

NORM Contamination in the Petroleum Industry

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Summary. Contamination of oil and gas facilities with naturally occurring radioactive materials (NORM) is widespread. Some contamination may be sufficiently severe that maintenance and other personnel may be exposed to hazardous concentrations. Contamination with radium is common in oil-production facilities, whereas contamination with radon and radon decay products is more prevalent in natural-gas production and processing facilities. Although largely unregulated until recently, U.S. states, notably Louisiana and Texas, have or are enacting legislation to control NORM contamination in the petroleum industry.

Introduction

NORM contamination can be expected at nearly every petroleum facility. Some of it can be sufficiently severe that maintenance and other personnel may be exposed to hazardous concentrations. In addition, the industry must comply with new regulations. Mississippi and Louisiana have enacted legislation to control NORM; Texas will have regulations early in 1993; and other states, as well as Canada, can be expected to have similar regulations shortly.

Two general types of common NORM contamination will be controlled by these regulations.

1. Radium contamination of petroleum production facilities—specifically of pipe scale and sludge and scale in surface vessels. In addition, produced water may be radioactive from radium dissolved in underground water.

2. Radon contamination of natural-gas production facilities. This includes contamination with the long-lived decay products of radon. Facilities that remove ethane and propane from natural-gas facilities are especially susceptible to NORM contamination.

Naturally occurring radionuclides are widespread in the environment. In many geologic formations, radium, radon, and other radioactive elements are associated with oil and gas. When oil and gas are produced, traces of these radioactive elements also are produced. When the formation water contains traces of radium (radium-226, a decay product of uranium, and radium-228 from thorium), scale in the production pipe can become radioactive, sometimes containing several thousand picocuries of radium per gram of scale.^{1,2} The radioactivity results when radium coprecipitates with barium and strontium sulfates in the scale formation.

Radium also can contaminate scale and sludges in surface equipment by similar mechanisms, including carbonate precipitates and sulfate deposits. Produced water may contain dissolved radium. This can lead to contaminated sludges in waste pits and radioactive water.

Contamination of gas wells, pipelines, and gas processing facilities results primarily from radon produced with natural gas.³⁻⁶

NORM Contamination

NORM contamination in the oil and gas industry commonly occurs as radioactive scale, films, and sludges.

Radium-Contaminated Scale and Sludge.

Radioactive scale can contain uranium, thorium, radium, and associated decay products from the production of oil and associated brines contaminated with NORM. The radioactivity in the scale in production pipe originates mainly from radium, which coprecipitates with barium and strontium sulfate. Other isotopes in the uranium-238 and thorium-232 decay series also may be present. Contaminated scale may contain up to several hundred thousand picocuries of radium per gram of scale.

Radioactive scale may be found in surface processing and transport equipment and in downhole tubing. For example, piping, sludge pits, filters, brine disposal/injection wells, and associated equipment may be contaminated with radium NORM. Also, soils and equipment contaminated from well tubing workovers conducted to remove scale—both at the wellsite and at remote pipe cleaning yards—may be contaminated with NORM.

Films. Radioactive films, coatings, or plating can form from natural-gas production or processing. Often invisible to the naked eye, these films contain radon and its decay products, normally with no radon precursors (e.g., radium) associated with them. Because of radon contamination in natural gas, these radioactive films can be found at gas wellheads; in transport piping, headers, treater units, and pumps; and within natural-gas processing plants or other light-hydrocarbon facilities.

Sludge Contaminated With Decay Products of Radon. Radioactive sludges in pipelines, processing plants, natural-gas liquid (NGL) storage tanks and delivery facilities, pigging operations, and gas lines and other filter assemblies can be contaminated with

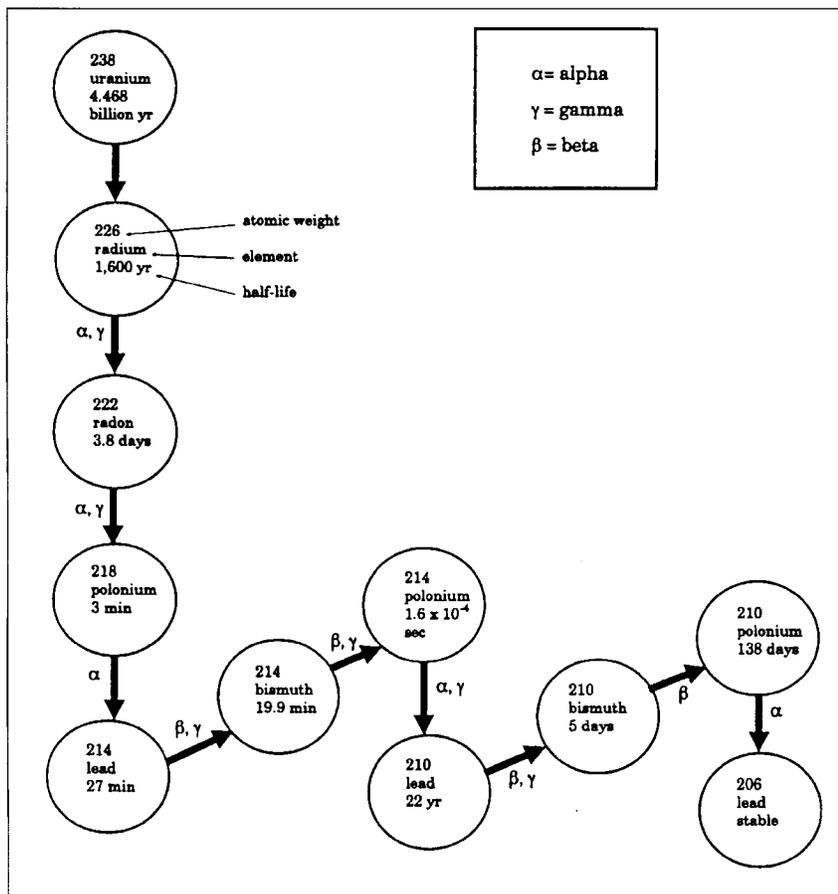


Fig. 1—Radioactive decay of uranium-238.

radon in the natural gas. Sludges also may be contaminated with several thousand picocuries per gram of the long-lived radon decay products (i.e., lead-210, bismuth-210, and polonium-210). These heavy-metal decay products may attach to dust particles and aerosols to become part of the sludge.

Filter assemblies in gas lines remove the radon decay products from the gas with other particulate matter and can become very radioactive.

History of NORM Contamination

Radium has been known as a trace contaminant of underground water for a long time but wasn't reported to be a contaminant of scale until the early 1980's, when the problem was first reported in the North Sea. Radon contamination of natural gas has been known for nearly 100 years.⁷ However, it was only in 1971 that radon was found to concentrate in the lighter natural-gas liquids during processing and could present a serious health hazard to industry personnel, particularly maintenance employees.

Some radon was undoubtedly removed with the NGL's before 1971. However, deep extraction techniques developed to remove more ethane from the gas also extracted significantly greater concentrations of radon. The problem was discovered when the radon contamination in propylene became sufficiently high to interfere with liquid level sensors detecting slurry levels in a polypropylene plant.

The radioactive scale problem in the oil and gas industry has been reported in the literature.^{1,2} With the notable exception of a 1975 report by Gesell⁸ and a paper by Gray⁹ in 1990, NORM contamination of gas facilities by radon and its decay products has not been as extensively reported.

Radium and Radon

Radium-226 is the fifth decay product of uranium-238, and radium-228 is the fourth decay product of thorium-232. Uranium and thorium are present in most soils and rocks in widely varied concentrations in the Earth's crust throughout the world. Some radium salts (e.g., radium chloride) are soluble in water, and underground water can dissolve the radium in the uranium and thorium formations. The radium may stay dissolved in the water as long as contact with sulfate and carbonate formations is limited. The radium-contaminated water may be produced with oil and gas.

Radon is a naturally occurring, highly mobile, chemically inert radioactive gas in the uranium-238 decay series. Radon-222 is produced by the radioactive decay of radium-226. Because radium is widely distributed in the Earth's crust, radon also is widely distributed. Recent reports of radon-contaminated buildings throughout the world attest to the wide distribution of radon in the environment. Radon is a noble gas, similar to helium and argon, and it is extremely un-

TABLE 1—RADON CONCENTRATIONS IN NATURAL GAS AT THE WELLHEAD*

Location of Well	Radon Concentration (pCi/L)
Borneo	1 to 3
Canada	
Alberta	10 to 205
British Columbia	390 to 540
Ontario	4 to 800
Germany	1 to 10
The Netherlands	1 to 45
Nigeria	1 to 3
North Sea	2 to 4
U.S.	
Colorado, New Mexico	1 to 160
Texas, Kansas, Oklahoma	1 to 1,450
Texas Panhandle	10 to 520
Colorado	11 to 45
California	1 to 100

*From *Radon Concentrations in Natural Gas at the Well*, U.N. Scientific Committee on the Effects of Atomic Radiation; Sources and Effects of Ionizing Radiation, United Nations, New York City (1977).

TABLE 2—BOILING POINTS AT 760-mm MERCURY

	°F
Methane	-258.0
Ethane	-124.0
Radon	-79.2
Propylene	-53.9
Propane	-44.4
Butane	+31.1

reactive chemically. Once formed by the radioactive decay of radium-226, radon is free to migrate as a gas or dissolve in water without being trapped or removed by chemical reaction. Migrating through rocks and soil, radon is produced with natural gas at the wellhead. Table 1 shows that radon contamination of natural gas is a worldwide problem, and particularly high concentrations of radon are reported in the U.S. and Canada.

When radon-contaminated produced gas is processed to remove the NGL's, much of the radon is removed also. Radon's boiling (or condensing) point is intermediate between the boiling points of ethane and propane. Upon subsequent processing, radon tends to accumulate further in the propylene distillation stream. Table 2 shows the boiling points of radon, the lighter NGL's, and propylene. As expected, radon usually is recovered more completely in plants with high ethane recovery. The radon is concentrated in the lighter NGL's and is detected relatively easily with radiation survey meters.

As long as it is contained and controlled within vessels, equipment, and piping, radon generally is not a health hazard to employees and the public. Even if radon-contaminated propane were released, the threat of fire or asphyxiation would far outweigh the hazard of a short-lived radiation exposure.

Although other radon isotopes exist [e.g., radon-220 (thoron)] from the decay of thorium-232, the only radon isotope of concern

TABLE 3—PRIORITY AREAS OF CONCERN FOR HIGH RADON AND RADON DECAY PRODUCT CONTAMINATION

NGL facilities
De-ethanizers
Stills
Fractionators
Product condensers
Flash tanks
Pumps in liquid service
Piping in liquid service
NGL storage tanks
Truck terminals
Filter separators
Dessicants
Waste pits
Pipelines
Filters
Pig receivers
Machine shops
In-house
Contract

is the 3.8-day half-life radon-222. Radon-220 and other radon isotopes have very short half-lives and will have decayed before the gas is produced at the wellhead. Because the half-life of radon-222 is 3.8 days, 99% of the radon will decay to its long-lived lead-210 decay product in 25 days.

Radon Decay Products

Radon itself is not a particularly hazardous material. Because it is chemically unreactive, it does not accumulate in the body. The health hazards associated with radon exposure are from its decay products. These long-lived radioactive materials present a growing problem to the industry, especially to personnel who may be exposed to contaminated surfaces, sludges, and other waste materials. Fig. 1 shows each atom of radon-222 eventually decays to an atom of lead-210 and subsequently to bismuth-210 and polonium-210 before decaying to stable lead-206. The half-life of lead-210 (a solid metal material) is 22 years. Therefore, the concentrations of radioactive lead, bismuth, and polonium will continue to increase in pipelines, gasoline plants, tank cars, and trucks for more than 100 years.

Contaminated facilities and waste-material problems must be recognized and addressed. The presence of the radioactive metals from radon decay cannot be detected on the outside of contaminated equipment and vessels. Unlike radon, the radiations that the decay products emit are easily absorbed by the walls of the equipment. If present in sufficiently high concentrations, radon can be detected externally to storage vessels, pumps, etc. Radon has moderately energetic gamma radiation in its decay that can be detected with gamma survey meters.

If an alpha/beta probe is held close to contaminated internal surfaces and concentrations are sufficiently high, survey meters may detect the presence of the radon decay products. However, laboratory analyses are

usually required to determine concentrations of lead, bismuth, and polonium accurately.

These radioactive materials are not a health hazard unless they are ingested or inhaled into the body—e.g., during repair and maintenance on the facility. If inhaled, the dust and aerosols containing NORM can attach to the lung surfaces, where they emit alpha radiation into the tissue of the lung lining. Studies of uranium miners indicate that extended exposure to these radon decay products pose an increased risk of lung cancer.^{10,11}

NORM in NGL Facilities

Although entire natural-gas and NGL systems may be contaminated with NORM, some facilities will be contaminated to the extent that they present significant decontamination and disposal problems. Gasoline plants and other NGL facilities will be among the most highly contaminated areas in a system.

During processing in a gasoline plant, the levels of external radiation from radon in propane 1 ft from a liquids pump may be as high as 25 milliroentgens (mR)/hr. Radiation levels up to 6 mR/hr have been detected at outer surfaces of storage tanks containing fresh propane. Sludges in gasoline plants are often contaminated with several thousand picocuries of lead-210 per gram.

Table 3 shows vessels and equipment in NGL service that may be significantly contaminated with NORM. Although NORM contamination will be general throughout an NGL facility, the contamination usually will be greatest in areas of high turbulence, such as in pumps and valves.

When employees open equipment and vessels, precautions must be taken to prevent exposure to radioactive contamination.¹² Maintenance procedures should include the use of respirators and good hygiene to prevent inhalation of radioactive dust. Grinding, if necessary, should be done wet to minimize dust.

Occasionally, a plant or other facility that has been processing light hydrocarbons, particularly ethane and propane, is taken out of service and the facility sold or dismantled. Any equipment with internal surface deposits of NORM must receive special consideration when scrapped, sold, transferred, or otherwise disposed of, particularly when the facility is being released for unrestricted use. Analyses for lead-210 usually will be required to verify the extent of contamination and to determine if special handling is needed. Particular care must be used to prevent employee exposure to NORM contamination.

There are potential liabilities involved if contaminated equipment, vessels, and other parts of the facility are released or sold for unrestricted use without first being cleaned and tested to be essentially free of NORM contamination according to state and federal regulations.

Much of the material wastes from a facility contaminated with NORM must be

handled as low-level radioactive waste and disposed of accordingly. Contaminated wastes should be consolidated and separated from noncontaminated waste to keep radioactive waste volumes as low as possible. Consolidated contaminated wastes should be stored in a controlled-access area. The area should be surveyed with a radiation survey meter and, if required, should be posted according to state and federal regulations.

Other NORM Contamination

Besides vessels and equipment in NGL service, other facilities susceptible to significant contamination include pigging operations, machine shops, and filter assemblies.

Pipeline sludges can obtain small radium-226 concentrations together with a few hundred to several thousand picocuries of radon decay products per gram. These sludges require the same handling as low-level radioactive wastes. The pig itself may be contaminated. This may require handling the pig with gloves and storing it in an area with restricted personnel access.

Machine shops present a special NORM situation. For example, pumps in NGL service may be among the most highly contaminated equipment in a plant. Occasionally, these pumps may need to be checked for leaking seals or impeller balance. NORM contamination inside a pump is often chemically bonded to the pump structural metal and cannot be easily removed without scraping and grinding. Because rebalancing is usually done by grinding until balance is established, the grinding may generate significant quantities of radioactive dust that can contaminate personnel as well as the shop facility. This can pose a very serious problem if contract machine shops are used.

Although pipelines and equipment in dry-gas service may be only marginally contaminated, filter assemblies in dry-gas service may be contaminated with very high concentrations of NORM and require special handling to prevent inhalation of the radioactive dust and contamination of the environment during changing of the filters and other required maintenance.

Radiation Surveys

NORM contamination is detected by radiation surveys with Geiger-Mueller or scintillation probes on a suitable survey meter. The gamma radiation emitted by radium and radon are sufficiently energetic that they are detected relatively easily if present in high concentrations. The radiations emitted by the decay products of radon are not easily detected. The radiations from lead-210 (low-energy gammas), bismuth-210 (betas), and polonium-210 (alphas) will not penetrate vessel and equipment walls and are detected only with low efficiency when a suitable probe (e.g., an alpha pancake probe) is used directly on the contaminated surface. Because these radon decay products are detected, at best, with low efficiency, any reading on the survey meter above background indicates significant contamination.

Samples should be taken and submitted to a laboratory for analysis. The exempt concentration levels for these radionuclides are very low, and contamination above the exempt concentrations is common. Because the radiations are easily absorbed, areal surveys of the ground and soil around petroleum facilities for radon-decay-product contamination are generally not meaningful and samples must be taken for laboratory analyses.

Radium and radon emit sufficiently energetic radiation to make their detection somewhat easier. The gamma rays will commonly penetrate structure walls, making external radiation surveys with Geiger-Mueller or scintillation detectors meaningful. The exempt concentrations in the Louisiana and Mississippi regulations and in pending regulations in other states are so low, however, that concentrations of radium and radon near the exempt levels are very difficult to measure accurately. A well-trained technician is required to make such surveys with confidence. Again laboratory analyses may be needed to determine accurately the amount of contamination. Such analyses are probably required when the facility or property is being sold, abandoned, or otherwise released. Accurate records of contamination will be required to prevent future litigation.

Disposal of NORM Wastes

The disposal of NORM-contaminated wastes is a major problem with no completely satisfactory solution. The disposal of NORM wastes is regulated by Louisiana and Mississippi and will be regulated in all other states as their regulations become effective. Options are limited. For example, the NORM wastes must be separated from non-NORM wastes and cannot be disposed of by "ordinary" methods of waste disposal, such as landfills. Disposal of contaminated wastes with uncontaminated material in a landfill or by other methods of disposal is not allowed unless the contamination level is below exempt concentrations in state and federal regulations. The few facilities licensed to accept NORM wastes are expensive to use and require a complete paper trail.

Although individual states or groups of states are obligated to have low-level radioactive waste repositories by 1993, these facilities may not accept NORM wastes from the petroleum industry. This is the case in Texas, for example, where the Texas Low Level Radioactive Waste Repository is designed to accept radioactive wastes from medical facilities, educational institutions, and industrial non-NORM wastes. The cost of disposal will be expensive—Texas estimates that the cost of storing radioactive wastes in its low-level repository will be about \$175/ft³.

Currently, the most economical and practical method may be to store the NORM wastes on the facility property in an area with controlled access. The revised Louisiana regulations address the disposal problem and require a proposed disposal plan be

submitted to the state within 90 days of the NORM generation.

It sometimes may be possible to dilute the wastes sufficiently with noncontaminated material so that the NORM concentrations are below exempt levels. For example, moderately contaminated soil may be diluted with noncontaminated soil or radium-contaminated water may be diluted with "clean" water. If sufficiently diluted, the resulting wastes may possibly be disposed of by ordinary methods.

Reinjection of radium-contaminated water is a possible solution to the disposal of such water. Injection of other NORM wastes (e.g., contaminated scale) in a Type II injection well may be the best possible disposal method for these wastes when allowed by the regulations.

The high cost of disposing of NORM wastes is opening new opportunities for R&D in methods and techniques for reducing waste volumes. For example, production waste may be contaminated above exempt levels with radium-226 and radium-228. If the radium could be removed from the water economically, the costs of disposing of the contaminated water would be reduced significantly. There are R&D ef-

"The high cost of disposing of NORM wastes is opening new opportunities for R&D in methods and techniques for reducing waste volumes."

orts in progress to do this, such as using resins and membranes to absorb or separate the radium from water and other corrosive liquids. Similar efforts are being applied to concentrate radium and lead-210 and its radioactive daughters from organic and inorganic sludges. If successful and economical, this may be a solution to the disposal of large volumes of NORM-contaminated wastes.

Decontamination of facilities by sandblasting can generate large volumes of NORM wastes. Novel methods of "sandblasting" with materials that will minimize the solid wastes are being explored. Reaming out scale from production pipe can generate large quantities of NORM wastes. Because only a fraction of the scale, possibly as low as 5% to 10%, may be contaminated above exempt concentrations, preliminary gamma surveys of the pipe to locate NORM sites can be used to guide reaming operations and to reduce NORM-contaminated scale wastes. Contaminated scale may be spotty (i.e., not uniform within the pipe), so the total joint should be surveyed on all sides. External scale on the pipe also can be contaminated with radium, necessitating careful handling to prevent ingestion or inhalation

of NORM dust and contamination of the environment.

As an alternative to reworking or cleaning of contaminated production pipe, the pipe can be left in place in the ground. It is not required to pull the pipe and remove the contaminated scale.

The trend in U.S. state regulations is toward more regulation and control of NORM wastes. NORM disposal will undoubtedly become very expensive.

Regulations

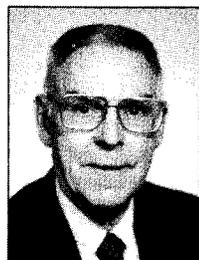
Radium and radon in oil and gas operations produce radioactive waste materials that contaminate facilities and equipment, exposing employees to hazardous materials and creating waste disposal problems. Such wastes and facilities should be treated as much as possible like other facilities and equipment covered by the U.S. Atomic Energy Act (e.g., soil contamination limits, criteria for facilities and equipment released for unrestricted use, and rules for proper handling and disposal of contaminated materials).

Several state and federal agencies have potential jurisdiction over NORM, but their application to NORM is unclear. NORM does not fall under the definition of source, special nuclear, or by-product material as currently defined in the Atomic Energy Act. Therefore, NORM is not subject to the Nuclear Regulatory Commission regulations. States have laws and regulations governing the use, possession, handling, and disposal of radioactive materials, but their application to NORM is still unclear. Except for Louisiana and Mississippi, no specific state regulations for the control of NORM contamination exist. Texas and several other states are expected to have NORM regulations in 1993. Louisiana specifically exempts the wholesale and retail distribution, possession, use, and transportation of oil and natural gas and NGL's from the regulations. The exemption, however, does not apply to contaminated facilities, such as pipelines, gasoline plants, and other physical facilities.

The Louisiana and Mississippi and other proposed state regulations are very specific regarding disposal of contaminated wastes and sale, abandonment, or release of facilities that may be contaminated. Companies doing production pipe cleaning and workovers must be specifically licensed, as do contractors supplying decontamination services. Louisiana has required radiation surveys of every petroleum facility in the state. As proposed, the Texas regulations will not require such extensive surveys. Texas will require surveys only of specific licensed facilities.

To ensure compliance, companies must be familiar with the regulations as they evolve. Although only Louisiana and Mississippi have regulations in effect, Texas, other states, and Canada are expected to have regulations soon for the control of NORM in the petroleum industry. The U.S. Environmental Protection Agency (EPA) is also

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considering enacting NORM regulations on the federal level.

Regulatory developments must be monitored as current knowledge of the NORM issues evolves. Where possible, industry input should be directed to minimize an over-regulation of NORM contamination in the industry.

Suggested Program for the Control of NORM

The following are suggestions for use in establishing a program for the control of NORM contamination.

1. Determine whether there is a NORM contamination problem.

2. Determine areas of potential NORM exposure and contamination.

A. Make gamma radiation surveys of facilities and equipment.

B. Make wipe tests on accessible interior surfaces of selected equipment and vessels, especially any in NGL service.

C. Obtain samples of sludges and scale and analyze for radium and lead-210.

D. Obtain samples of other waste materials, such as dessicants and filters.

E. Analyze produced water and waste pond water for radium.

3. Establish programs to ensure personnel safety, product quality, customer satisfaction, and protection of the environment.

A. Establish policy on periodic surveys, inspection and maintenance procedures, product controls, and record keeping.

B. Provide safety-manual material that informs employees and details required procedures, particularly for maintenance personnel.

C. Recommend a management and audit system.

D. Develop plans and procedures for the disposal of contaminated waste materials, equipment, and facilities.

E. Prepare a public relations release to use if questioned by employees, customers, the public, and the media.

4. Inform facility personnel of the possibility of NORM contamination.

5. Review governmental regulations to ensure regulatory compliance.

Conclusions

1. NORM contamination can be expected at nearly every petroleum facility.

2. The presence of NORM in oil and gas production facilities, gas processing plants, pipelines, and other petroleum equipment and facilities is not, in general, a serious technical problem.

3. The concentrations of NORM contamination and the energies of the radiation are relatively low and do not usually present a health hazard to the public or to most personnel in the industry. Some facilities may be more highly contaminated, however, and may be hazardous to maintenance personnel in particular.

4. Radium contamination of pipe scale can be a serious problem requiring special procedures for the removal and disposal of contaminated scale to prevent contamination of personnel and the environment.

5. Produced water may be contaminated with radium, requiring special procedures for the protection of the environment.

6. Surface equipment and facilities at production sites also may be contaminated with NORM, requiring special repair and maintenance procedures and the disposal of NORM-contaminated wastes.

7. The buildup of long-lived radon decay products (specifically lead-210) in gas pipelines, gasoline plants, and refineries requires that specific procedures be implemented for inspection and maintenance personnel to ensure their safety when working on the internal parts of equipment and facilities where radon may have been present.

8. A serious problem that must be addressed is the disposal of radioactive materials and equipment. Options available for the disposal of NORM and NORM-contaminated wastes are limited.

9. Although only Louisiana and Mississippi have enacted regulations for the control of NORM, Texas will have regulations early in 1993, and other states and Canada can be expected to enact similar legislation. The U.S. EPA is considering enacting NORM regulations on the federal level.

10. The industry must comply with the regulations.

Although potentially hazardous to personnel and the environment, NORM contamination is controllable.

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SI Metric Conversion Factors

curie × 3.7*	E+10 = Bq
°F (°F-32)/1.8	= °C
ft × 3.048*	E-01 = m
ft ³ × 2.831 685	E-02 = m ³
R × 2.58	E-04 = C/kg

*Conversion factor is exact.

Provenance

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