamma Risk per pCi/m^2
Ra-226	2.8E-09	9.4E-11	5.7E-11
Po-210	2.4E-09	1.4E-10	2.9E-16
Pb-210	1.4E-09	5.5E-10	0
Th-228	7.2E-08	1.3E-11	4.8E-11
Ra-228	5.8E-10	7.0E-11	3.1E-11
Th-230	2.9E-08	2.3E-11	2.7E-14
Th-232	2.9E-08	2.1E-11	2.0E-14
U-234	2.5E-08	7.5E-11	2.4E-14
U-235	2.3E-08	7.3E-11	5.5E-12
U-238	2.2E-08	7.4E-11	7.23E-13

b. 70-year lifetime risk of fatal cancer from one year of exposure.

III. RADON RISK CONVERSION FACTORS[c]

Exposure Scenario	Inhalation Risk per pCi/m^3
Indoor Exposure	4.4E-08
Outdoor Exposure	4.4E-09

c. 70-year lifetime risk of fatal cancer from one year of exposure to Rn-220 and Rn-222 daughters.

4.1.1 The PATHRAE Dose Assessment Model

The PATHRAE dose assessment model (EPA87a) was initially developed as an analytical tool to assist EPA in developing standards for low-level radioactive waste and below regulatory concern waste disposal. The PATHRAE model estimates health effects which could occur if radioactive wastes were disposed of in a near surface facility, sanitary landfill, or other geological setting. PATHRAE can be used to calculate effective dose equivalents[a] to members of the critical population group from the disposal of radioactive material at sites located in diverse hydrogeologic, climatic, and demographic settings. An important PATHRAE model feature is its simplicity in analyzing a comprehensive set of radionuclides, disposal settings, and exposure pathways. The effects of changes in disposal site and facility characteristics can be readily investigated with relatively few parameters needed to define the problem.

PATHRAE models both off-site and on-site pathways through which persons may come in contact with radioactivity from disposed material. The off-site pathways include groundwater transport to a well and a river, surface water runoff to a river, and atmospheric transport of radioactive particulates. On-site pathways include direct gamma exposure, dust inhalation, exposure from foodstuffs grown on-site, and inhalation of radon gas and radon daughters.

4.1.2 The PRESTO-EPA-PILCPG Computer Code

PRESTO-EPA-PILCPG methodology has been developed under EPA direction (RAE91a). The EPA uses PRESTO-EPA-PILCPG methodology for evaluating maximum annual doses, via atmospheric pathways, to members of the critical population group (CPG) from the disposal of NORM wastes. The maximum annual radiation doses to the CPG is calculated for 10 radionuclides. PRESTO-EPA-PILCPG determines the nuclide and pathway specific doses for each year of exposure. These doses are then summed over all nuclides and pathways.

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[a] Throughout this report the term "dose" refers to the effective whole body dose equivalent.

4.1.3 The COMPLY Computer Code

The COMPLY computer program was designed to demonstrate compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAPS) in 40 CFR 61, Subpart I. It has various levels of complexity, the simplest being a computerized version of the tables of concentration and possession limits in EPA89c. The most complicated is an air dispersion calculation using a user-supplied wind rose.

In the analyses reported here, the COMPLY code was used to estimate doses to off-site residents. The code was used directly to estimate dose rates from dust migration and from the smelt-refining of NORM contaminated scrap steel.

4.1.4 The MICROSHIELD Computer Code

Where the exposure geometry is not readily modeled by PATHRAE or PRESTO-EPA-PILCPG (e.g., truck driver transporting NORM-contaminated equipment), MICROSHIELD is used to estimate the external gamma dose. MICROSHIELD (GRO85) is a microcomputer adaptation of the ISOSHLD II (ENG66) mainframe code for analyzing gamma radiation shielding. MICROSHIELD has solution algorithms for 14 different geometries which include point, line, sphere, disk, cylinder, plane, and rectangular volume sources; and slab, cylindrical, and spherical shield configurations. MICROSHIELD sorts individual gamma energies from each isotope in the source term into 21 energy groups. Dose rate calculations are performed by one of three geometry-based calculational routines which include analytical expressions, Simpson's rule integration, and point-kernel integration. Execution of the program proceeds by repeating the solution algorithm for each energy group that has any activity until all 21 energy groups have been evaluated.

The MICROSHIELD code user supplies input information describing the characteristics of the exposure scenario to be evaluated. This input information includes: distance between the source and the exposed individual; source inventory; dimensions of the source region; the dimension, locations, and orientations of intervening shields; and the material (including air) used for these intervening shields.

4.1.5 The VARSKIN Computer Code

The VARSKIN code (NRC81) computes the beta radiation dose rate to any specified depth of the skin from up to five radionuclides on the surface of the skin. The calculational method is based on the tables of absorbed energy distributions around point sources in water that have been developed by M.J. Berger (BER71). By running the code several times, the radiation dose from more than five radionuclides can be computed.

4.2 EXPOSURE SCENARIOS

Scenarios based on the exposure pathways identified in Chapter 3 and the assessment models used are presented and discussed below. Scenarios have been divided into three groups: unrestricted general use of contaminated oil and gas production equipment, recycling of oil and phosphogypsum production equipment, and reuse of phosphogypsum.

4.2.1 Oil and Gas

The scenarios for evaluation of possible health impacts from the commercial uses of oil and gas production wastes are presented in this section. These evaluations are based on the waste inventories, current industrial practices, generic site parameters, and radiological properties of the NORM-contaminated equipment and wastes. Health impacts from the reprocessing and uses of NORM-contaminated equipment are estimated for workers at the storage and reprocessing facility, for the persons belonging the critical population group (CPG), and for the general population in the vicinity of storage and smelter sites.

Certain input parameters are common to all exposure scenarios. Dose and risk conversion factors, shown in Table 4-1, depend on the radioisotopes. As discussed in Chapter 2, NORM isotopes are the uranium and thorium series. The oil and gas production waste that is reused is equipment that is contaminated with scale containing NORM. As discussed in Chapter 2, 30 percent of the equipment waste is assumed to be NORM-contaminated, 10 percent of the overall volume is assumed to be scale and the median and high radium (Ra-226 and Ra-228) concentration of the NORM, as shown in Table 2-2, are 360 and 2,400 pCi/g.

4.2.1.1 Equipment Released to Schools

NORM-contaminated oil and gas equipment has been donated to schools for use as playground equipment, fencing, and welding shop practice material (FUE92). Two scenarios, as illustrated in Figures 4-1 and 4-2, are postulated to estimate school yard exposures from past equipment releases. Input parameters for describing the two scenarios are presented in Table 4-2. The first scenario involves a child playing on a jungle-gym built with NORM-contaminated water line tubing (worst case - RAE92). It is assumed that the playground equipment consists of 7 equal horizontal, open ended tubes. The child is postulated to be on the average within 0 ft. of one, 3 ft. of 2 tubes, and 6 ft. of the remaining 4. The child is being supervised by a teacher at sufficient distance as to not be exposed to direct gamma radiation. However, the teacher is exposed to the contaminated dust generated from tubal vibrations caused by the children playing.

The child is exposed to direct gamma radiation from the NORM contamination. Additionally, it is assumed that an area of 0.8 m^2 (~0.1 m diameter) of the tubing closest to the child has been corroded to allow the child to directly contact the NORM-contaminated scale. As the child plays, scale is shaken loose and allowed to become airborne. A contaminant dust loading factor for the air surrounding the jungle-gym is calculated, as presented below, assuming a constant contaminant dust density is maintained within each tube. It is then assumed that the dust is blown out of the pipe and diluted into the volume of the airspace surrounding the jungle gym. This air is then blown off site.

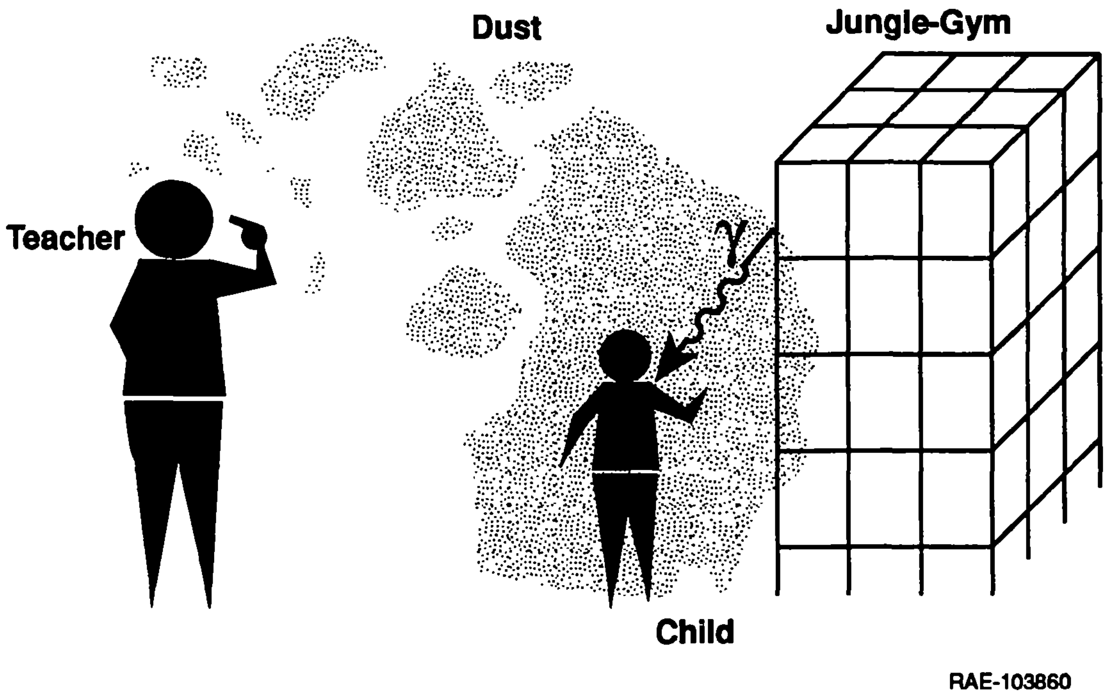

Figure 4-1. Exposure pathways from a jungle-gym contaminated with NORM.

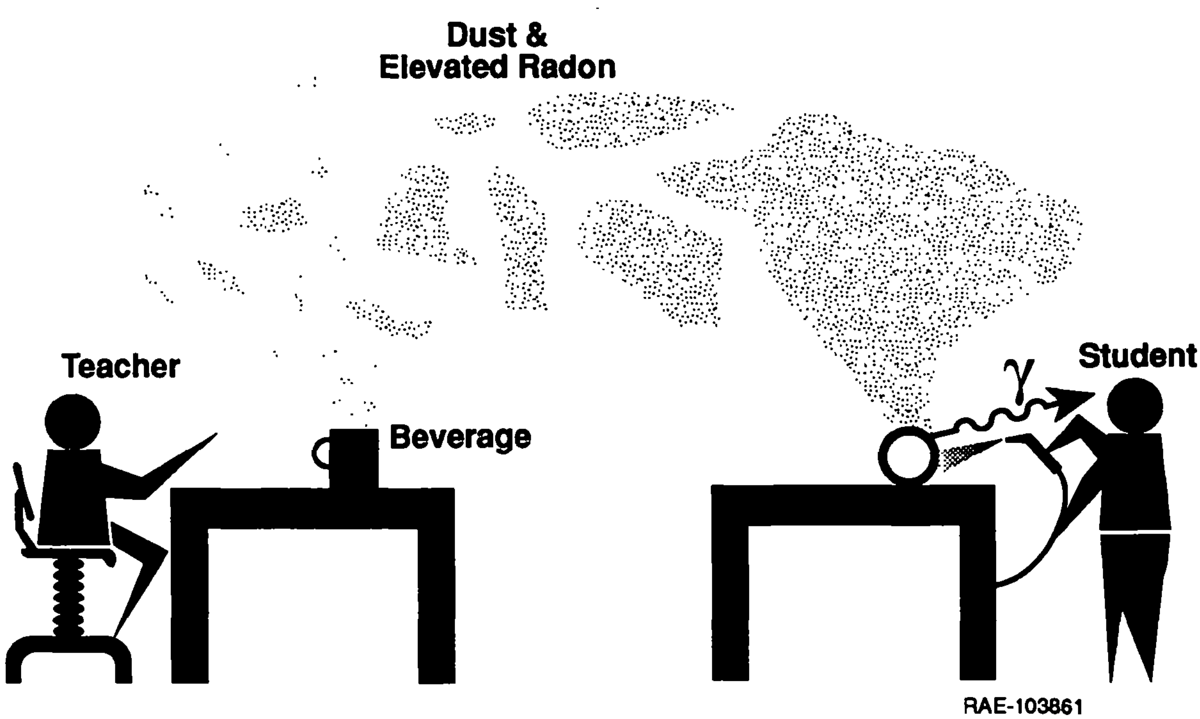

Figure 4-2. Exposure pathways from the use of NORM contaminated scrap steel in a welding shop.

Table 4-2. Input parameters for school scenarios.

Parameter	Unit	Value	Basis
Duration of year child plays on jungle-gym and in shop	hr/yr	400	Average 200 day school year at 2 hours of exposure per day
Student/child respiration rate	m^3/yr	3700	EPA89b
Playground airborne contaminant loading	$\mu g/m^3$	2.31E-02	See equation 4-1 for 7 pipes
Teachers Beverage Volume	cm^3/cup	63	Assumed
Duration teacher spends in shop	hr/yr	1000	Calculated from average 200 day school year at 5 hours of exposure per day
Average distance child is from contaminated gym bar	m	1.35	Calculated from bar distribution
Corrosion diameter for dermal exposure	m	0.1	Assumed to be sufficiently large to allow direct contact with the scale
Teacher's contaminated beverage consumption rate	m^3/yr	4.0E-2	Calculated from 200 mL/day ingestion
Shop total dust loading	$\mu g/m^3$	100	EPA91, reuse
Teacher respiration rate	m^3/yr	8000	EPA89b
Fraction of dust in shop that is considered contaminated	percent	10	Assumed
Radon emanation coefficient		0.10	RAE88, EPA91
Dust settle rate into teachers beverage	m/s	0.01	EPA91
Welding student distance to pipe	cm	30	Assumed (1 ft)

Table 4-2. Continued.

Parameter	Unit	Value	Basis
Duration child is in direct contact with NORM, exposed from corroded steel jungle-gym bar	min/day	10	Assumed
Density of scale	kg/m^3	2600	RAE92, EPA91, CRC85
Welding shop ventilation rate	1/hr	2	AVN88
Vertical cross sectional area of jungle-gym	m^2	4.6	Calculated from 7 ft x 7 ft
Air volume of shop	m^3	85	20 ft x 20 ft x 7.5 ft
Number of pipes in shop		1	Assumed
Length of pipe in shop and for jungle-gym	m	2.1	Assumed
Diameter of shop & gym piping	in	3	EPA91
Scale thickness	in	1	EPA91
Volume of air surrounding jungle-gym	m^3	9.7	Assumed
Fraction of time wind is blowing parallel to jungle-gym pipes		9.3E-2	EPA91
Constant internal contaminant dust loading maintained within tubes	$\mu g/m^3$	100	EPA91
Cross sectional open area of pipes	cm^2	1.6	RAE92
Average wind velocity blowing parallel to pipes	m/s	4.5	EPA91
Steel density	g/cm^3	7800	EPA91, GRO85, RAE92
Cup Surface Area	cm^2	12.6	Assumed

$$\rho_{eff} = \frac{RR}{AE * V2} \qquad (4\text{-}1)$$

where

ρ_{eff} = Contaminant dust loading factor for air volume surrounding jungle gym (kg/m^3)

RR = $f\ \rho\ A1\ v$ = release rate of contaminant from the tubing (kg/s)

AE = $\frac{v\ A2}{V2}$ = Air exchange rate of the volume of air surrounding the jungle-gym (Air Volumes/s)

V2 = Volume of the air surrounding the jungle gym (m^3)

f = Fraction of time wind is blowing parallel to tubing

ρ = Constant dust loading maintained within tubing (kg/m^3)

A1 = Cross-sectional area of the tubing opening (m^2)

v = Average velocity of the wind when blowing parallel to tubing (m/s)

A2 = Vertical cross section area of the volume of air surrounding the tubing (m^2)

The second scenario involves a student practicing welding in an instructional metal shop. The contaminated equipment is cut into small usable sections and welded. The cutting and welding allow for dust contamination of the shop environment. Additional exposures to the student are from direct gamma radiation from the contaminated scrap metal. An instructor is also present in the shop, but at sufficient distance as to not be exposed to the direct gamma radiation. The instructor is assumed to have a beverage at his desk into which airborne contaminants settle.

4.2.1.2 Unrestricted Residential Reuse

Unrestricted residential reuse of petroleum equipment has occurred under a variety of conditions. A scenario based on the unrestricted releases of ZAL92, as presented in Figure 4-3, for exposure

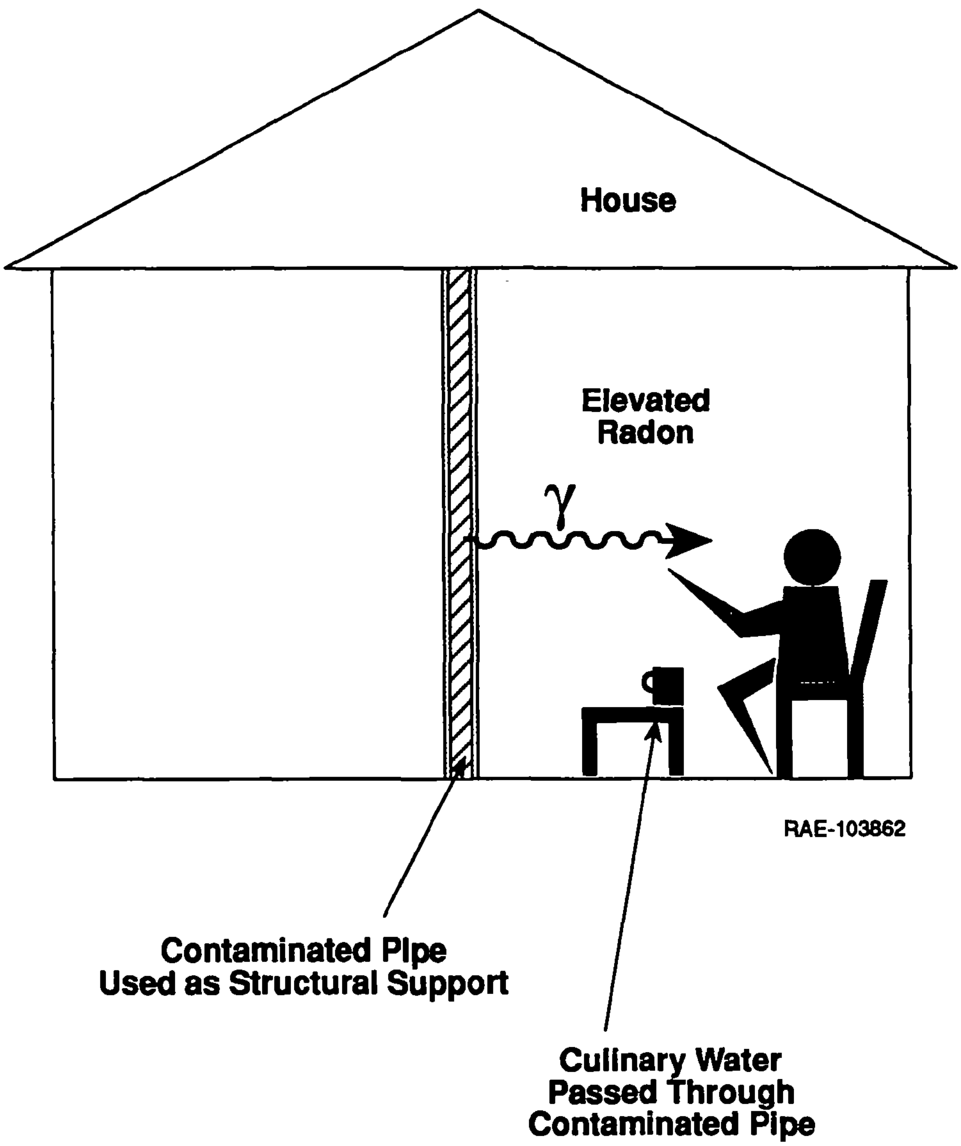

Figure 4-3. Exposure pathways from the unrestricted use of NORM contaminated equivlant in residential applications.

to NORM remaining in former petroleum equipment is that of residential reuse of the equipment. Tubing, which contains scale, is used by an individual in constructing a domestic water system, and a piece of larger pipe or other equipment containing scale is used inside the house for structural support of a floor, ceiling, etc. The tubing used as structural support is assumed to be used in such a manner to not allow NORM contaminants to become airborne inside the house. However, indoor radon is assumed to be generated from the scale and allowed to fill the house. Table 4-3 presents the input parameters for these scenarios.

The methodology used by the NRC in its Environmental Impact Statement for 10 CFR 61 (NRC81) is used to estimate the rate at which radionuclides are leached from the plumbing used in the residential culinary water supply. Under this methodology, the rate at which radionuclides leach from contaminated material is dependent on the rate at which water infiltrates through the waste, the radionuclide partitioning ratio, and the contact time fraction. Using the NRC methodology with respect to leaching from irradiated components, the leach rate for the scale was taken to be factor of 10 less than the rate calculated for standard soil type wastes.

4.2.1.3 Pipe Cleaning

When the equipment is cleaned or refurbished for reuse, workers are within exposure proximity of the NORM deposits. Reuse within the industry includes removal of NORM deposits from inside the equipment. Until recently, mechanically abrasive tools were used to ream the scale from tubular goods and pipes (CHA91).

Presently most of the pipe cleaning is being done with a high pressure water lance (also called "hydrolaser" for hydroblasting) (ZAL92, CHA91). The high pressure (up to 10,000 psi) fluid is directed through high pressure hose to an operator-controlled gun (DOE80). The equipment is operated on a pad to allow complete control of liquids and solids. Pipes to be cleaned are placed within a metal shroud to contain the spray. The "gun" is slowly fed into the pipe as the pipe is rotated. The scale is separated from the liquid and stored for disposal. The cleaned pipes have been sold under unrestricted release (KEA92).

Table 4-3. Residential reuse input parameters.

Parameters	Unit	Value	Basis
Duration spent at average distance from support pipe	hr/day	2.2	EPA91
Average distance from support pipe	m	1.0	assumed
Respiration rate	m^3/yr	8000	EPA91
Volume of water consumed from contaminated plumbing	m^3/yr	0.37	EPA91 (100 percent of average)
Pipe density	kg/m^3	7800	EPA91, GRO85
Scale density	kg/m^3	2600	EPA91, RAE92, CRC85
Radon emanation coefficient		0.10	RAE88, EPA91
Contact time fraction	1/yr	1.1E-03	calculated
Load bearing pipe height	m	2.3	AVN88
Load bearing pipe diameter	in	3	AVN88
Scale thickness	in	1	EPA91
Ventilation rate	hr^{-1}	0.35	AVN88
Duration spent in house	hr/day	18	AVN88
Leach fraction of NORM scale:			
Ra-226	l/yr	5.14E-07	NRC81
Ra-228	l/yr	5.14E-07	NRC81
Th-228	l/yr	5.14E-07	NRC81
Pb-210	l/yr	5.14E-07	NRC81
Po-210	l/yr	1.29E-07	NRC81
Length of pipe used in plumbing	m	10	assumed
Diameter of plumbing pipe	in	3	assumed
House Volume	m^3	85	assumed

Although the use of hydrolasers or hydroblasters increases problems associated with waste disposal, worker exposures are significantly reduced (dust emissions lowered, remote access capable, exposure duration lowered). Therefore, this scenario, as illustrated in Figures 4-4 and 4-5, considers mechanical abrasive, and remote hydroblasting. It is assumed that the cleaner works on the waste equipment generated by the reference 10 well facility described in Table 2-4 for a year's duration. Tubing is assumed to be cut to 1.8 m (6 ft) lengths to facilitate cleaning. Exposures to the worker are assumed to be limited to the pipe being cleaned. Additionally, exposures to a resident adjacent to the mechanical pipe cleaning facility from dust inhalation is analyzed. Input parameters characterizing this scenario are listed in Tables 4-4 and 4-5.

4.2.1.4 Storage of Contaminated Equipment

The contaminated equipment is stored for varying times at the oil and gas production facility or at an equipment storage area (ZAL92). During this storage time, yard and office workers are exposed to direct gamma exposure and dust inhalation. Additionally, residents living adjacent to the storage yard are exposed to the direct gamma and dust resuspended from the equipment piles. Since no refurbishing, cleaning, smelting, or cutting is assumed to take place in the storage yards, exposures to the adjacent residents due to contaminated dust inhalation is negligible and not considered in this scenario.

The volume of contaminated equipment at the storage yard is assumed to be that generated from an average 10 well facility, (see Table 2-4). This equipment is generally stacked in piles at ground level and exposed to atmospheric conditions (ZAL92). No additional atmospheric barriers, such as a storage building or protection roof, are considered here. Additionally, it is assumed that the equipment is generally stored for short term intervals. Source term decay and groundwater transport due to rainfall are not considered in this scenario. Input parameters characterizing this scenario, as illustrated in Figure 4-6, are listed in Table 4-6.

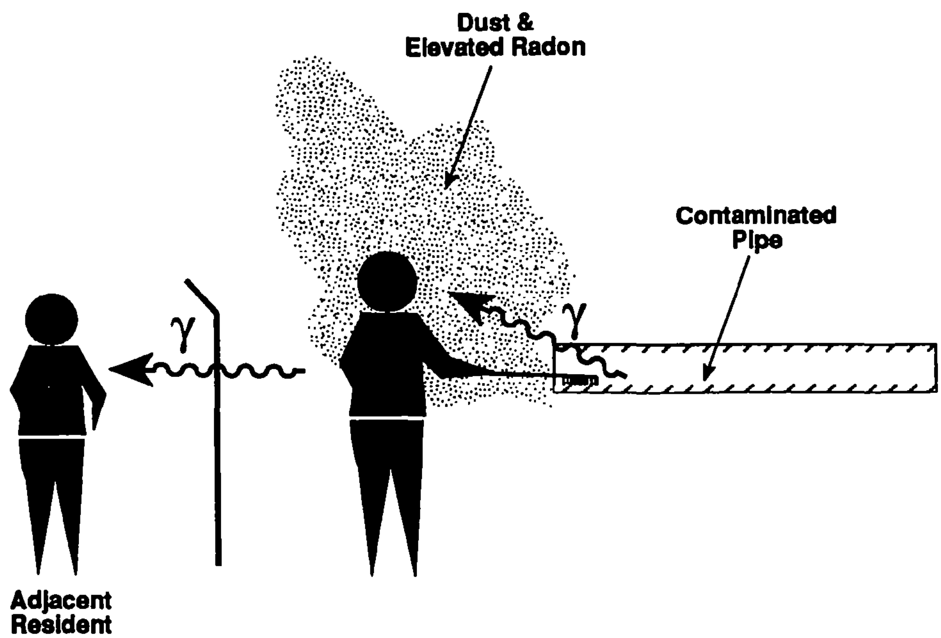

Figure 4-4. Exposure pathways from the mechanical cleaning of NORM contaminated tubing and pipe.

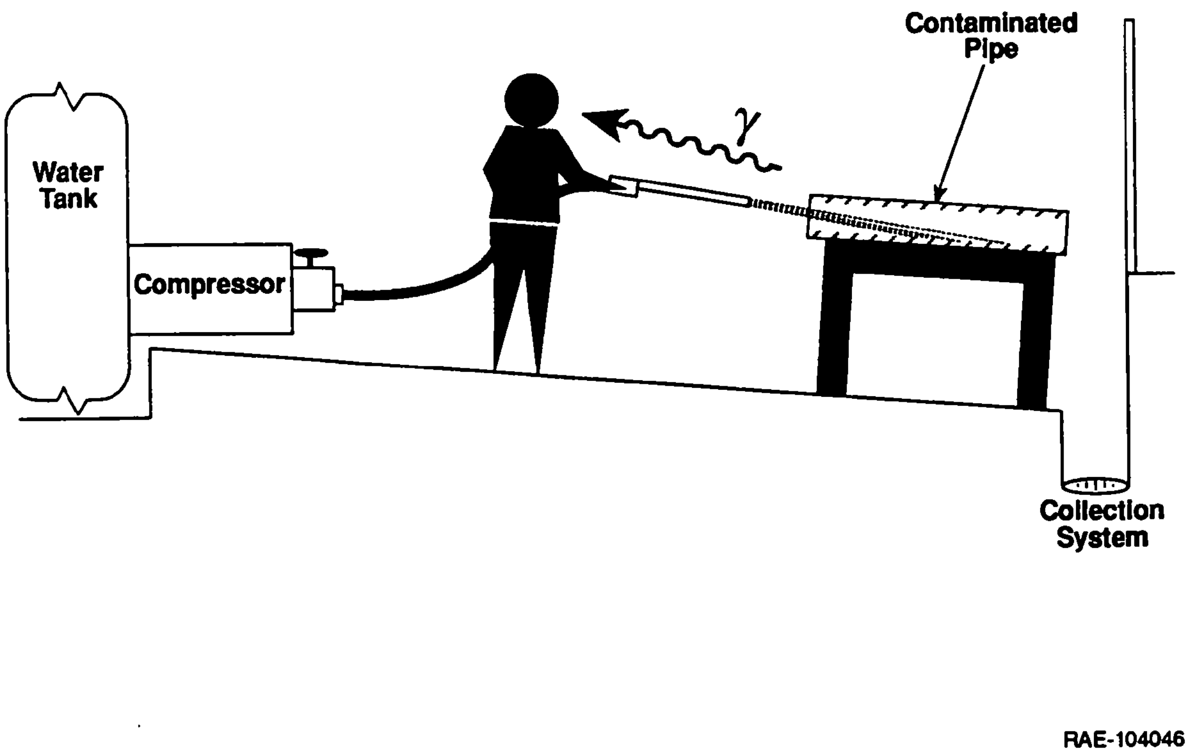

Figure 4-5. Exposure pathways from the hydrolaser cleaning of NORM contaminated tubing and pipe.

Table 4-4. Input parameters for the mechanical abrasive pipe cleaner scenario.

Parameters	Unit	Value	Basis
Duration of the year worker is employed	hr	2000	EPA91
Dust loading	$\mu g/m^3$	100	EPA91
Respiration rate	m^3/yr	8000	EPA91
Density of scale	kg/m^3	2600	EPA91, CRC85, RAE92
Density of piping	kg/m^3	7800	EPA91, GRO85
Average distance to pipe	ft	1	MAD79
Thickness of NORM	in	1	EPA91
Thickness of pipe	cm	0.95	assumed, EPA91
Average length of pipe being cleaned	m	1.8	assumed
Outer radius of pipe	in	3.0	EPA91
Downwind distance to adjacent resident	m	100.00	EPA91
Fraction of time wind is blowing toward resident		9.3E-2	EPA91
Average wind velocity	m/s	4.5	EPA91

Table 4-5. Input parameters for the hydroblaster cleaning scenario.

Parameter	Unit	Value	Basis
Duration worker is employed	m/yr	2000	EPA91
Dust loading	$\mu g/m^3$	100	EPA91
Respiration rate	m^3/yr	8000	EPA91
Scale density	kg/m^3	2600	EPA91, CRC85, RAE92
Pipe density	kg/m^3	7800	EPA91
Average distance to pipe	ft	10	KEA92, MAD79
Dust collection efficiency	percent	95	KEA92, MAD79
Number of pipes being cleaned in facility at once		1	assumed
Thickness of NORM	in	1	EPA91
Thickness of pipe	cm	0.95	EPA91
Average length of pipe	m	1.8	assumed
Outer radius of pipe	in	3.0	EPA91

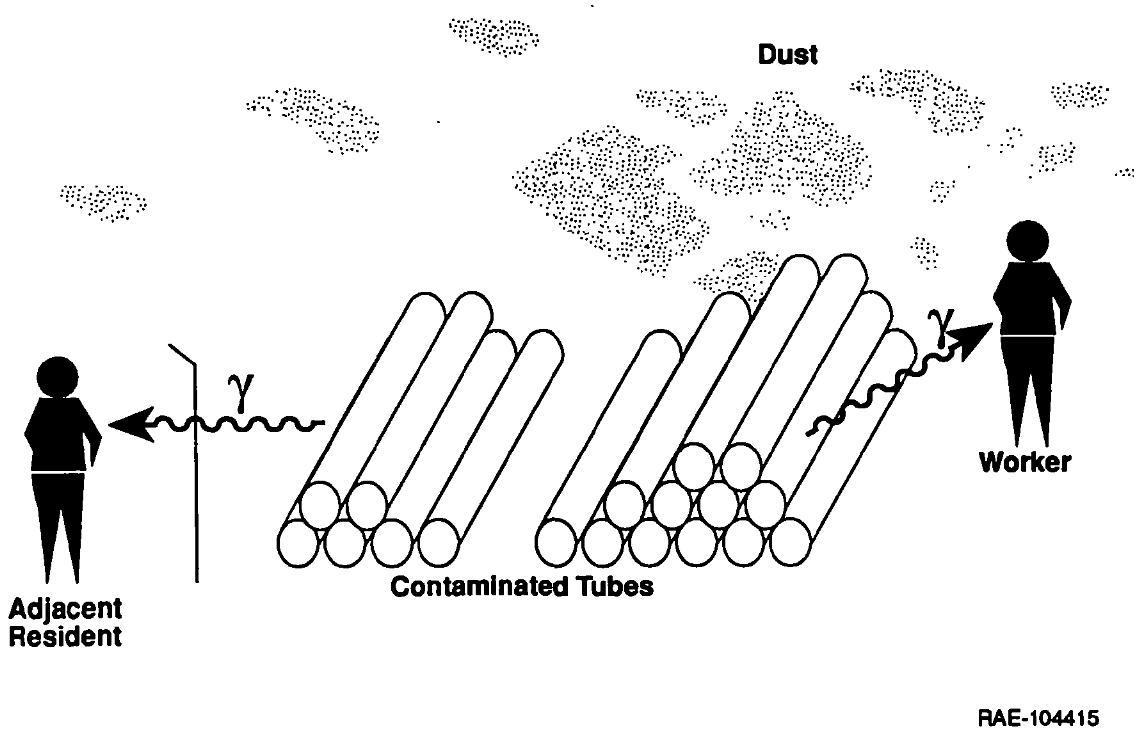

Figure 4-6. Exposure pathways from the storage of NORM contaminated tubing.

Table 4-6. Storage yard exposure scenario input parameters.

Parameter	Unit	Value	Basis
Duration in a year yard worker is exposed	hr.	2000	EPA91
Average worker distance from contaminated equipment	m	3	assumed
Total air dust loading	$\mu g/m^3$	50	EPA91
Average thickness of scale	in	1	EPA91
Average pipe lengths in yard	ft	10	assumed
Respiration rate	m^3/yr	8000	EPA91
Density of scale	kg/m^3	2600	EPA91, CRC85, RAE92
Density of pipe	kg/m^3	7800	EPA91, GRO85
Inner diameter of pipe	in	3	EPA91
Average height of scrap steel pile	m	3	assumed
Volume of contaminated scrap steel stored	m^3	128.8	(reference 10 well facility)
Distance to adjacent resident	m	100	assumed
Fraction of time adjacent resident is exposed to gamma		0.75	assumed
Contaminant dust loading	g/m^3	3.23E-6	(e.g., 4-1 for volume of equipment)
Fraction of time wind is blowing parallel to pipes		9.3E-2	EPA91
Average wind velocity	m/s	4.5	EPA91

4.2.1.5 Transportation of Contaminated Equipment

Oil and gas production equipment is generally shipped to a storage yard to await further use (EPA91, ZAL92). During shipment, the truck driver, as illustrated in Figure 4-7, is assumed to be the only exposed individual. Additionally, it is assumed that the truck driver is responsible for transporting the volume of used equipment from an average ten well facility to the storage yard. Using an average volume for a standard semi trailer-truck, 67.3 m^3 (ROY92), it is postulated to take a total of three trips for the truck driver to transport the material to the storage yard. Conservatively, no additional scrap metal from other sources is assumed to be transported with the NORM-contaminated oil and gas production equipment. Input parameters characterizing this scenario are listed in Table 4-7.

4.2.1.6 Steel Mill and Scrap Yard Alarm Systems

Monitors are becoming more commonly used in steel mills and scrap yards. Initially, monitors were installed to detect low-level radioactive waste and radioactive sources. However, these alarm systems also have the ability to detect NORM contamination. In fact, the identification of NORM-contaminated scrap has caused the rejection of scrap metal shipments (ZAL92). The detection of NORM depends on the radium concentration, location in the load, sensitivity of alarms, and location of the alarms.

MICROSHIELD is used to calculate the radiation exposure at a monitor two feet from a truck, as illustrated in Figure 4-7, loaded with NORM-contaminated scrap steel. Conservative radium concentration estimations in a truck load on NORM-contaminated equipment are determined by assuming an average of ten percent of the volume of NORM-contaminated scrap steel in the load is NORM scale (EPA91).

Several loading schemes or NORM distributions are evaluated: the NORM-contaminated equipment is preferentially loaded on one side (assumed to be the easiest to detect), the NORM is mainly concentrated on one side, but shielded by one layer of uncontaminated piping; and the

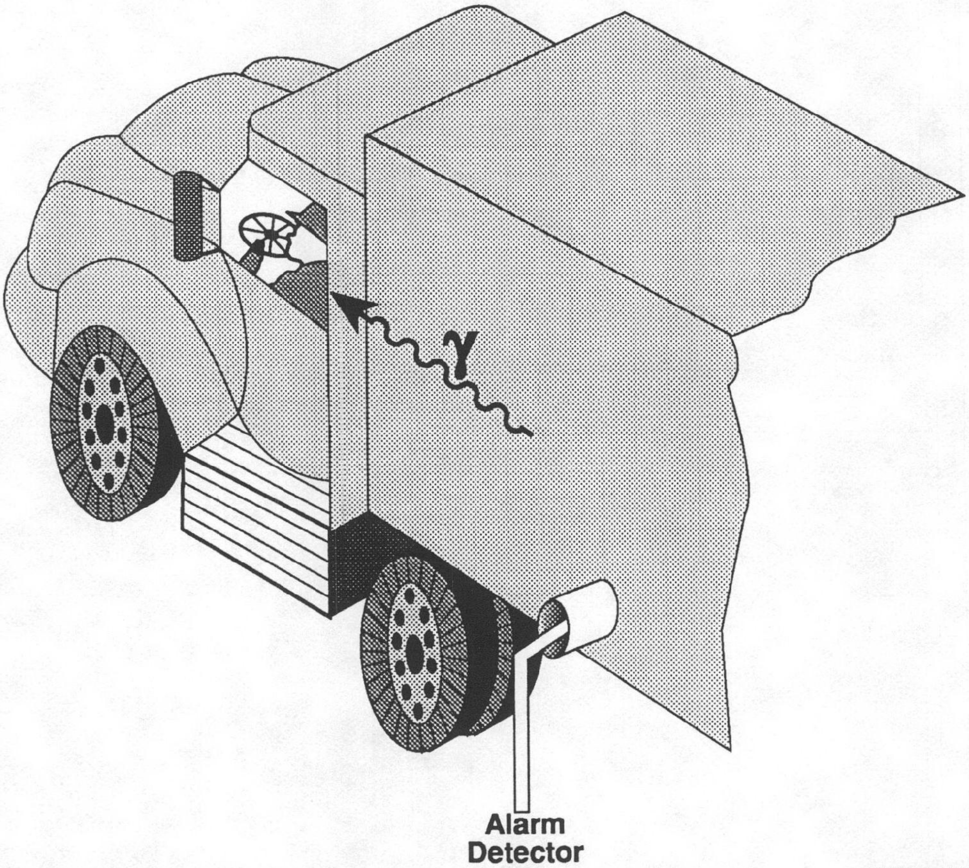

Figure 4-7. Exposure pathways from the transport of NORM contaminated material.

Table 4-7. Transportation scenario input parameters.

Parameter	Unit	Value	Basis
Average miles traveled per trip	miles	50	ZAL92, FUE92
Average speed traveled	miles/hr	40	assumed
Number of trips per year		3	assumed
Cab distance from trailer	m	1	ROY92
Trailer length	ft	40	ROY92
Trailer height	m	2.4	ROY92
Trailer width	m	2.3	ROY92
Scale density	kg/m^3	2600	EPA91, CRC85, RAE92
Steel density	kg/m^3	7800	EPA91
Volume of trailer	m^3	67.3	calculated
Total volume of load	m^3	42.9	calculated
Total height	m	1.5	calculated
Fraction of median 10 well volume per load		0.33	calculated

NORM is uniformly distributed throughout the load (assumed to be the hardest to detect). Input parameters characterizing the evaluation of the alarm systems are listed in Table 4-8.

4.2.1.7 Recycled to Smelter

Although some smelting operations may produce steel for new oil-field equipment from old NORM-contaminated equipment, other operations produce products to be released to the general public. In a typical batch-smelting operation of contaminated steel, the furnace is charged with the steel and slagging material. As the contaminated steel is melted, the scale deposits are volatilized. The volatilized materials are then carried out with the stack gases, or they are trapped in the slagging material and removed with the slag. Compounds that are not volatilized migrate into the slag layer as a result of density differences between the molten steel and the metal compounds.

The scenarios considered in this assessment conservatively model emissions from a 30-minute batch processing of the gas-fired furnace described in Case 2 of Section 3.1.2.4. As discussed above, the slagging agents used directly affect the amount of NORM contaminant that is allowed to escape in the effluent gases. The two scenarios, as illustrated in Figure 4-8, consider both extremes (~100 percent of the NORM is volatilized and released with the effluent gases, and ~100 percent of the NORM is captured by the slagging agents and transported to the slag pile). As discussed in Section 3.1.2.4, the resulting product in either case is considered uncontaminated. The dust contamination from the flue gas and the gamma emissions from the slag pile expose both a yard worker and an adjacent resident. Input parameters characterizing these scenarios are presented in Table 4-9. This scenario is considered conservative since some smelters monitor incoming scrap metal and most reprocess scrap from other sources not associated with the oil and gas production field.

Table 4-8. Alarm scenario input parameters.

Parameter	Unit	Value	Basis
Trailer distance to alarm	ft	2	BER92
Trailer length	ft	40	ROY92
Trailer height	m	2.4	ROY92
Trailer width	m	2.3	ROY92
Scale density	kg/m^3	2600	EPA91, CRC85, RAE92
Steel density	kg/m^3	7800	EPA91
Volume of trailer	m^3	67.3	calculated
Total volume of load	m^3	42.9	calculated
Total height	m	1.5	calculated
Fraction of median 10 well volume per load		0.33	calculated

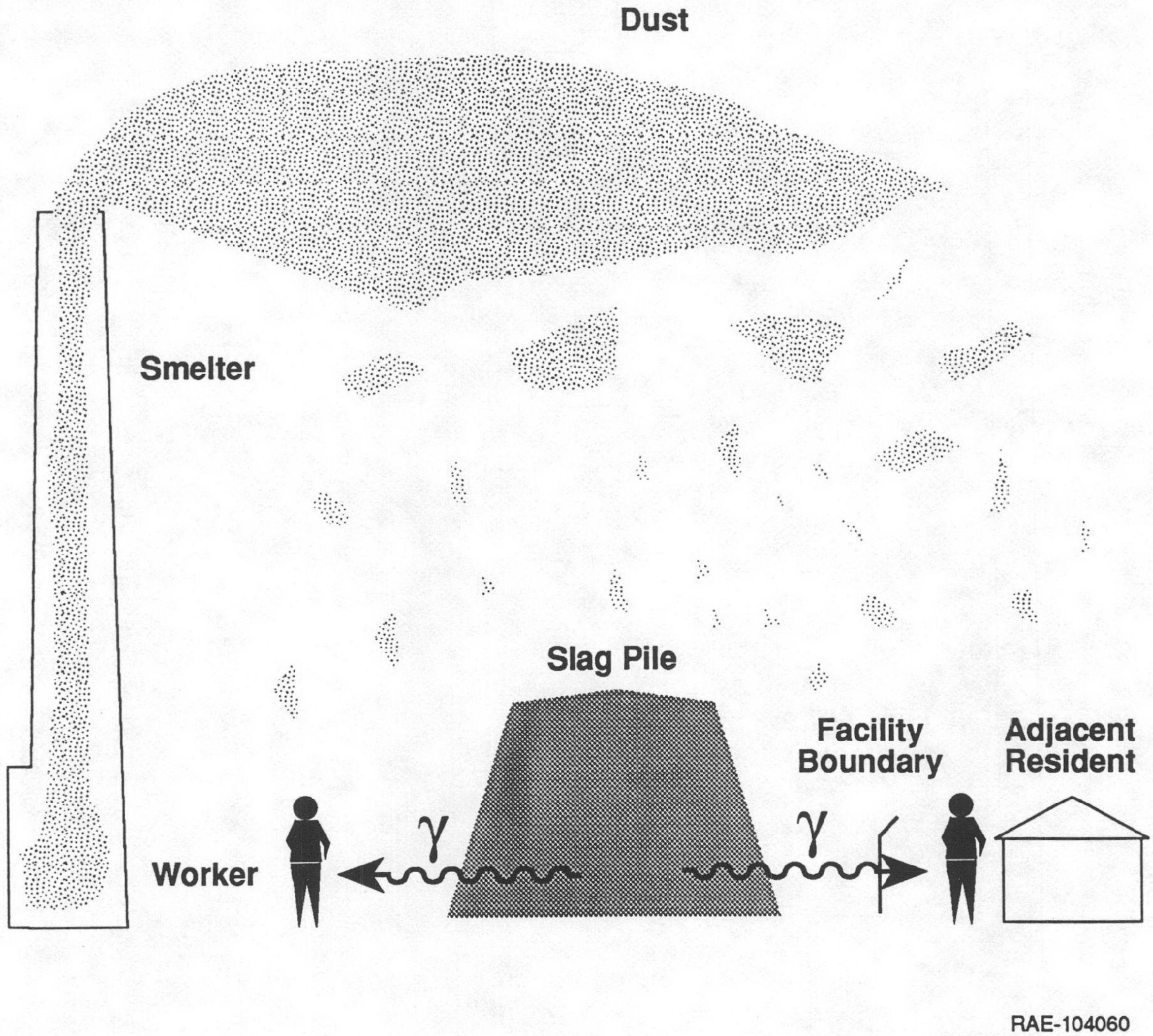

Figure 4-8. Exposure pathways from the smelting of NORM contaminated scrap steel.

Table 4-9. Smelting input parameters.

Parameters	Unit	Value	Basis
Quantity of metal smelted per batch	tons	50	ROW92
Duration worker is exposed to slag pile	hr/yr	2000	EPA91
Worker respiration rate	m^3/yr	8000	NRC81
Dust loading	µg/m^3	100	EPA91
Distance to adjacent resident	m	100	assumed
Number of contaminated batches per year	b/yr	5	calculated
NORM concentration in slag if slagging agents used	pCi/g	170	calculated (see Section 3.1.2.4)
NORM concentration in flue gas if no slagging agents are used	pCi/L	170	see Section 3.1.2.4
Furnace effluent discharge rate	L/min	2.83E+5	ROW92
Fraction of time resident is exposed to dust or gamma		0.75	assumed
Distance of adjacent resident to smelter stack to slag pile	m	100	assumed
Fraction of time wind is blowing toward resident		9.3E-2	EPA91
Average wind speed blowing towards resident	m/s	4.5	EPA91
Average Pasquill stability class of air blowing towards resident	1/2 1/2	C D	EPA91
Mass of slag per 50 ton batch	ton	9.5	calculated
Average density of slag	g/cm^3	3.0	NRC78
Slag pile volume[a]	m^3	14.4	calculated from waste generated from 10 well facility
Slag pile height	m	2	assumed
Distance of worker to slag pile and smelter stack	m	10	assumed
Average stack gas velocity	m/s	2.7	assumed
Inside stack diameter	m	2.5	assumed

a No additional dilution is utilized for the slag pile. Generally, slag generated for smelting of non-contaminated equipment will provide significant dilution.

4.2.2 Phosphogypsum

The results of evaluations of possible health impacts from the production and commercial uses of phosphogypsum wastes are dependent on the waste inventories, generic site parameters and radiological properties of the NORM wastes. The majority of this information comes from the recent ORP work, "Development of Background Information and Risk Analyses of Alternative Phosphogypsum Uses" (BID91).

The exposure scenarios evaluated for this risk assessment include potential exposures to individuals from the use of phosphogypsum in agriculture, road construction, and research activities. Additionally, exposures from the cleaning of the stainless steel filter pans used in the separation of the phosphoric acid and the phosphogypsum are evaluated. Exposures are calculated for both the median and high concentrations presented in Table 2-5. Non-scenario-specific parameters are compiled as Table 4-10.

4.2.2.1 Phosphogypsum in Agriculture

Two scenarios involving the agricultural use of phosphogypsum are evaluated. These scenarios, as illustrated in Figure 4-9, assume a moderate-sized sand field, used to grow crops, with the exposed individual being 100 m from the site edge. The first scenario involves the use of phosphogypsum as a source of calcium and sulfur for soils deficient in these elements. The second involves its use in sediment control for soils that have been eroded and leached. Values of environmental and climatological parameters used in the risk assessment are representative of a humid permeable site.

4.2.2.1.1 Phosphogypsum as a source of calcium and sulfur

Parameters which characterize the scenario involving phosphogypsum as a source of calcium and sulfur on agricultural fields are shown in Table 4-11. The parameter values in Table 4-11 are based on the responses by agricultural users of phosphogypsum to a survey by The Fertilizer

Table 4-10. **Site-specific input parameters for phosphogypsum risk assessments (Basis for Values: BID91).**

Parameter	Units	Value
Phosphogypsum application rate--agricultural scenarios		
Fertilizer	MT/acre/yr	0.66
Soil conditioner	MT/acre/yr	4.05
Phosphogypsum application interval--agricultural scenarios	--	biennially
Total years of application--agricultural scenarios	yrs	100
Agricultural field size		
Fertilizer	acre	138
Soil conditioner	acre	556
Tillage depth--agricultural scenarios		
Fertilizer	m	0.22
Soil conditioner	m	0.30
Agricultural field soil density	kg/m^3	1.50E+03
Roadbed material density	kg/m^3	2.25E+03
Distance to nearest residence		
Fertilizer	m	100
Soil conditioner	m	100
Road construction scenarios	m	100
Distance to river	m	5.00E+03
River flow rate	m^3/yr	1.00E+08
Density of aquifer	kg/m^3	1.80E+03
Porosity of aquifer	--	0.33
Horizontal velocity of aquifer	m/yr	20
Vertical distance to aquifer		
Fertilizer scenario	m	3.0
Soil conditioner scenario	m	10.0
Construction scenarios	m	3.0

Table 4-10. (Continued.)

Parameter	Units	Value
Water infiltration rate		
Fertilizer scenario	m/yr	0.40
Soil conditioner scenario	m/yr	0.25
Construction scenarios	m/yr	0.40
Fraction of food eaten grown on-site	--	0.50
Adult breathing rate	m^3/yr	8.00E+03
Average dust loading in outside air	kg/m^3	5.00E-07
Average dust loading in R&D lab	kg/m^3	1.00E-07
Atmospheric stability class	--	4
Fraction of time wind blows toward receptor	--	0.093
Average wind speed	m/sec	4.5
Dust resuspension rate for off-site transport	m^3/sec	5.0E-07
Dust deposition velocity	m/sec	1.0E-03
Radon emanating power	--	0.30
Radon diffusion coefficient		
Soil	m^2/yr	2.2E+01
Concrete	m^2/yr	1.6E+01
Air change rate in reclaimer house	changes/hr	2
Exposure fraction for indoor exposure	--	0.75
Equivalent exposure fraction for outdoor exposure	--	0.50
Surface erosion rate	m/yr	2.0E-04
Volume of drinking water consumed annually by an individual	m^3/yr	0.37
Length of road perpendicular to aquifer	mile	10
Aquifer thickness	m	10

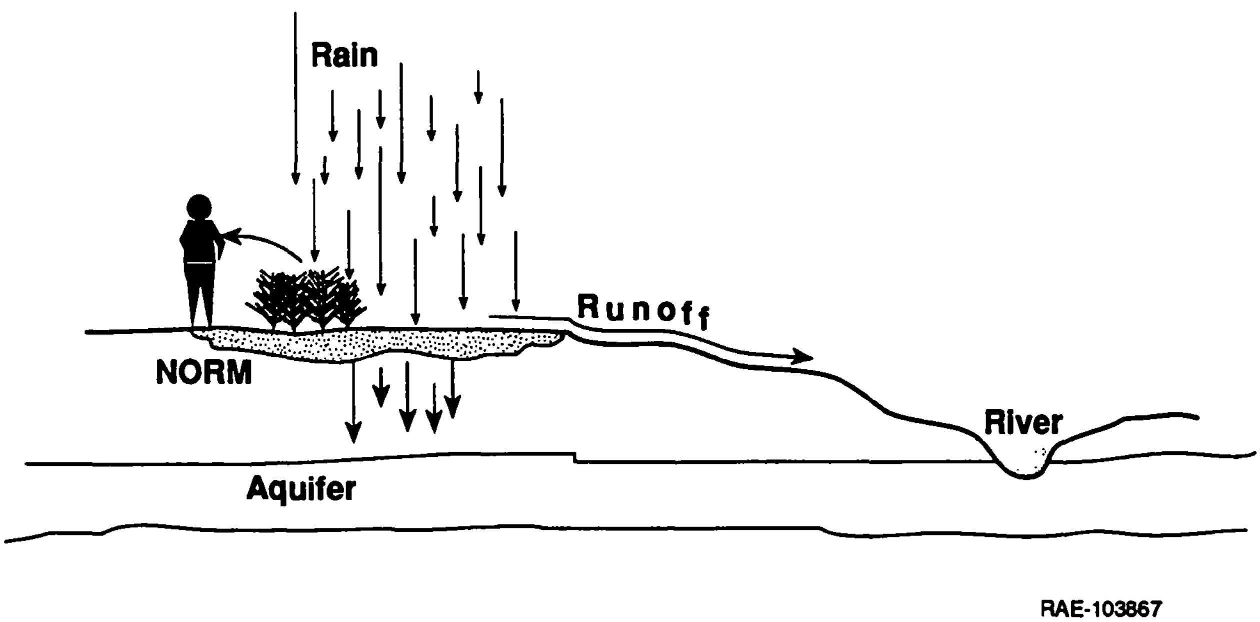

Figure 4-9. Exposure pathways from the agricultural use of phosphogypsum.

Table 4-11. Phosphogypsum use parameters for agricultural scenarios (Basis: BID 91).

	Soil Additive Scenario	Sediment Control Scenario
Kilograms of phosphogypsum per acre		
Initial	664	8,000
Subsequent		4,000
Acre per farm	138	556
Tillage depth (cm)	22	30
Application rate	Biennial	Biennial
Distance to nearest residence (m)	100	100

Institute (TFI89). The reference agricultural field for the first scenario is postulated to be located in a humid permeable site. Values of environmental and climatological parameters used in the risk assessment are representative of a humid permeable site.

Dose calculations for the first scenario assumes biennial application of phosphogypsum to the reference site for a period of 100 years. Phosphogypsum is spread over a field and diluted by mixing with the soil. Hence the incremental radionuclide concentrations in the soil are much lower than the concentrations in the phosphogypsum itself. Over time, as phosphogypsum continues to be applied, the radionuclide concentrations in the soil are expected to increase until equilibrium is reached with competing mechanisms that remove the gypsum, and its radioactive constituents, from the soil. These removal mechanisms include plant uptake, leaching by infiltration of surface water, and wind and water erosion. The Ra-228 part of the radionuclide content in the soil is also reduced as a result of radioactive decay. A simple mass balance equation is used to estimate radionuclide concentrations in the reference soil as a result of biennial applications of phosphogypsum for a period of 100 years.

$$\frac{dC}{dt} = K - kC \qquad \textbf{(4-2)}$$

where

C = Ra-226 concentration (pCi/g)

K&k = arbitrary constants

The solution to equation 4-2 is obtained through standard differential equation solution techniques, and is found to be:

$$C = \frac{K}{k}(1 - e^{-kt}) \qquad \textbf{(4-3)}$$

Using the boundary condition of C=0 at t=0, the arbitrary constants can be solved for. The resulting solution then becomes:

$$C_s = \frac{k_i\ C_{pG}}{W} * \frac{1}{k_2 + k_3 + k_4 + k_5} * (1 - e^{-(k_2 + k_3 + k_4 + k_5)t}) \qquad (4\text{-}4)$$

where

C_s	=	Ra-226 concentration in soil (pCi/g)
C_{pG}	=	Ra-226 concentration in phosphogypsum (pCi/g)
k_i	=	application rate of phosphogypsum (g/yr)
W	=	mass of soil (g)
k_2	=	Ra-226 decay rate (4.3×10^{-4} yr^{-1})
k_3	=	rate loss of Ra-226 due to uptake by plants (2.6×10^{-6} yr^{-1})
k_4	=	rate loss of Ra-226 by leaching (2.8×10^{-5} yr^{-1})
k_5	=	rate loss of Ra-226 by wind erosion (8.9×10^{-4} yr^{-1})

Using the data in Table 4-11, the soil Ra-226 concentration can be calculated after 100 years of biennial phosphogypsum application (see Table 4-12). A summary of the soil Ra-226 concentrations calculated for the scenarios involving phosphogypsum is presented in Table 4-13.

4.2.2.1.2 Phosphogypsum as sediment control for soils that have been eroded and leached

Parameters which characterize this scenario are also shown in Table 4-11. The reference agricultural site for this scenario is assumed to be located in the south-western United States. The phosphogypsum is initially applied at the rate of 8 MT per acre, followed by biennial applications of 4 MT per acre. As in the first scenario, an application period of 100 years is postulated. For a median Ra-226 concentration of 31 pCi/g in phosphogypsum, the increase in

Table 4-12. Ra-226 soil concentration calculation parameters (Basis: BID91).

Parameter	Fertilizer	Sediment Control
k_2 (yr^{-1})	4.3E-04	4.3E-04
k_3 (yr^{-1})	2.6E-06	2.6E-06
k_4 (yr^{-1})	2.8E-05	2.8E-05
k_5 (yr^{-1})	8.9E-04	8.9E-04
k_i (g/yr)	4.6E+07	1.1E+09
t (yrs)	100	100
W (g)	1.9E+11	1.0E+12
median C_s (pCi/g)	31	31
high (C_s (pCi/g)	48.6	48.6

Table 4-13. Ra-226 soil concentrations (Basis: BID91).

Scenario	Median Ra-226 Concentration (pCi/g)	90 Percentile Ra-226 Concentration (pCi/g)
Fertilize	0.71	1.11
Sediment Control	3.22	5.05

the Ra-226 concentration in the tilled soil after 100 years of biannual application is calculated to be 3.22 pCi/g.

The agricultural worker is assumed to spend 2,000 hours per year at the agricultural site, performing activities such as plowing, fertilizing, harvesting, etc. The worker would probably use machinery for most of these activities which would provide some shielding from direct gamma radiation (as in the construction scenarios, plowing equipment on average provides a shielding factor of 0.6). However, to ensure conservatism in the results of this risk analysis, no credit for shielding is taken in calculating the dose from direct exposure to gamma radiation (BID91).

The on-site individual is assumed to live in a house constructed on a site which was previously used for agriculture. For conservatism, this individual is also assumed to work at this same site.

The CPG is defined to include individuals who might be exposed to the highest doses as a result of normal daily activities. For this phosphogypsum risk assessment, the member of the CPG is assumed to be an adult at the nearest residence as defined in Table 4-11. The person obtains all water from a well adjacent to the house. Fifty percent of foodstuffs are assumed to be grown on-site.

4.2.2.2 Phosphogypsum in Road Construction

Two scenarios, as illustrated in Figure 4-10, involving phosphogypsum in road construction are evaluated. The first involves the use of phosphogypsum in a road base for a secondary road. The second scenario involves the use of phosphogypsum as a concrete additive.

4.2.2.2.1 Phosphogypsum in a road base for a secondary road

The road base consists of a 1:2 phosphogypsum:soil mixture with a density of 2.25 g/cm^3 (2.25 MT/m^3). Assuming a Ra-226 concentration of 31 pCi/g in phosphogypsum, the Ra-226

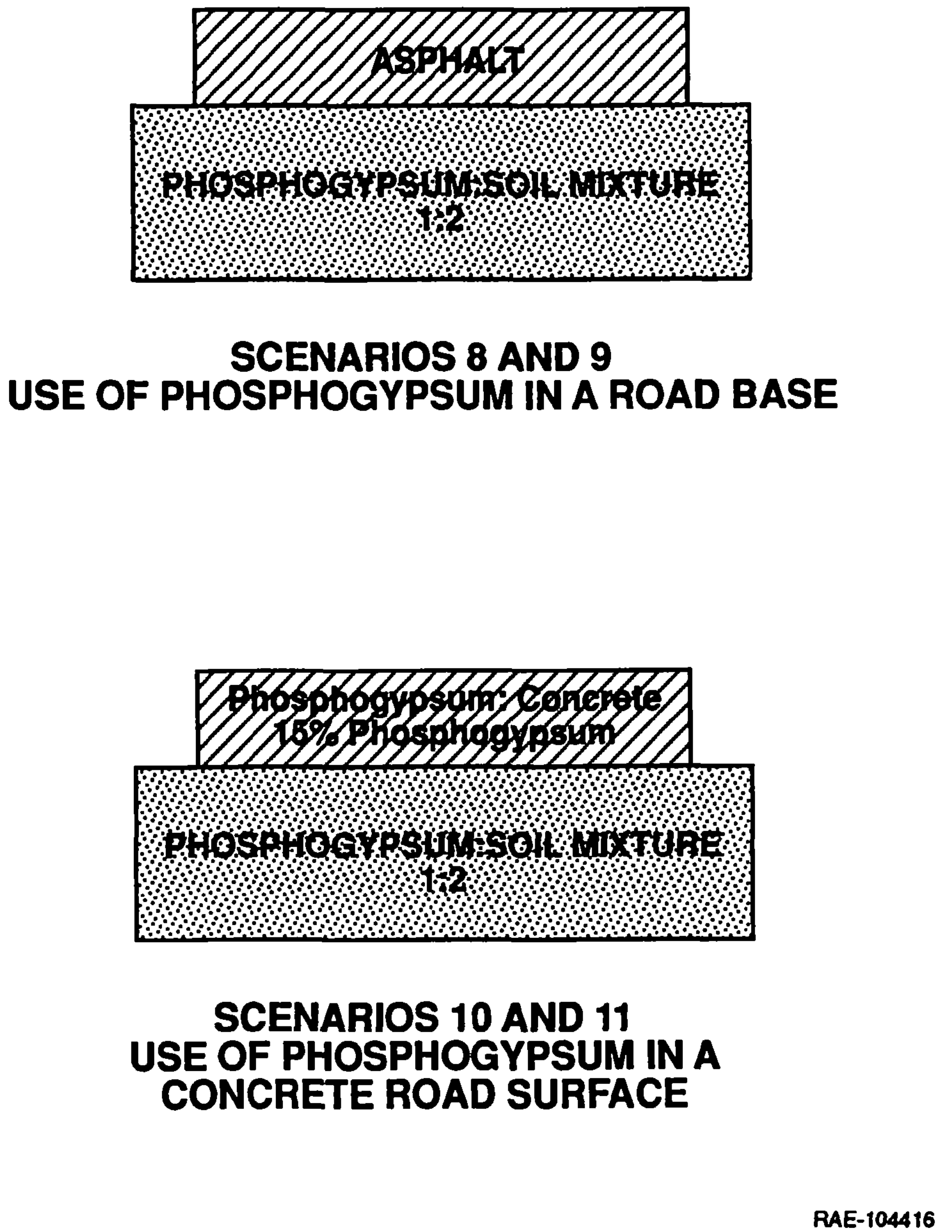

Figure 4-10. Scenarios involving the use of phosphogypsum in road construction.

concentration in the road base is 10 pCi/g. The road base is 9.15 m (30 ft) wide and 0.25 m (10 inches) thick and is covered by a 0.12 m (5 inch) thickness of asphalt.

4.2.2.2.2 Phosphogypsum in a concrete road surface

The concrete road surface incorporates 15 weight percent phosphogypsum. Assuming a Ra-226 concentration of 31 pCi/g in phosphogypsum, the Ra-226 concentration in the road surface is 4.7 pCi/g. The road surface is 7.32 m (24 ft) wide and 0.12 m (5 inches) thick. The road base under the concrete surface is the same as for the first road construction scenario.

Radium often occurs naturally in concrete constituents. In a study of the radioactive properties of commercially available concrete for the State of Florida (RAE91b), radium concentrations in concrete samples from 1.0 pCi/g to 2.4 pCi/g were measured. Radium in commercially available concrete varies directly with the origin of the constituents (RAE91b). Due to this variance, radium in the concrete evaluated in this analysis is assumed to be only from the phosphogypsum additive.

The construction worker is assumed to be engaged eight hours per day for 250 days per year in constructing a 16-km (10-mile) section of road. Gamma exposures are calculated for a worker who is employed directly on the road surface and a worker who uses equipment such as a bulldozer or road grader which provides some shielding from gamma radiation. The shielding coefficient is 0.6.

The person driving on the road is assumed to use the road from home to work, and return. This person travels the road one hour per day for 250 trips per year. The automobile in which this person rides provides some shielding from direct gamma radiation. The shielding coefficient is 0.6.

The reclaimer is assumed to build a house on the roadbed at some future time (presumed to be 50 years after road construction) after the road is closed and the road surface has crumbled and been removed. In addition to living in a house at the site, the reclaimer drills a well for water and plants a vegetable garden in the contaminated soil. The vegetable garden provides 50 percent of the reclaimer's foodstuffs.

The member of the CPG is assumed to live in a house located 100 meters from the road. Potential doses to a member of the CPG could result from direct gamma exposure or from the use of contaminated well water.

4.2.2.3 Phosphogypsum in Research and Development Activities

One scenario, as illustrated in Figure 4-11, is evaluated in which phosphogypsum is used in research and development to evaluate the properties of this material for commercial applications. In this scenario, exposures are estimated for a worker who spends four hours per day, 250 days per year in a laboratory containing one open 55-gallon drum of phosphogypsum. The worker is exposed via direct gamma radiation, dust inhalation, and radon inhalation pathways. MICROSHIELD is used to estimate the external gamma dose; the worker is assumed to be positioned at an average distance of one meter from the drum of phosphogypsum. To estimate the exposure from dust inhalation, a dust loading of 100 micrograms/m^3 is postulated. This value is derived from 40 CFR 50.6(b), which specifies a level of 50 $\mu g/m^3$ as the arithmetic mean level of primary and secondary standards for airborne particulate matter. The value is doubled to provide a conservative estimate. To estimate the indoor radon exposure, two air changes per hour are assumed.

4.2.2.4 Cleaning of Stainless Steel Filter Pans

The production of phosphogypsum involves the separation of phosphoric acid and phosphogypsum using large fiberglass covered stainless steel filter pans (EPA91). During this process, scale is deposited on the surface areas of the pan and fiberglass mat. Due to the high cost of the filter pans, the current industrial practice involves cleaning the pans for reuse (KEA92). The cleaning of the filter pans exposes workers to direct gamma radiation, contaminated dust inhalation, and indoor radon inhalation risks.

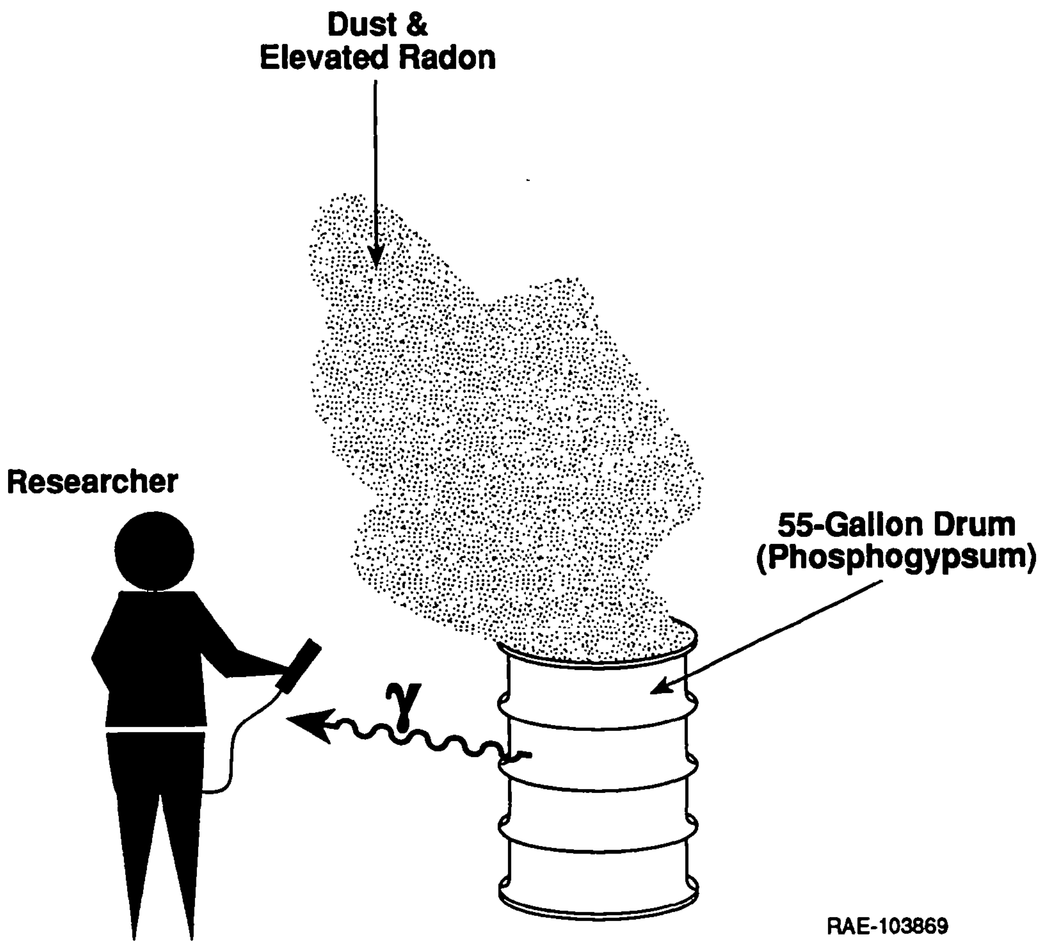

Figure 4-11. Exposure pathway from research activities using phosphogypsum.

This scenario involves the cleaning of stainless steel filter pans by hydrolasers. The scenario consists of a worker operating a hydrolaser from the remote distance of ten feet. The Ra-226 concentration of the scale is taken to be 100 times the normal for phosphogypsum 3,000 pCi/g (EPA91). Additionally, it is assumed that the worker is exposed to a total of six m^3 of scale for the 2000 hour working year. The input parameters characterizing this scenario are presented in Table 4-14.

Table 4-14. Stainless steel filter pan cleaning scenario input parameters.

Parameter	Unit	Value	Basis
Duration workers employed	m/yr	2,000	EPA91
Dust loading	$\mu g/m^3$	100	EPA91
Respiration rate	m^3/yr	8,000	EPA91
Phosphate scale density	kg/m^3	2,600	CRC85, BID91, KEA92
Average distance of exposure[a]	ft	10	assumed
Dust collection efficiency	percent	95	KEA92, MAD79
Number of pans being cleaned in facility at once		1	assumed
Volume of scale	m^3	6	EPA91
Radon emanation coefficient	m^3/yr	0.20	EPA91

a It is assumed that the worker is exposed for a full 2,000 hours to the filter pans being cleaned.

5. Risk Assessment Results

This chapter presents the calculated risks associated with the reprocessing and reuse of NORM-contaminated oil and gas production equipment and phosphogypsum, according to the scenario outlined in Chapter 4. Results are reported for median and 90 percentile concentrations of NORM.

5.1 OIL AND GAS PRODUCTION

Risk assessment results for exposures resulting from NORM-contaminated oil and gas production equipment are summarized below. Additionally, alarm exposures and distributions are presented. State and Federal regulations are presented where applicable.

5.1.1 Maximum Individual Exposures

The risks due to the exposures to NORM from the oil and gas production wastes are summarized in Tables 5-1 through 5-4. The calculated risks are for fatal cancers. If a calculated risk is 7.0E-05, an exposure to the indicated level of radiation for one year will, in a 70-year lifetime, probably cause seven fatal cancers in an exposed population of 100,000 persons. From Table 5-1 and 5-2, the risks resulting from the unrestricted release of median and 90 percentile NORM-contaminated equipment are presented. The risk to a student playing on a jungle gym contaminated with median and 90 percentile levels of NORM are 1.2E-05 and 7.8E-05, respectively. These risks are primarily due to direct gamma exposure. A student in the welding class that uses median and 90 percentile NORM-contaminated equipment has risks of 1.0E-06 and 7.0E-06. Again, the major contributor is direct gamma radiation. The shop student experiences higher dust and radon inhalation doses than the child playing on the playground equipment. However, there is less NORM-contaminated equipment in the shop than composed in the jungle gym, reducing the direct gamma and overall dose to the welder.

Table 5-1. Risk assessment results for unrestricted release scenarios with median NORM concentrations.

Person - Pathway	Dose (mrem/yr)	Risk (fatal cancers)
Child on jungle gym		
Direct gamma	4.5E+01	1.2E-05
Dust inhalation	1.6E-04	2.1E-11
Dermal	0.0E+00	
TOTAL	**4.5E+01**	**1.2E-05**
Student in welding class		
Direct gamma	4.0E+00	1.0E-06
Dust inhalation	6.6E-02	1.4E-08
Radon inhalation		4.0E-13
Dermal	0.0E+00	0.0E+00
TOTAL	**4.1E+00**	**1.0E-06**
Teacher in welding class		
Ingestion	8.2E-03	7.4E-10
Dust inhalation	3.6E-01	7.5E-08
Radon inhalation		2.1E-12
TOTAL	**3.7E-01**	**7.6E-08**
Teacher Supervising Jungle Gym		
Dust	8.2E-04	1.7E-08
Resident Reuse		
Direct gamma	1.8E+00	1.6E-10
Ingestion	2.7E-05	2.4E-12
Radon		8.2E-12
TOTAL	**1.8E+00**	**1.7E-10**

Table 5-2. Risk assessment results for unrestricted release scenarios with 90 percentile NORM concentrations.

Person - Pathway	Dose (mrem/yr)	Risk (fatal cancers)
Child on jungle gym		
Direct gamma	3.0E+02	7.8E-05
Dust inhalation	1.0E-03	2.2E-10
Dermal	0.0E+00	
TOTAL	**3.0E+02**	**7.8E-05**
Student in welding class		
Direct gamma	2.7E+01	6.9E-06
Dust inhalation	4.5E-01	9.2E-08
Radon inhalation		2.6E-12
Dermal	0.0E+00	0.0E+00
TOTAL	**2.7E+01**	**7.0E-06**
Teacher in welding class		
Ingestion	5.5E-02	5.1E-09
Dust inhalation	2.4E+00	5.1E-07
Radon inhalation		1.4E-11
TOTAL	**2.5E+00**	**5.2E-07**
Teacher Supervising Jungle Gym		
Dust inhalation	5.5E-03	1.1E-07
Resident Reuse		
Direct gamma	1.2E01	1.1E-09
Ingestion	1.8E-04	1.6E-11
Radon		5.5E-11
TOTAL	**1.2E+01**	**1.2E-09**

Table 5-3. Risk assessment results for the contaminated oil production equipment reprocessing scenarios for median NORM concentrations.

Person - Pathway	Dose (mrem/yr)	Risk (fatal cancers)
Worker in storage yard		
Direct gamma	2.0E+01	5.5E-06
Dust inhalation	2.3E+01	4.9E-08
TOTAL	**2.0E+01**	**5.6E-06**
Truck driver		
Direct gamma	3.4E-02[a]	9.0E-09[a]
Resident adjacent to storage yard		
Direct gamma	7.2E-02	1.9E-08
Dust inhalation	1.1E-03	5.4E-11
TOTAL	**7.3E-03**	**1.9E-08**
Worker in smelter yard with no slag control		
Dust inhalation	9.3E+02[b]	2.0E-04[b]
Worker in smelter yard with slag control		
Direct gamma	5.6E+00	1.5E-06
Resident adjacent to smelter with no slag control		
Dust inhalation	4.3E+01[c]	9.2E-06[c]
Resident adjacent to smelter with slag control		
Direct gamma	1.4E-01	3.7E-08
Mechanical abrasive pipe cleaner		
Direct gamma	5.2E-04	4.5E-14
Dust inhalation	7.2E+00	1.5E-06
TOTAL	**7.2E+00**	**1.5E-06**
Hydrolaser pipe cleaner		
Direct gamma	7.5E-05	6.6E-16
Dust inhalation	3.6E-01	7.5E-08
TOTAL	**3.6E-01**	**7.5E-08**
Resident adjacent to cleaning facility		
Dust inhalation	1.9E-02	4.0E-09

a 1.1E-02 mrem/yr per trip and 3.0E-09 fatal cancers per trip.
b 1.86E+02 mrem/yr per batch and 4.0E-05 fatal cancers per batch.
c 8.6E+00 mrem/yr per batch and 1.8E-06 fatal cancers per batch.

Table 5-4. Risk assessment results for the contaminated oil production equipment reprocessing scenarios for 90 percentile NORM concentrations.

Person - Pathway	Dose (mrem/yr)	Risk (fatal cancers)
Worker in storage yard		
Direct gamma	1.4E+02	3.6E-05
Dust inhalation	1.6E+00	3.3E-07
TOTAL	**1.4E+02**	**3.6E-05**
Truck driver		
Direct gamma	2.2E-01[a]	6.0E-08[a]
Resident adjacent to storage yard		
Direct gamma	5.1E-01	1.3E-07
Dust inhalation	7.3E-03	3.6E-10
TOTAL	**5.1E-01**	**1.3E-07**
Worker in smelter yard with no slag control		
Dust inhalation	6.2E+03[b]	1.3E-03[b]
Worker in smelter yard with slag control		
Direct gamma	3.7E+01	1.0E-05
Resident adjacent to smelter with no slag control		
Dust inhalation	2.9E+02[c]	6.1E-05[c]
Resident adjacent to smelter with slag control		
Direct gamma	9.2E-01	2.5E-07
Mechanical abrasive pipe cleaner		
Direct gamma	3.4E-03	3.0E-13
Dust inhalation	5.1E+00	1.0E-05
TOTAL	**5.1E+00**	**1.0E-05**
Hydrolaser pipe cleaner		
Direct gamma	5.1E-05	4.4E-15
Dust inhalation	2.4E+00	5.1E-07
TOTAL	**2.4E+00**	**5.1E-07**
Resident adjacent to cleaning facility		
Dust inhalation	1.3E-01	2.7E-08

a 7.3E-02 mrem/yr per trip and 2.0E-08 fatal cancers per trip.
b 1.2E+03 mrem/yr per batch and 2.7E-04 fatal cancers per batch.
c 5.7E+01 mrem/yr per batch and 1.2E-05 fatal cancers per batch.

The risks to the shop instructor and the playground supervising teacher from median levels of NORM contamination are 7.6E-08 and 1.7E-08, respectively. These risks are higher than the student's for dust and radon inhalation because of the increased exposure time. However, without the dominating direct gamma component, the teacher and instructor doses are significantly less than those experienced by the students.

Tables 5-1 and 5-2 also present the risks to individuals using NORM-contaminated equipment in residential construction. The resident's risks from the use of median and 90 percentile NORM-contaminated equipment for plumbing and building materials are 1.7E-10 and 1.2E-09, respectively. The major contribution to the overall doses is from direct gamma radiation from contaminated piping. The direct gamma dose to the individual is significantly less than that experienced from the student because of the larger average distance from which the resident is exposed. The estimated radium concentration in the water from median NORM concentration in scale is 105 pCi/m^3 or 0.1 pCi/L. As discussed in chapter 1, this does not violate the National Drinking Water Standards (40 CFR 141) for radium of 40 pCi/L. In order to exceed the 40 CFR 141 radium limits, radium scale concentrations in this scenario need to be in excess of 1.4E+05 pCi/g.

Exposures resulting from the preprocessing of used oil and gas production equipment are presented in Tables 5-3 and 5-4. The risks to a truck driver transporting median concentrated NORM-contaminated oil and production equipment experiences a risk of 9.0E-09. This is directly resulting from exposure to direct gamma radiation. The risk is significantly less to the truck driver than that experienced by the child playing on the jungle gym because of the decreased time of exposure and the increased shielding and distance to contamination.

Other occupational exposures are reported for the pipe cleaners, and the smelter and storage yard workers. Risks to the mechanical and hydrolaser pipe cleaners from median NORM-contaminated equipment are 1.5E-06 and 7.5E-08. Exposures to the hydrolaser cleaner are less than those to the mechanical cleaner primarily due to the added distance and dust control provided by hydroblasting. The exposure to the resident adjacent to the mechanical cleaning facility from median NORM contaminated dust is 4.0E-09.

The risks summarized for the smelter yard worker and adjacent resident are presented in two parts to allow for the modeling of the effects of varying slagging agents. The risks from exposure to median concentration NORM equipment to the smelter yard worker if all of the NORM is captured in the slag is 1.5E-06. However, if slagging agents are used that do not serve to capture the NORM radionuclides, then the risk to the exposed worker is 2.0E-04. If a particular slagging agent is used in which 30 percent of the NORM can be captured, then the risk to the worker is calculated as [(0.30 x 1.5E-06) + (0.70 x 3.0E-04)] or 1.4E-04. Similar combinations can be made for the adjacent resident [(0.30 x 3.7E-08) + (0.70 x 9.2E-06) = 6.5E-06].

5.1.2 NORM Transportation

The exposures from the several loading schemes of median concentrated NORM distributions evaluated are illustrated in Figures 5-1 through 5-3. As illustrated in Figure 5-1, if median concentrated NORM is preferentially loaded on one side (assumed to be the easiest to detect), the exposure to an alarm would be 2.2E+01 μR/hr. If the NORM is mainly concentrated at one side but shielded by a layer of uncontaminated piping, the exposure at the alarm would be 1.5E+01 μR/hr. The effects of the shielding provided by clean piping can be seen in Figure 5-2. Exposures to the alarm are exponentially proportional to the thickness of the clean layer of piping between the NORM and the detector. Additionally, Figure 5-3 illustrates the alarm-position exposures from varying concentrations of NORM contamination in a uniformly distributed load of oil production pipe. As can be seen, NORM radium concentrations need to be as high as 200 pCi/g to be detected by the alarm.

As noted earlier, the DOT defines a regulated radioactive material as "*any material having specific activity greater that 0.002 μCi/g*" (49 CFR 173). Assuming that 100 percent of the truck load is NORM-contaminated (~10 percent NORM scale by volume), and a median value of the

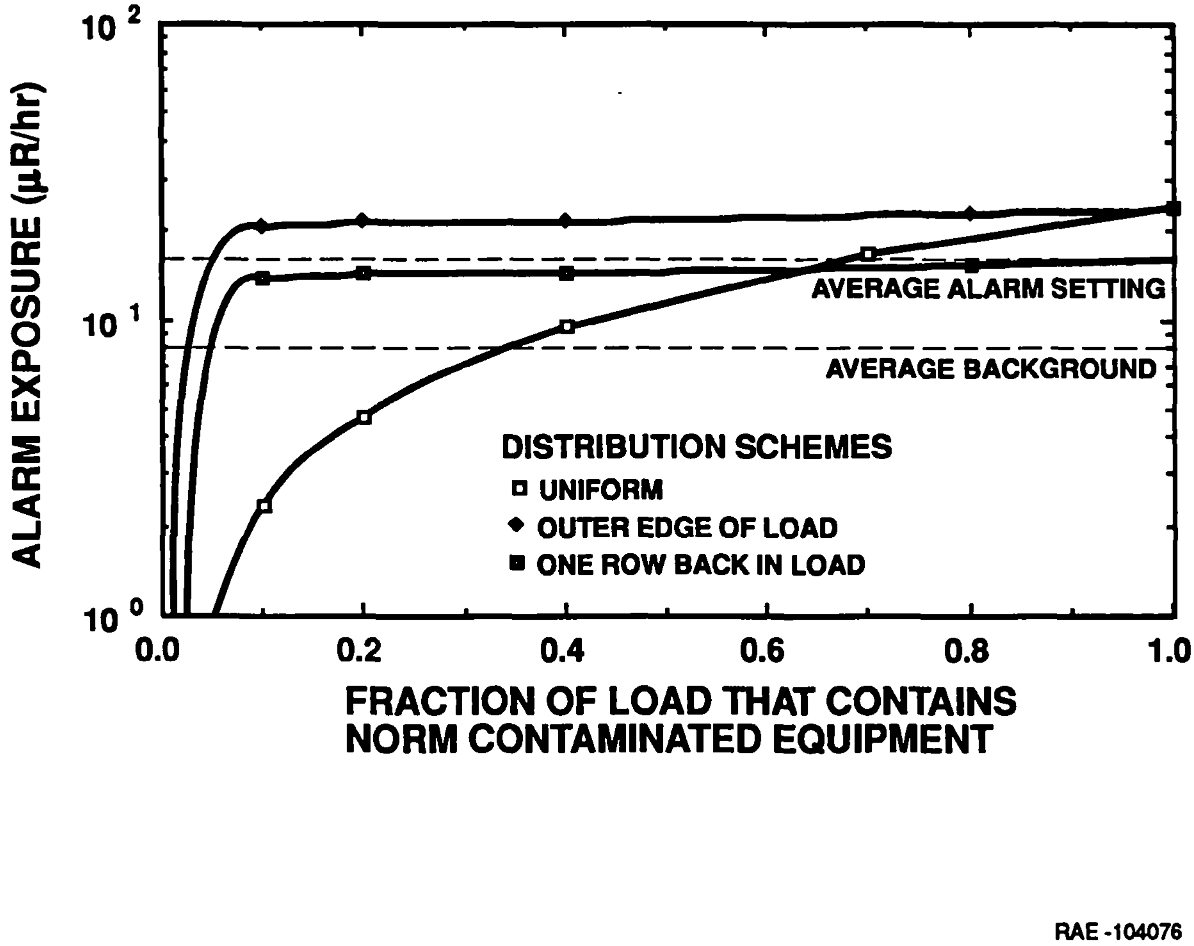

Figure 5-1. Alarm exposures from NORM contaminated trailers for varying loading schemes.

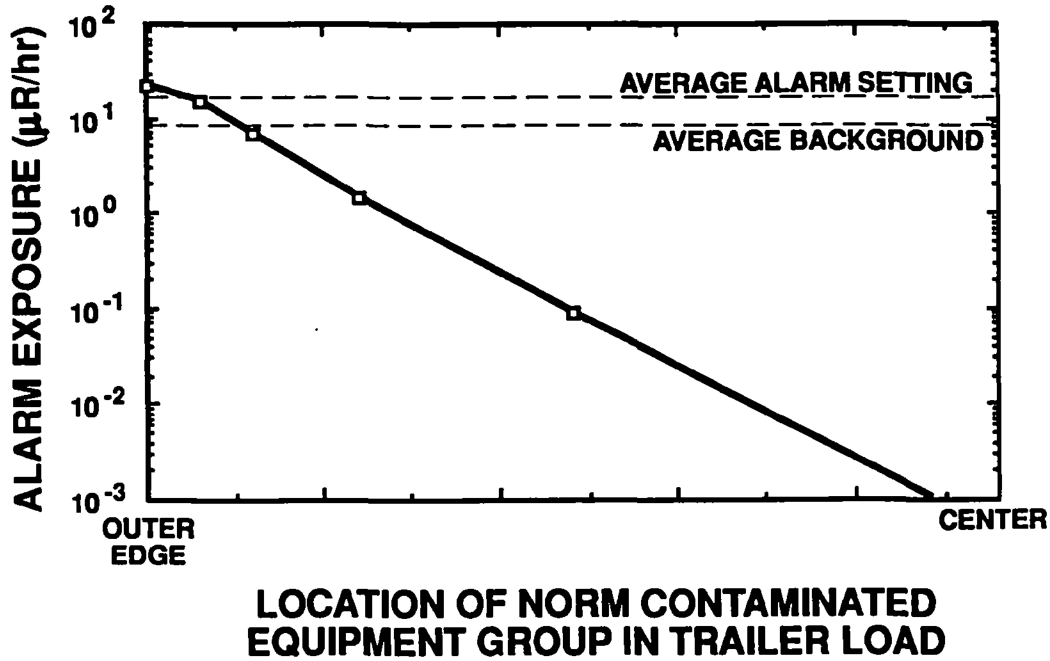

Figure 5-2. Variations in alarm exposures with respect to NORM contaminated equipment group position in load.

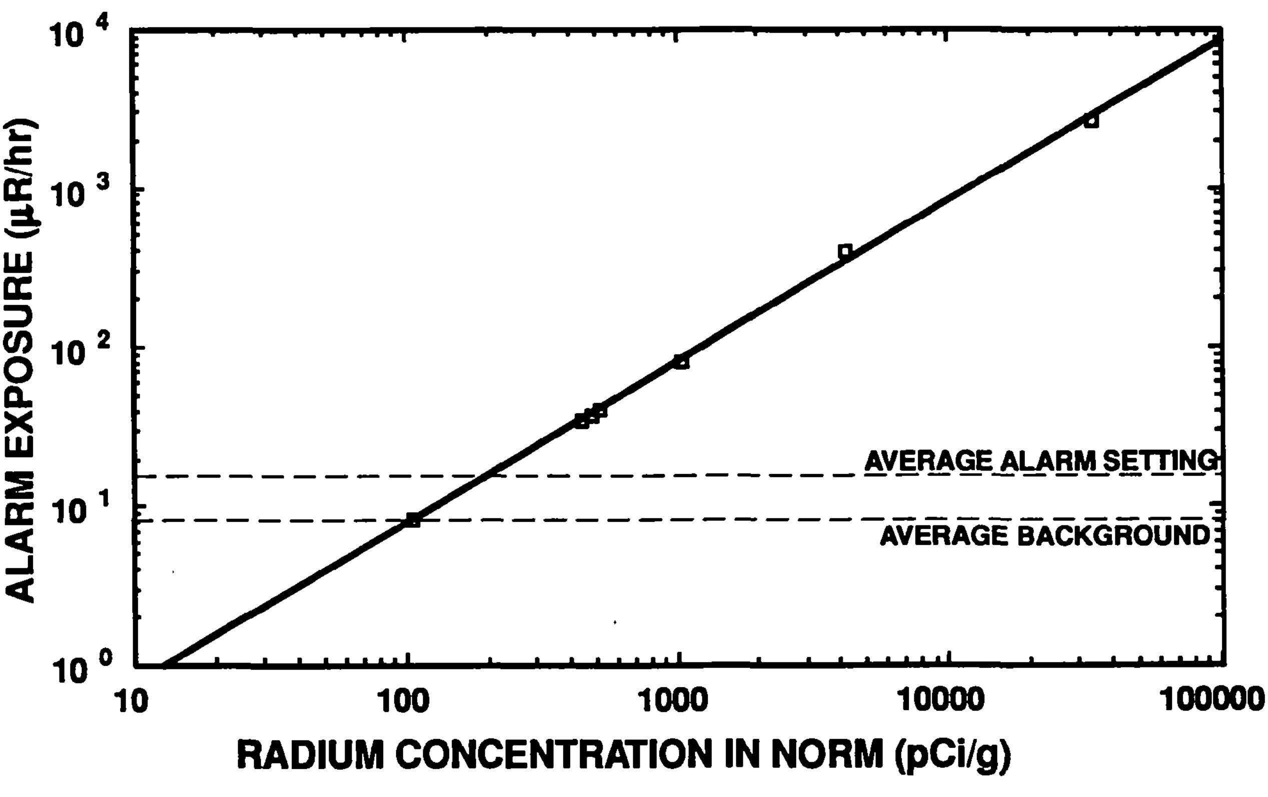

Figure 5-3. Alarm exposures for uniformaly distributed loads of NORM contaminated equipement vs. radium concentration of the NORM.

total radium concentration in the NORM scale to be 360 pCi/g. This concentration of NORM would be generally detectable. However, it would not be considered "radioactive material" as defined by 49 CFR 173 and as such would not be subject to DOT regulations. In order for a truck loaded with NORM-contaminated equipment to be regulated by DOT, the radium concentration in the NORM scale must be 726 pCi/g or higher.

5.2 PHOSPHOGYPSUM

The results of the phosphogypsum risk assessment are given in this section. Results are presented for the commercial use of phosphogypsum in agriculture, road construction, and research and development. Exposure scenarios used for this risk assessment are described in Section 4.2.2.

5.2.1 Phosphogypsum in Agriculture

Estimated doses and risks for the soil additive scenario, involving an average phosphogypsum application rate on a moderate size sand field used to grow peanuts, are shown in Tables 5-5 and 5-6. Estimated doses and risks for the sediment control scenario are also shown in Tables 5-5 and 5-6. The risks shown in Tables 5-5 and 5-6 are estimated lifetime (70-year) risks from one year of exposure.

For each of the agricultural scenarios, the highest doses and risks result from external gamma exposure and from indoor radon inhalation to the on-site individual. For the fertilizer scenario, the lifetime risk to the on-site individual from one year of external gamma exposure is estimated to be 3.7E-06 for 31 pCi/g phosphogypsum. The lifetime risk from one year of indoor radon inhalation is estimated to be 3.1E-06, for median NORM concentrations. For the sediment control scenario, the lifetime risk to the on-site individual from one year of external gamma exposure is estimated to be 1.7E-05. The lifetime risk from one year of indoor radon inhalation is estimated to be 1.4E-05.

Table 5-5. Risk assessment results for agricultural scenarios involving median phosphogypsum concentrations.

	Fertilizer		Sediment Control	
	Dose[a] (mrem)	Risk[b]	Dose[a] (mrem)	Risk[b]
Agricultural Worker Direct Gamma	4.3E+00	1.7E-06	2.0E+01	7.7E-06
Agricultural Worker Dust Inhalation	8.4E-02	6.8E-09	9.6E-01	7.7E-08
On-Site Individual Direct Gamma	9.0E+00	3.7E-06	4.0E+01	1.7E-05
On-Site Individual Indoor Radon	---[c]	3.1E-06	---[c]	1.4E-05
On-Site Individual Well Water Use	---[c]	---[c]	---[c]	---[c]
Member of CPG - Inhalation of contaminated dust	8.4E-04	6.8E-11	7.7E-03	6.5E-10
Member of CPG - Ingestion of drinking water from contaminated well	---[c]	---[c]	---[c]	---[c]
Member of CPG - Ingestion of foodstuff contaminated by well water	---[c]	---[c]	---[c]	---[c]
Member of CPG - Ingestion of foodstuff grown on fertilized soil	5.9E-02	6.2E-09	2.6E-01	2.7E-08
Individual - Ingestion of river water contaminated by groundwater	---[c]	---[c]	---[c]	---[c]
Individual - Ingestion of river water contaminated by surface runoff	9.9E-03	9.0E-10	1.7E-01	1.6E-08

a. Dose or dose commitment from one year of exposure.
b. Lifetime risk from one year of exposure.
c. No radionuclides are calculated to reach the on-site well via the groundwater pathway for almost 10,000 years, or the off-site river or well for at least 100,000 years because of groundwater velocities and retardation factors.

Table 5-6. Risk assessment results for agricultural scenarios involving 90 percentile phosphogypsum concentrations.

	Fertilizer		Sediment Control	
	Dose[a] (mrem)	Risk[b]	Dose[a] (mrem)	Risk[b]
Agricultural Worker Direct Gamma	6.8E+00	2.6E-06	3.1E+01	1.2E-05
Agricultural Worker Dust Inhalation	1.3E-01	1.1E-08	1.5E+00	1.2E-07
On-Site Individual Direct Gamma	1.4E+01	5.8E-06	6.3E+01	2.6E-05
On-Site Individual Indoor Radon	---[c]	4.9E-06	---[c]	2.3E-05
On-Site Individual Well Water Use	---[c]	---[c]	---[c]	---[c]
Member of CPG - Inhalation of contaminated dust	1.3E-03	1.1E-10	1.2E-02	1.0E-09
Member of CPG - Ingestion of drinking water from contaminated well	---[c]	---[c]	---[c]	---[c]
Member of CPG - Ingestion of foodstuff contaminated by well water	---[c]	---[c]	---[c]	---[c]
Member of CPG - Ingestion of foodstuff grown on fertilized soil	9.2E-02	9.7E-09	4.1E-01	4.4E-08
Individual - Ingestion of river water contaminated by groundwater	---[c]	---[c]	---[c]	---[c]
Individual - Ingestion of river water contaminated by surface runoff	1.6E-02	1.4E-09	2.8E-01	2.5E-08

a. Dose or dose commitment from one year of exposure.
b. Lifetime risk from one year of exposure.
c. No radionuclides are calculated to reach the on-site well via the groundwater pathway for almost 10,000 years, or the off-site river or well for at least 100,000 years because of groundwater velocities and retardation factors.

5.2.2 Phosphogypsum in Road Construction

The results of the risk assessment for use of phosphogypsum in road construction are summarized in Tables 5-7 and 5-8. In evaluating the risk to the construction workers from external gamma radiation during road construction, two cases (with and without shielding effects) are considered to bracket the worker doses which could be received from external gamma radiation. Worker doses were evaluated for the case of no asphalt cover over the roadbed to maximize the resulting doses.

For the road construction scenarios, the highest doses and risks result from external gamma exposure and indoor radon inhalation by the reclaimer. For the road base scenario, the lifetime risk to the reclaimer from one year of external gamma exposure is estimated to be 3.1E-05 for 31 pCi/g phosphogypsum. The lifetime risk from one year of indoor radon inhalation is estimated to be 7.0E-05 for 31 pCi/g phosphogypsum.

For the concrete additive scenario, the lifetime risk to the reclaimer from one year of external gamma exposure is estimated to be 5.9E-05 for 31 pCi/g phosphogypsum. The lifetime risk from one year of indoor radon inhalation is estimated to be 8.1E-05 for 31 pCi/g phosphogypsum.

5.2.3 Phosphogypsum in Research and Development Activities

The results of the risk assessment of the use of phosphogypsum in research and development activities are summarized in Tables 5-9 and 5-10. For the research and development scenario, a researcher is postulated to work in a laboratory and be exposed to an open 55-gallon drum of phosphogypsum. Doses to the researcher from external gamma radiation, dust inhalation, and indoor radon inhalation are evaluated.

The doses and risks to the researcher from external gamma radiation and dust inhalation are estimated to be comparable to worker doses from the agricultural and road construction scenarios.

Table 5-7. Risk assessment results for road construction scenarios involving median phosphogypsum concentrations.

	Road Base		Concrete Additive	
	Dose[a] (mrem)	Risk[b]	Dose[a] (mrem)	Risk[b]
Construction Worker -No Shielding- Direct Gamma	5.0E+01	1.9E-05	5.0E+01	1.9E-05
Construction Worker -With Shielding- Direct Gamma	2.9E+01	1.1E-05	2.9E+01	1.1E-05
Construction Worker Dust Inhalation	1.2E+00	1.0E-07	1.2E+00	1.0E-07
Person Driving on Road Direct Gamma	2.6E-01	9.6E-08	3.0E+00	1.1E-06
Member of CPG Direct Gamma	5.0E-02	2.0E-08	5.9E-01	2.3E-07
Member of CPG - Ingestion of Drinking Water From Contaminated Well	---c	---c	---c	---c
Member of CPG - Ingestion of Foodstuff Contaminated by Well Water	---c	---c	---c	---c
Reclaimer Direct Gamma	8.4E+01	3.1E-05	1.7E+02	5.9E-05
Reclaimer Indoor Radon Inhalation	---c	7.0E-05	---c	8.1E-05
Reclaimer Well Water Use	---c	---c	---c	---c
Reclaimer - Ingestion of Foodstuff Grown On-Site	3.1E-01	1.9E-08	3.1E-01	1.9E-08
Individual - Ingestion of River Water Contaminated by Groundwater	---c	---c	---c	---c
Individual - Ingestion of River Water Contaminated by Surface Runoff	2.4E-02	1.8E-09	2.4E-02	1.8E-09

a. Dose or dose commitment from one year of exposure.

b. Lifetime risk from one year of exposure.

c. No radionuclides are calculated to reach the on-site well via the groundwater pathway for almost 10,000 years, or the off-site river or well for more than 100,000 years because of groundwater velocities and retardation factors.

Table 5-8. Risk assessment results for road construction scenarios involving 90 percentile phosphogypsum concentrations.

	Road Base		Concrete Additive	
	Dose[a] (mrem)	Risk[b]	Dose[a] (mrem)	Risk[b]
Construction Worker -No Shielding- Direct Gamma	7.8E+01	2.9E-05	7.8E+01	2.9E-05
Construction Worker -With Shielding- Direct Gamma	4.6E+01	1.7E-05	4.6E+01	1.7E-05
Construction Worker Dust Inhalation	1.9E+00	1.6E-07	1.9E+00	1.6E-07
Person Driving on Road Direct Gamma	4.1E-01	1.5E-07	4.8E+00	1.8E-06
Member of CPG Direct Gamma	7.8E-02	3.0E-08	9.2E-01	3.5E-07
Member of CPG - Ingestion of Drinking Water From Contaminated Well	---c	---c	---c	---c
Member of CPG - Ingestion of Foodstuff Contaminated by Well Water	---c	---c	---c	---c
Reclaimer Direct Gamma	1.3E+02	4.9E-05	2.5E+02	9.2E-05
Reclaimer Indoor Radon Inhalation	---c	1.1E-04	---c	1.3E-04
Reclaimer Well Water Use	---c	---c	---c	---c
Reclaimer - Ingestion of Foodstuff Grown On-Site	4.9E-01	2.9E-08	4.9E-01	2.9E-08
Individual - Ingestion of River Water Contaminated by Groundwater	---c	---c	---c	---c
Individual - Ingestion of River Water Contaminated by Surface Runoff	3.7E-02	2.7E-09	3.7E-02	2.7E-09

a. Dose or dose commitment from one year of exposure.
b. Lifetime risk from one year of exposure.
c. No radionuclides are calculated to reach the on-site well via the groundwater pathway for almost 10,000 years, or the off-site river or well for more than 100,000 years because of groundwater velocities and retardation factors.

Table 5-9. Risk assessment results for the research and development scenario involving median phosphogypsum concentrations.

	Dose[a] (mRem/yr)	Risk[b]
Researcher		
Direct gamma	3.0E+00	1.1E-06
Dust inhalation	1.1E+00	9.9E-08
Indoor radon inhalation		2.5E-05
Total	**4.1E+00**	**2.6E-05**

a. Dose or dose commitment from one year of exposure.
b. Lifetime risk from one year of exposure.

Table 5-10. Risk assessment results for the research and development scenario involving 90 percentile phosphogypsum concentrations.

	Dose[a] (mRem/yr)	Risk[b]
Researcher		
Direct gamma	1.4E+01	5.8E-06
Dust inhalation	4.9E+00	2.0E-06
Indoor radon inhalation	-	1.2E-04
Total	**1.9E+01**	**1.3E-04**

a. Dose or dose commitment from one year of exposure.
b. Lifetime risk from one year of exposure.

The greatest risk to the researcher is estimated to be from indoor radon inhalation. The indoor radon inhalation risk is estimated to be 2.5E-05 for 31 pCi/g phosphogypsum.

5.2.4 Cleaning of Stainless Steel Filter Pans

The results of the risk assessment of the cleaning of the stainless steel filter pans used in separating phosphogypsum from the dissolving acid are presented in Table 5-11. Doses to the worker from external gamma radiation, dust inhalation, and indoor radon inhalation are evaluated. The overall doses and risks to the workers are similar to estimated exposures to oil and gas production equipment cleaners. Risks from cleaning steel filter pans contaminated with median and 90 percentile NORM concentrations are 2.6E-06 and 3.0E-06 with the main pathways being direct gamma and dust inhalation.

Table 5-11. Risk assessment results for the stainless steel filter pan cleaner scenarios.

Filter Pan Cleaner	Median NORM Concentration Dose (mrem/yr)	Median NORM Concentration Risk	90 Percentile NORM Concentration Dose (mrem/yr)	90 Percentile NORM Concentration Risk
Direct Gamma	4.8E+00	1.7E-06	5.8E+00	2.0E-06
Dust Inhalation	1.0E+01	8.7E-07	1.2E+01	1.0E-06
Indoor Radon		1.9E-10		2.3E-10
TOTAL	**1.5E+01**	**2.6E-06**	**1.8E+01**	**3.0E-06**

6. Conclusions

The PATHRAE PRESTO-EPA-PILCPG and MICROSHIELD methodologies are employed to identify potential radionuclide dose rates and risks to individuals from the transportation, recycling process, and reuse of NORM-contaminated oil and gas equipment and phosphogypsum.

The pathways that are evaluated for potential radiation exposure include radon inhalation, dust inhalation, external gamma radiation, contaminant ingestion, and dermal exposures. The external gamma pathway dominates the listed dose results. However, the indoor radon pathway, for which doses were not estimated, generally dominates the risk for each scenario where it is considered. The potential exposure scenarios from oil and gas production equipment include: the transport operator, scrap and smelter yard workers, school children on a jungle-gym and in a shop class, teacher of the shop class, resident reusing materials, the adjacent resident to the smelter, and the storage yard.

The potential exposure scenarios from phosphogypsum use and equipment cleaning include: an agricultural worker, an onsite individual, construction worker, person driving on a road, a reclaimer, a researcher, filter pan cleaner, and a member of the CPG.

Scenarios considered are grouped into three main groups: unrestricted release of NORM-contaminated equipment, reprocessing of contaminated equipment, and alternative uses of phosphogypsum. Contaminated equipment analyzed generally included pipe and tubing. Typical NORM concentrations are used in the analysis of the scenarios.

The magnitudes of the dose rates to the individuals were found to be influenced by many characteristics. Pathway characteristics, contaminant concentrations and thicknesses, and scenario dependent characteristics all had impact on the dose rates and projected risks. Other findings and observations are:

1. The past practices of or inadvertent unrestricted reuse of NORM-contaminated equipment in the school environment does not pose an elevated risk to the student (1.2E-05) or the teacher (7.6E-08). Use of

contaminated equipment in house construction also does not pose an elevated risk to the resident (1.7E-10).

2. Risks involved in the manual cleaning of contaminated equipment (1.5E-06) can be reduced by additional safety precautions for dust control, gamma exposure shielding, radon mitigation, and remote processing (7.5E-08 for hydroblasting).

3. For radium-226 concentrations of 31 pCi/g in phosphogypsum, the dominant risks are to the: on-site individual (6.8E-06) for the fertilizer scenario; on-site individual (3.1E-05) for the sediment control scenario; the reclaimer for the road base (1.0E-04) and concrete additive (1.4E-04) scenarios; and the researcher at 2.6E-05. The exposures involved in the reuse of phosphogypsum in agriculture and as a road base are directly proportional to radionuclide concentration.

4. The risks in all scenarios involving uses of phosphogypsum associated with the inhalation of radon are significant, and often dominant, and are increased by disturbance or dispersal of the NORM.

5. DOT regulations apply to shipments of radioactive material at a concentration of 2000 pCi/g or higher. However, for truckloads of 100 percent NORM-contaminated equipment, a median NORM radium concentration of 200 pCi/g is required to set off average steel mill and scrap-yard alarms (and cannot be released for general reuse if in Louisiana). A truckload of NORM-contaminated equipment with the median concentration of 360 pCi/g must be at least 74 percent full to be detected.

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