Bulletin on Management of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Production

API BULLETIN E2
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Upstream Segment

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FOREWORD

This bulletin on the management of naturally occurring radioactive materials (NORM) has been prepared by API to provide relevant guidance to oil and gas operating companies. This publication is under the jurisdiction of the API Production Waste Issues Group under direction of the Executive Committee of Environmental Conservation.

Cooperative efforts between federal and state regulatory agencies, industry, and other interested parties are expected to generate much useful information regarding NORM in the next several years. This document will be updated as new scientific information becomes available concerning NORM.

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Suggested revisions are invited and should be submitted to the Standards and Publications Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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SECTION 1—GENERAL

1.1 INTRODUCTION

Naturally occurring radioactive materials (NORM) are present in oil and gas operations at some locations and can deposit in well tubulars, surface piping, vessels, pumps, and other producing and processing equipment. The purpose of this document is to inform oil and gas operators of the possible presence of NORM and to provide relevant information on protecting workers, the public, and the environment. The objective of this document is to provide general information to users so that they have an understanding of the fundamental radiation issues associated with the management of NORM. Issues where the advice of a professional health physicist, industrial hygienist, or other technical expert may be useful are identified and guidance provided. Readers are advised to contact their state regulatory office and work very closely with that office on all NORM issues.

Radiation can result from both man-made and natural sources. Man-made sources include dental x-rays and well logging tools. Natural sources of radiation include the sun (cosmic rays) and radiation from naturally occurring materials found in the earth's crust and in living organisms. Radioactive materials are unstable and decay over time, emitting ionizing radiation. If body tissue or organs are exposed to excessive radiation, biological damage can occur in the individuals exposed or in their descendants, increasing the risk of cancer or birth defects. Thus, it is important to protect humans from unnecessary exposure to excessive levels of radiation.

NORM is found throughout the natural environment and in man-made materials such as building materials and fertilizer, as well as in association with some oil and gas production. NORM found in oilfield operations originates in subsurface oil and gas formations and is typically transported to the surface in produced water. As the produced water approaches the surface and its temperature drops, precipitates form in tubing strings and surface equipment. The resulting scales and sludges may contain radium and radium decay products as well as other uranium and thorium progeny. In addition, radon is sometimes contained in produced natural gas and can result in the formation of thin radioactive lead films on the inner surfaces of gas processing equipment.

Measurements on the outer surfaces of equipment containing NORM usually indicate levels of radiation that are below levels considered to be of concern. When equipment is opened for inspection or repair, inhaling or ingesting NORM can expose personnel to radioactivity. Therefore, in these situations, workers should take precautions to prevent the generation of dust and wear protective equipment. It is also important that NORM waste or equipment containing NORM be managed and disposed by methods that protect the public from unnecessary exposure.

1.2 HISTORY

During the early 1980s, radioactivity was observed in North Sea oil and gas operations, and in 1986 NORM was identified in tubing removed from a well in Mississippi during a routine workover. Since that time, many operators in the United States have surveyed their operations. NORM was found to be present at some locations. In oil and gas operations, NORM is typically present at widely scattered locations, in small quantities, and at low levels of radioactivity.

After the discovery of NORM in Mississippi in 1986, the American Petroleum Institute:

- Gathered more than 36,000 nationwide measurements of external radioactivity
- Studied methods for measuring NORM in petroleum equipment
- Evaluated alternatives for disposing of NORM waste

API has continued to study the management of NORM issues. API has prepared reports on the following topics:

- Disposal cost studies
- Surveys of NORM in petroleum production and gas processing facilities
- Methods for measuring NORM in petroleum production equipment
- Management and disposal alternatives for NORM in oil production and gas plant equipment
- Dose estimates and indoor radon concentrations attributed to remediated oilfield NORM

Reports on these studies are available by writing the Coordinator—Upstream Environmental Affairs, American Petroleum Institute, 1220 L Street Northwest, Washington DC 20005. These studies and similar studies performed by individual companies are the basis for much of the material in this document.

This document represents API's guidelines on practical methods for managing NORM as of the publication date. IT IS RECOMMENDED THAT OPERATORS CONSULT FEDERAL AND STATE REGULATORY AGENCIES TO ASCERTAIN WHAT LEGAL REQUIREMENTS MAY APPLY.

1.3 NORM IN OIL AND GAS PRODUCTION

NORM represents a wide range of materials that are radioactive in their natural state. These materials include carbon 14 and potassium 40, both of which are present in the human body. The radioactive elements of concern in oil and gas production occur naturally throughout the earth's crust and are sometimes present in the formations from which oil and gas are produced. These elements include uranium, thorium, and their respective progeny. The isotopes of concern are radium-226 (Ra-226), radium-228 (Ra-228) and their progeny (Appendix A).

Small amounts of uranium are occasionally produced with the oil and gas. These elements, like other mineral elements, are present in oil and gas bearing formations in varying concentrations. Many oil and gas bearing reservoirs contain shales that may contain higher than average amounts of these radioactive elements. Depending on their solubility, these elements may find their way into production fluids since they are present in the formation. Many of the physical and chemical characteristics of oil and gas formations tend to increase the solubility of these elements in production fluids.

When the radioactive elements are brought to the surface with the produced fluids, a number of changes can take place depending on the characteristics of the specific site. Usually the radioactive elements stay with the water phase of the production fluids and may either incorporate themselves in pipe scale (radium coprecipitated in barium sulfate), or precipitate into sludges. Formation of NORM scale occurs when radium substitutes for barium in barite scale, producing a coprecipitated (Ba, Ra)SO4 scale. Substitution of radium for calcium and strontium occurs in a similar manner.

The ability of radium to substitute is due to the similarity in ionic radius, molecular size, and valence of the elements. The amount of substitution is often small, due to the higher abundance of barium in solution versus radium. Usually, very little remains in the oil. Consequently, radioactive sludges and scales can build up within process equipment such as pipes, heater treaters, separators, and salt water tanks. In addition to radium containing scales; scale containing lead (Pb-210) and polonium (Po-210) may accumulate in pipelines, in down hole piping and separators, although this is less common. It is usually associated with the formation of sulfide precipitates.

Radon may be dissolved in produced water and/or oil and released at atmospheric pressure; however it usually follows the gas production steam. Since the boiling point of radon lies between that of ethane and propane, the highest levels of the longer-lived radon progeny, lead-210 (Pb-210), bismuth-210 (Bi-210), and polonium-210 (Po-210), are generally found in pumps, tanks and product lines associated with ethane/propane processing in gas operations. These radon progeny may also accumulate in gas processing equipment such as inlet filters and reflux pumps. The accumulations may be associated with a thin black film coating (ferric sulfide), a sludge (also known as pipe rouge), or a clean metal surface. It is important to note that accumulations of these types, e.g. ferric sulfide or sludge may not have any associated increased level of radioactivity. The affinity for the accumulations also varies. They may be easily removable (typically observed with sludge or pipe rouge) or require more aggressive techniques such as grinding. The formation of ferric sulfide in gas vessels is caused by the action of hydrogen sulfide on steel.

Various NORM occurrence surveys have found significant concentrations of NORM in only a small percentage of oil and gas production operations. These facilities are generally limited to certain geographical areas: the Gulf Coast (from the Florida panhandle to Brownsville, Texas), northeast Texas, southeast Illinois and southern Kansas. This suggests that operations located in those areas may have a higher probability of finding significant occurrences of NORM. This does not mean that NORM is absent in other locations. The only way to be sure that oil and gas operations do not have significant levels of NORM is to survey the site as detailed in Section 3.

NORM may be found in downhole tubing as well as in above-ground processing equipment, saltwater disposal/injection wells and associated equipment; in soils containing NORM as a result of well workovers; tank cleaning and salt water leaks; in tubing; and in pipe cleaning and other associated operations. In production facilities, water-handling equipment exhibits the greatest NORM activity levels. Depending on the location the NORM activity level in pipe scale can range from background levels to thousands of picocuries/gram (pCi/g) [tens of becquerels/gram (Bq/g)], while NORM activity in oilfield sludges ranges from background levels to several hundred pCi/g (tens of Bq/g). The average value of NORM activity associated with pipe scale and oilfield sludges is typically less than 1000 pCi/g (37 Bq/g).

1.4 UNITS OF MEASUREMENT

An understanding of NORM requires an understanding of the various forms of radiation measurement (Appendix B). NORM measurements are taken to determine the concentration of radioactive materials present in scale, sludge, soil, etc., or to determine the potential for radioactive exposure to people near the material. Currently in the United States, there are two systems of measure for units of radioactivity and radiation levels. This document will use the traditional and indicate the international system (SI) units in parenthesis. Table 1.1 summarizes the units used in each system.

Table 1.1—Units of Radioactivity and Radiation Levels

Application	SI units	Traditional US units	Conversion factors
Radioactivity	becquerel (Bq)	picocurie (pCi)	1 Bq = 27 pCi
Concentration	becquerel/gram (Bq/g)	picocurie/gram (pCi/g)	1 Bq/g = 27 pCi/g
Surface activity	Bq/100 cm^2	disintegrations per minute/100 $centimeters^2$ (dpm/100 cm^2)	1 Bq/100 cm^2 = 60 dpm/100 cm^2
Exposure	Coulomb/kilogram (C/kg)	Roentgen (R)	1 C/kg = 3876 R
Dose equivalent	sievert (Sv)	rem	1 Sv = 100 rem

1.4.1 Concentration/activity level

The quantity of a radioactive material is not determined by weight or volume, but by level of radioactivity. The activity is the number of radioactive atoms that will disintegrate and emit radiation in a given unit of time. The unit of measurement for activity is the curie (1 curie equals 2.2 trillion disintegrations per minute). The curie represents a relatively large amount of radioactive material. The activity of radioactive material found in most oil and gas production operations is relatively small. Therefore, the unit most frequently used to describe these materials is the pCi (1-trillionth of a curie). The unit most used in the SI system is Bq (1 Bq equals 27 pCi).

The concentration of NORM in scale, sludge, soil, water, or air is determined by laboratory analysis of a sample of the material, and is generally expressed in terms of pCi/gm (Bq/g) of solid material or pCi per liter (pCi/l) of water or air. Average background soil values for Ra-226 may range from one-half to several pCi/g (less than 1 Bq/g), whereas NORM-impacted oilfield scales and sludges may range from 50 to several thousand pCi/g, or from a few Bq/g to approximately 100 Bq/g. As noted above, the average value of NORM activity associated with pipe scale and oilfield sludges is typically less than 1000 pCi/g (37 Bq/g)

1.4.2 Surface activity

Radioactive material that has been deposited on surfaces is called surface activity. It may be loosely deposited, much like ordinary dust, or it may be fixed quite firmly by some chemical or physical means such as chemical bonding, adsorption, or adhesion. This distinction is important, and surface activity is classified on the basis of how easily it can be removed. Measurement of surface activity is reported in units of disintegrations per minute per 100 centimeters squared (dpm/100 cm^2) or Bq per 100 centimeters squared (Bq/100 cm^2). Measurements are performed to determine total and removable surface activity. An example of the application of this measurement in oilfield NORM is the measurement of Pb-210 and associated progeny when workers access pressure vessels to inspect and clean the welds at gas plants. Measurements are collected in units of cpm, which are converted to dpm (Bq) using appropriate conversion factors based on the detector used.

1.4.3 External measurements

When scales and sludges are contained within equipment or tubulars and cannot be sampled, the presence of NORM can be determined through external measurement taken with an instrument such as a calibrated scintillation detector. This instrument measures the gamma rays that are emitted by the scale and penetrate the equipment wall. Readings are commonly taken in counts per minute (cpm) or microroentgens per hour (μR/hr). The rem has recently been replaced with the sievert (1 Sv = 100 rem).

SECTION 2—INFORMATION ON CONTROLLING THE DEPOSITION OF NORM-CONTAINING SCALE

The deposition of NORM-containing scale and the costs associated with its disposal can be reduced by the use of scale inhibitors in some cases. A scale inhibition program allows the NORM to remain in solution in the produced water. A successful inhibition program requires a thorough understanding of the water chemistry present in the formation as well as a cost benefit evaluation. It is rare that NORM control alone will be sufficient to justify the cost of scale inhibition. This section discusses the following topics:

- Scale formation
- Controlling scale deposition
- Application of scale inhibitors
- Implementation of a successful scale control program

2.1 SCALE FORMATION

NORM-containing scale results from the coprecipitation of radium sulfate along with barium sulfate or strontium sulfate scale. This can occur due to the mixing of incompatible formation waters with injection brines or workover fluids or during surface processing of produced water. Changes in temperature or pressure during the production of fluids can also result in scale formation.

Scale formation, whether it involves NORM or not, is a multi-step process. First, the concentration of a crystallizing mineral must exceed its solubility limit. Second, small particles or rough surfaces must be present to serve as sites where scale crystallization can start. These sites can result from either the spontaneous crystallization of the scaling mineral or from the presence of corrosion products, fines from the producing formation, or roughened surfaces on production equipment. Third, mineral ions must adsorb onto the surfaces of these sites and be incorporated into the crystal structure. Finally, scale deposits can develop if conditions permit adherence of crystals to the surfaces of production equipment. Interference with any of these steps can be a useful part of a scale control strategy.

2.2 CONTROL OF SCALE DEPOSITION

Engineering controls are the first line of defense against any form of scale deposition. Scale tends to accumulate in mechanical components downstream of points where excessive pressure drop and turbulence occur. Modification of these components can reduce scale formation. In some cases, the mixing of incompatible waters can be avoided by treatment of injection fluids or by proper design of surface facilities.

Scale inhibitors may be useful in situations where scaling conditions cannot be avoided through the use of engineering controls. Scale inhibitors are compounds that act at low concentrations (1-50 ppm) to interfere with the formation or growth of scale crystals. The low concentrations at which scale inhibitors are effective distinguish them from chemicals that dissolve existing scale or prevent scale formation by chelation. These materials must be applied at concentrations greater than those of the scaling species. The types of compounds in common use as scale inhibitors are phosphonates, polycarboxylates, and phosphate esters.

Screening tests that determine the minimum concentration of inhibitor needed to prevent scaling under the proposed conditions of application provide the basis for inhibitor selection. Temperature of application, brine pH, and brine composition are significant factors in inhibitor selection. Phosphate esters exhibit good performance per unit cost, but their application is limited to temperatures below 212°F. Phosphonates may be applied up to 250-300°F. Polycarboxylates are the most temperature stable and may be used up to 450°F. System pH has a significant influence on inhibitor performance. All three types of inhibitors have similar performance in near-neutral pH. As the pH drops, higher inhibitor concentrations are needed to prevent scaling. Divalent ions in highly saline brines can cause precipitation of inhibitors. Polycarboxylates suffer marked degradation in performance under acidic conditions and are particularly subject to precipitation in highly saline brines. The pH sensitivity of inhibitor performance depends on the molecular structure of the inhibitor and can vary significantly among inhibitors of a given type.

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SECTION 3—SURVEY TECHNIQUES AND APPLICATIONS

This section provides information describing radiation measurement and sampling techniques and appropriate applications in NORM surveys. This section also gives information on instrument maintenance and calibration and associated records.

3.1 SURVEY MEASUREMENT AND SAMPLING TECHNIQUES

NORM surveys generally involve the following measurement and sampling techniques:

- Gamma surface scans
- Exposure rate measurements
- Direct measurements for total and removable alpha or beta surface activity
- Radionuclide concentrations in media (e.g., soil, sediment, sludge, water, air)
- Personnel monitoring for external radiation exposure
- Personnel monitoring for internal radiation exposure

The following sections discuss each measurement or sampling technique and describe the application of the technique to monitoring for oilfield NORM.

3.1.1 Gamma surface scans

Instrumentation used to perform gamma surface scans typically includes a ratemeter/scaler coupled to a 1 or 2 inch sodium iodide scintillation detector. Surfaces are scanned to identify areas of elevated direct radiation which, based on the results of the scan, may require further investigation. The surveyor passes the detector slowly over the surface while keeping it as close to the surface as conditions allow. Increases in the count rate, as indicated by the audible output of the instrument, are monitored, and areas of elevated direct radiation are identified for further investigation.

The area or item under investigation should be systematically surveyed. The surveyor should pay particular attention to areas such as pipe elbows where solids may accumulate. The meter probe should be in close proximity with the external surface of the equipment (normally not more than 1 centimeter away) and moved slowly across the equipment surfaces. The survey instrument's response switch should be set to the “fast” position during the initial scanning of the equipment. This setting minimizes the possibility of not detecting NORM deposits. Wherever NORM deposits have been identified, the response switch should be set to the “slow” position in order to obtain more accurate readings.

Production equipment, particularly water-handling equipment, should be surveyed for external gamma radiation. In addition, equipment being removed from service, released for maintenance work, or released for unrestricted use (e.g., sold or scrapped) should be surveyed for NORM.

Gamma surface scans of soil areas should be conducted over the subject land area on a delineated grid. The grid spacing should be optimized for the size of the area to be surveyed, as well as for the potential for identifying areas with elevated readings: the smaller the area to be surveyed, the smaller the grid spacing. Some regulatory agencies require that grid spacing not exceed 10 meters (30 feet). One technique that has been particularly useful for large areas is the use of a gamma-sensitive detector used in conjunction with a global positioning system. Use of this type of system allows simultaneous recording of detector response and positioning information. Areas exhibiting elevated readings should be identified for follow-up investigations, which may include additional radiation measurements (e.g. exposure rate measurements) and soil sampling.

3.1.2 Exposure Rate Measurements

Exposure rate measurements are performed using a gamma-sensitive survey instrument. Instruments may be a single unit that contains a read-out device and detector (for example, a micro-R meter) or two units such as a rate meter/scaler attached to a sodium iodide detector. To perform the measurement, the surveyor places the detector in a location where the measurement is desired and allows the meter to stabilize. The average value observed is recorded.

Many states have established exposure rate guideline values for equipment and areas. These guidelines specify the measurement location. Exposure rate measurements are usually performed at contact or at 1 meter.

Exposure rate measurements are usually performed on NORM-impacted soil areas, tubulars or equipment, and areas identified by gamma surface scans. The following measurement locations are recommended:

- Both ends of tubulars and pipes
- All openings in fittings (i.e. Ts, elbows), manifolds, etc.
- Both ends and the throats of valves
- Individual deposits or accumulations within vessels and tanks

Correlations can be developed to relate gamma or exposure rate measurements to concentrations of NORM in scale or sludge. The operator should exercise caution when using relationships of this type because of the many variables that can affect the relationship. Some of these variables include NORM density, volume, thickness, nuclide composition, and detector efficiency. Facility and equipment-specific correlations will yield better results than generic correlations. Generally, this will require the laboratory analysis of a number of samples collected from equipment reading at different exposure rates to develop a reliable correlation. In a similar fashion a correlation for solid waste could be generated by collecting a number of measurements from samples of known concentrations in a repeatable geometry such as a 1 liter open mouth plastic jar. Typically the accuracy of these correlations is on the order of plus or minus 50%.

3.1.3 Direct Measurements

Measurements for total and removable alpha and beta activity are performed on surfaces of equipment. For direct measurements, an appropriate detector is coupled to a ratemeter-scaler. A Geiger-Mueller (GM) tube is usually used for beta measurements, and a zinc sulfide scintillator is usually used for alpha measurements. However, many types of detectors are currently available. The surveyor places the detector in contact with the surface at the location where the measurement is desired and counts are accumulated for a predetermined length of time, typically 1 minute. The resulting value is in cpm. Conversion factors that correct for detector efficiency, count time, and geometry are applied to convert cpm to more useful units such as disintegration per 100 cm^2 (dpm/100 cm^2)or Bq per 100 cm^2 (Bq/100 cm^2).

Measurements to determine removable activity levels are collected by applying moderate pressure to a piece of filter paper or smear paper and wiping the surface over an area of approximately 100 cm^2. The activity on the smear can be determined by counting the filter paper using the survey instrumentation described above, or the smear can be sent to a radioanalytical laboratory to be counted. Appropriate conversions are applied to report results in units of dpm/100 cm^2 or Bq/100 cm^2.

Measurements to determine total and removable surface activity are usually performed at gas plants. During operations, while gas is flowing through the process equipment, locations where radon progeny are being accumulated may be detectable through external surveys. However, if the equipment item has been out of production service for more than 4 hours or the production stream has changed and does not contain radon, it is unlikely that such external surveys would detect internal accumulations of radon progeny. Such equipment could contain significant quantities of Pb-210 and progeny. Under such conditions, internal surveys should be made while the equipment is opened. Suitable limits used to assess radon progeny deposits are listed in state radiation control regulations as surface activity or contamination limits.

3.1.4 Radionuclide Concentration In Media

In some instances it may be necessary to determine concentrations of NORM in media such as air, soil, scale, and water. Collection techniques vary and require specialized equipment. Analytical laboratories or environmental professionals can provide additional information and describe appropriate sampling techniques. Upon collection, care should be taken to maintain a documented history of the sample. This is referred to as maintaining chain of custody. Samples are sent to radioanalytical laboratories for determination of radionuclide concentration.

Soil sampling is the most common form of media sampling at NORM-impacted sites. Reasons for soil sampling may include determining the concentration of radionuclides before the land is released for unrestricted use, or before the sale or purchase of the lease, and characterizing the existing surface activity. Additional soil samples should be collected from a non-NORM impacted area of the site to document the existing soil background levels. It is also possible to make rough estimates for radionuclide concentrations based on external measurements if enough field correlation data exists for the given site. As a general rule these estimates would be used to make follow up analysis decisions when addressing a NORM impacted site and would not be a sufficient basis to plan a remediation effort unless the correlations were specifically developed for a particular area."

3.1.5 Personnel External Radiation Dose Assessment

Personnel radiation exposures may be evaluated either by having personnel wear thermoluminescent dosimeters or film badges, which must be returned to and analyzed by the supplier. An alternative method is to survey with a tissue-equivalent scintillation detector, a shielded energy compensated GM probe, or an ion chamber survey meter capable of providing a readout in mrem/hour may be conducted. When the survey method is used, information on work location and time is required to estimate radiation dose.

The State organizations or the Occupational Safety and Health Administration (OSHA) establish limits for exposure of personnel. The annual occupational limit listed in 29CFR1910.1096(b)(1) is 5 rem (0.05 Sv). During any calendar quarter, the dose to the whole body shall not exceed 3 rem (0.03 Sv) as listed in 29 CFR 1910.1096(b)(2)(i); however, monitoring is done at some fraction of the limit value, generally 10 to 25% of the allowable limit. Work area radiation levels in the general industry segment are typically far below this regulatory level. Therefore, routine personnel radiation exposure surveys are not frequently done.

3.1.6 Personnel Internal Radiation Dose Assessment

Ambient airborne NORM concentrations are normally evaluated by filtering a high-volume air sample and having the filter analyzed by a radiometric laboratory. NORM deposits in equipment and piping do not present any airborne exposure concerns during normal operations. During maintenance or dismantling activities, airborne NORM exposure concerns are minimized by the application of typical industrial hygiene practices such as keeping NORM deposits wet and using respiratory protective equipment. On the other hand, during grinding, cutting, chipping and sanding, and during removal of NORM scale, airborne activity may occur. Under such conditions, it is advisable to evaluate employee exposure to ambient airborne concentrations of NORM.

Personnel exposures are evaluated by the same sampling and laboratory methodology except that personnel wear lapel air samplers that operate at 2 to 5 liters per minute versus the higher flow rate ambient air pumps. In both techniques, it is essential to know the volume of air sampled along with the radiometric results in order to calculate the airborne NORM concentrations.

3.2 INTEGRATION OF SURVEY TECHNIQUES

Numerous radiological measurement techniques have been discussed above. It is important that the individual performing the survey clearly understand and be trained in the procedures being used. The operator should identify the purpose of the survey and the values to which the results will be compared. The appropriate measurement technique will be selected based on this information. For example, if the objective of the survey were to determine the need for workers who need to be monitored for occupational exposure to radiation and radioactive materials, the survey would include determination of exposure rate and an evaluation of estimated internal doses. Survey measurements might include exposure rates and airborne concentrations of radioactive material. In contrast, if a property is being released from regulatory licensing, survey techniques would likely include gamma surface scans, exposure rate measurements, and determination of concentrations of NORM in soil. The selection of survey techniques is based on the objective of the survey and the guidelines to which the results of the survey will be compared.

3.3 INSTRUMENT CARE, MAINTENANCE, AND CALIBRATION

Portable survey meters typically used to conduct NORM surveys are generally quite rugged; however, the associated detectors and probes must be handled with care. As a matter of good practice, connecting cables should not be sharply bent because frequent sharp bending of the connecting cables will break the internal cable wire. Battery contacts need to be kept clean and free of corrosion residue. In humid environments, or if instruments are used infrequently, batteries should be removed from survey meters when the instruments are not being used. Survey instruments should be kept clean, and detectors (probes) need to be kept free of NORM residue.

NORM survey instruments should be returned to the manufacturers (or other qualified instrument calibration agents) at least annually (semi-annually in some jurisdictions) for general maintenance and calibration. Individual meters, detectors, and connecting cables should be calibrated as discrete instruments (units). Switching components between units voids the calibration(s). It is particularly important to ensure that instruments that are used to measure exposure rate are calibrated and respond appropriately to the radiation field present.

Instrument operational checks should be conducted before each use of an instrument (or after the detector has been dropped or banged against a solid object, etc.) to ensure that the instrument is functioning properly and providing representative readings. Operational checks include:

Battery check. Switch the meter dial to the “Battery” position and observe that the meter indicator moves into and remains in the accepted range, or depress the “Battery” button on the meter and observe the dial.

Source check. Expose the detector (probe) to a source of radioactivity of known strength and confirm that the meter registers the proper reading. It is not adequate to merely confirm a positive response by the meter. A damaged detector may provide a positive response, but the response will be much lower than the proper reading.

Various types (and strengths) of radioactive check sources may be purchased from most survey instrument suppliers. Operation checks of NORM survey instruments should be recorded on a form.

Note: There is some potential for sparking when detector cables are connected or disconnected, or when switches are turned on or off. Where explosive atmospheres may be encountered, tests for the presence of flammable gas/vapor should be made prior to the radiation survey.

3.4 RECORDS

All data collected during a NORM survey should be properly documented and accurate records should be maintained. Information and data collected may be subject to review and evaluation many years in the future.

All NORM survey information and data should be recorded on a form. Such forms should be completed in full for each survey. Example equipment classification abbreviations are provided in Table 3.1 to aid in the identification of equipment surveyed.

The records that should be maintained include:

- Field survey forms
- Instrument operational checks
- Instrument maintenance and calibrations
- Sample analytical results
- Thermoluminescent dosimeter (TLD) analyses

Table 3.1—Equipment Example Classification

Production Facilities:	
PROD	Production wellhead
WINJ	Injection wellhead
WOTHER	Other wellheads
MANIFOLD	Manifold/header piping, valves, etc.
SEP	Separators, including production separators, gunbarrels, etc.
FWKO	Free water knockouts
FLOAT	Flotation cells, wemcos, etc.
H/T	Heater treater
STANK	Stock Tanks
CTANKP	Condensate tank production
WTANK	Water tanks
PUMP	All pumps
SUMP	Sumps, including pits, pigtraps, ponds, etc.
FLINE	Flowlines, including all valves and elbows
GLINE	Gathering lines before processing
VRU	Vapor recovery units
PDEHYDRATOR	Production dehydration equipment
PIG	Production pig launcher/receiver
OTHER	All other measurements of in service equipment
SOIL	Soil readings at pipe yards, tank battery pads, etc.
TUBE	Production tubulars at pipe yards, etc.
SCALE	Scale sample readings

Gas Processing	
INLET LINE	All inlet lines to facility
SCRUBBER	Inlet scrubber, separators, etc.
SWEETENER	All gas sweetening equipment, including amine systems, etc.
DEHYDRATOR	Dehydration equipment: Glycol, EG and TEG systems, etc.
HEAT EXCH	Heat exchangers
FRAC TOWER	All process towers/columns
CYRO UNIT	All equipment associated with cryogenic process except reflux pumps
REFLUX PUMP	All reflux pumps
BOTTOMS PUMP	Pumps transferring liquid off the bottom of towers
METER	All metering equipment: meters, meter runs, screens, strainers, filters, etc.
GAS PIG	Gas processing pig launcher/receiver
PPUMP	Propane pump
OPUMP	All other pumps
PTANK	Propane tanks
CTANK	Condensate tank
OTANK	All other tanks
PRODUCT LINE	All product pipelines
COMPRESSOR	Compressors and associated equipment
REFRIG	All equipment associated with propane refrigeration system
GOTHER	All other gas processing equipment

SECTION 4—WORKER PROTECTION

4.1 PROGRAM NEEDS DETERMINATION

During normal operating conditions at NORM-impacted sites, external radiation exposure is usually low enough that no changes to normal work procedures are required. However, during non-routine operations such as well workovers, equipment maintenance, equipment handling and repair, and vessel entry, employees may have direct physical contact with NORM-impacted sand, scale, and sludges. Facilities should evaluate the levels of NORM and determine if employee exposures have the potential to require monitoring. Under existing regulations for workers classified as radiation workers by state or federal law, doses are required to be as low as reasonably achievable (ALARA), not to exceed an annual dose of 5 rem/yr (0.05 Sv), as specified in OSHA 1910.1096 (Appendix C). This limit applies to workers who handle NORM if they are classified as radiation workers by state regulations; otherwise, employees who handle NORM are subject to dose limits that apply to the general public. The public dose limit is 100 mrem/yr (1 mSv) from all sources. The operator should coordinate closely with regulators to ensure identification of the current guideline values. The evaluation should include estimated annual doses based on internal and external exposure pathways.

At facilities where NORM is not present in significant quantities, only periodic spot checking is necessary. This type of program would probably include a procedure for instrument calibration and maintenance, a survey procedure and appropriate forms, and a records procedure.

At facilities where employee exposures are not reasonably anticipated to exceed 500 mrem/year (5 mSv), but where NORM is known to exist, a slightly more stringent radiation protection program is necessary. A monthly survey that includes general area gamma scans and/or exposure rate measurements would be adequate. Elements for a program of this magnitude might include the following.

1. Organization and administration
2. Area monitoring and control
   a. Radiological controls
   b. Radiation monitoring
   c. Instrument calibration and maintenance
3. Radiological controls
   a. Posting and labeling
   b. Sealed radioactive source accountability and control
4. Records
5. Radiation safety training

In general, most in-house health and safety capabilities at NORM facilities are appropriate to develop a program of this type. However, for small organizations, the organization may elect to have a health physics professional assist in program development and implementation.

In general, if exposure to NORM-impacted material has the potential to result in worker doses that exceed 10% to 25% of the applicable guideline e.g. 0.5 to 1.25 rem (5 to 12.5 mSv), a comprehensive radiation protection program (RPP) is necessary and should be developed in consultation with a health physics professional. OSHA 1910.1096(d)(2)(i) identifies a monitoring threshold of 25% of the guideline value. A description of a program of this type is beyond the scope of this document but would potentially include the following elements:

1. Organization and administration
2. ALARA program
3. External dosimetry program
4. Internal dosimetry program
5. Area monitoring and control
   a. Radiological controls area radiation monitoring
   b. Airborne radioactivity monitoring
   c. Contamination monitoring and control
   d. Instrument calibration and maintenance

6. Radiological controls
   a. Radiological work planning
   b. Entry and exit controls
   c. Radiological work controls
   d. Posting and labeling
   e. Release of materials and equipment
   f. Sealed radioactive source accountability and control
7. Emergency exposure situations
8. Records
9. Reports to individuals
10. Radiation safety training
11. Limits for embryo/fetus

This list is provided to demonstrate the complexity of a full RPP. Items would be selected from this list based on the radiological conditions present, requirements specified by the regulatory body (typically the state), and the characteristics of the facility. As mentioned previously, this type of comprehensive program would be necessary only for facilities where the exposure was anticipated to exceed 500 mrem/yr (5 mSv).

4.2 WORKING WITH NORM-IMPACTED MATERIAL

To minimize potential internal exposure, the following work practices should be followed when working with materials and entering vessels that contain NORM.

a. Employees and contractors should be advised of the presence and potential risks of NORM and of the procedures to minimize exposure.
b. Eating, drinking, smoking, chewing, or applying cosmetics (e.g., sunscreen, lip balm) should not be allowed in the immediate work area where equipment or soil containing NORM is being handled.
c. If possible, openings on NORM-impacted equipment should be capped, sealed, or wrapped in plastic to minimize the generation of dust or the displacement of scale or sludge in the surrounding soil.
d. Personnel radiation exposures at NORM-impacted sites should be evaluated as described in Sections 3.1.5 and 3.1.6.
e. When moving, handling, or transporting tubulars or other open equipment that has been identified as NORM-impacted, personnel should wear protective boots, gloves, and coveralls to minimize contact with NORM.
f. NORM scale and sludge materials should be kept wet to minimize dust generation during handling.
g. If work required on equipment has the potential to generate airborne particulates, personnel should wear a respirator approved for radionuclides in addition to protective clothing. This applies even if the material is wet. Such work may include cutting, grinding, drilling, polishing or welding. At a minimum, the respiratory protection should consist of a half-face respirator with P100 cartridges, (formally classified as HEPA rated cartridges approved for radionuclide dust). These cartridges have a magenta or hot pink color code. Other options are full-face and supplied-air respirators.
h. Where there is a potential for significant dust containing radionuclides to be generated from material deposited on the ground, temporary plastic ground covers should be used if possible to contain any displaced NORM material. They should also be used to facilitate cleanup when work such as cutting, grinding or drilling is performed on NORM-impacted equipment. Sealed concrete paving should be considered wherever repetitive cleaning is done.
i. To prevent ingestion of NORM-impacted material, personnel should wash their hands and face before eating, drinking, smoking, chewing, or applying cosmetics after working on equipment containing NORM.

4.3 VESSEL ENTRY PROCEDURES

The following vessel entry procedures are recommended for NORM-impacted vessels.

a. Ventilate the vessel. In addition to eliminating most hydrocarbon vapors, this will also allow radon gas that the NORM deposits may have generated to dissipate. The ventilation period should be at least 4 hours to allow the decay of short-lived radon progeny to insignificant levels. Radiation detection equipment is not intrinsically safe for potentially explosive atmospheres. Consequently, proper hot work procedures and appropriate testing (LEL) should be performed prior to use in those environments
b. During initial vessel entry for cleaning or inspection, the use of a self-contained breathing apparatus, supplied-air respirator with air cylinder cascades, or other approved air supply is recommended.

c. Recommended personal protective equipment should include latex rubber or neoprene gloves, rubber work boots, rubber slicker suits or impermeable disposable paper suits, and a respirator.

d. Personnel radiation exposures associated with vessel entry should be evaluated as described in Sections 3.1.5 and 3.1.6.

e. All equipment containing NORM should be cleaned in a designated area. Rinsing off with soapy water or laundering should clean gloves, respirators, coveralls, boots, cleaning rags, and tools that contain NORM. If cleaning is not possible, the material should be placed in double bags, sealed, and held for proper disposal with other NORM waste. No NORM-impacted equipment or materials should leave the site unless properly sealed for storage or disposal.

f. Employees should observe good personal hygiene and should wash their hands and face before eating, drinking, smoking, chewing, or applying cosmetics to prevent any possible ingestion of NORM-impacted material.

SECTION 5—NORM REMOVAL GUIDELINES

This section summarizes general methods for removal of scale, sludge, and film from oil and gas production equipment and tubing. NORM-impacted gas plant equipment is also discussed. Removal operations should be carried out in a safe and practical manner to prevent any harm to workers or the environment. Removal operations range from manual cleaning to high-pressure water blasting of production equipment. NORM removal is often performed by a third party, typically a contractor specializing in and specifically licensed for this type of work. The cleaning and removal operations may be carried out at the equipment location or at the contractor's facility. Scale removal contractors will normally return NORM-impacted scale to the operator for disposal.

5.1 RESOURCES

A key factor in selecting a NORM removal procedure is the availability of adequate resources. Cleaning facilities, removal equipment, protective clothing, and safety equipment should be included in a resource evaluation.

Particular emphasis should be placed on waste handling facilities. Adequate waste handling facilities are necessary to prevent the spread of NORM material to the surrounding environment, which may significantly add to the cost of a removal operation.

In some states, contractors may be required to have adequate facilities and to be licensed by state regulatory agencies to perform NORM removal. However, it is prudent to perform an external assessment of facilities and, where warranted, radionuclide analyses of vessel contents before engaging any third party services. If the facility has a radioactive materials license, a review of the current status of that license and any deficiencies filed against the license is also recommended.

5.2 PERSONNEL SAFETY AND ENVIRONMENTAL PROTECTION

In general, NORM removal at dedicated facilities is more efficient, but tank, and some equipment cleaning, must be done on site. Before any type of NORM-removal operations is begun, certain precautions should be taken. Owners or operators of equipment or facilities directly performing their own cleaning should follow the following procedures. These procedures can also serve as a guide for evaluating the resources of third-party contractors performing such work. State regulators should be consulted to ascertain the eligibility of contractors to perform the required work. State regulators will also provide information regarding acceptable levels for direct radiation or activity levels that are appropriate for the operation to be performed.

Employees involved in NORM-removal operations should be properly trained. Records of training should be maintained as required by applicable state and federal regulations.

a. Equipment should be treated as being NORM impacted if external radiation levels exceed direct radiation levels specified by the state.

b. Permanent cleaning areas should be paved and curbed with concrete to avoid ground contamination. Plastic ground covers should be placed in and around a temporary NORM cleaning area before any cleaning operation begins. Plastic ground covers are used to contain contaminants and facilitate clean-up procedures after operations are complete.

c. Any type of NORM-removal activity should take place in a well-ventilated area.

d. All personnel involved in the removal process should be familiar with personal protective equipment that should be worn during removal operations. Personnel should also be familiar with proper procedures for confined space entry.

e. Personnel radiation exposures associated with NORM removal should be evaluated as described Sections 3.1.5 and 3.1.6 when exposure and concentration levels approach regulated values.

f. Entry into the cleaning area should be restricted to authorized personnel, and the number of people within the cleaning area should be kept to a minimum.

g. Workers should keep all materials that contain NORM in a wet state to prevent the inhalation of dust. Dry removal processes must be designed to prevent dust releases.

h. Radiation survey readings should be taken in and around the cleaning area before the cleaning operations begin. Initial readings should be compared to readings taken after cleaning operations are complete.

i. The removed scale, sludge, and other particles should be placed in appropriate containers for storage. All NORM-impacted process water should be contained, recirculated, or filtered to remove NORM material.

j. If the cleaning process does not reduce radiation levels to acceptable levels, the equipment could be stored, reused, or recleaned, but it should not be released for unrestricted use.

5.3 CLEANING METHODS

The choice of the removal procedure should depend on its removal efficiency as well as the resources, cost, and safety considerations outlined earlier.

5.3.1 Manual cleaning

Manual cleaning does not involve any machinery and may be as simple as hand washing equipment with detergent and water. The removal of NORM-impacted tank sludges could be done by manual cleaning (for example, shoveling the sludge from the tank and placing it into storage containers), or washing and pumping could do it.

5.3.2 Mechanical cleaning

Mechanical cleaning methods vary widely and may include high-pressure water washing, drilling or reaming, and vacuuming.

5.3.3 High-pressure water blasting

Water blasting is a commonly used method of NORM removal. It is used to clean scale from production equipment, such as separators and tanks, as well as from tubing and pipes. High pressure water blasting is usually defined as water jetting operations using pressure above 750 psi. NORM scale cleaning operations typically range in pressure from 10,000 psi to 30,000 psi.

High pressure washing systems should be closed systems. Wash water should not be allowed to escape to the environment but should be contained, recirculated, or filtered to remove scale. Any disposal of wash water should be accomplished through approved methods and in accordance with permit requirements.

5.3.4 Drilling or reaming

Drilling or reaming is typically used in the cleaning of production tubing and piping. A tube will be positioned on a cleaning rack and a reamer enters one end of the tube to begin cleaning. This process has high removal efficiency but may generate NORM-impacted dust if used as a dry process. Wet drilling processes may be used to reduce the amount of dust generated. As with high pressure water blasting, wet and dry drilling processes should be closed systems to prevent the release of NORM materials.

5.3.5 Vacuuming

Vacuum systems may be wet or dry processes and are generally effective in removing loose material. Vacuuming is often used before manually cleaning equipment. Vacuum systems should be properly filtered to prevent the spread of material to surrounding areas and reduce the potential for airborne activity. Care should be taken to ensure that large amounts of NORM material do not accumulate in the vacuum system.

5.3.6 Equipment in gas service

NORM material may occur in natural gas processing equipment as thin films, which are often invisible to the naked eye. These films may consist of radioactive materials that embed themselves into the walls of the processing equipment. Chemical film removal or grinding may be necessary to remove NORM film from gas plant equipment. Additionally, NORM material may accumulate as a dusty black powder on the internal surface of gas processing/storage equipment. The powder, often iron sulfide, has been shown to potentially contain elevated levels of Pb-210. It should be noted that, due to the radioactive species present, radiation conditions may exist when systems are opened for cleaning or refurbishment that may not be readily identified when the systems are closed.

SECTION 6—STORAGE OF NORM

Equipment containing NORM often must be removed from the production or plant site and stored at a centralized location before repair, sale, cleaning, or disposal. The following guidelines address practices for managing storage of this material. These practices help to ensure that employees at the NORM storage site are not exposed to excessive levels of radiation or radioactive material. Before operating a NORM storage site, the operator should determine that measures are consistent with applicable state regulations.

6.1 STORAGE SITE DESIGN

Containers and equipment containing NORM should be stored in a secure ventilated area with limited access. If the NORM is stored at a site with conventional oilfield equipment, the NORM area should be appropriately marked, and access should be limited to authorized personnel. The NORM storage area should be sized so that radiation levels at the perimeter of the area do not exceed 100 millirem/year (1 mSv/yr) (refer to Appendix C). To minimize radiation levels at the perimeter, material with higher radiation levels should be stored near the center of the area. Containers or equipment containing NORM should be secured against unauthorized removal from the storage site.

6.2 UNCONTAINED NORM

Uncontained NORM should be placed in sealed containers for long-term storage before permanent disposal. However, if necessary, NORM scale or sludge could be stored temporarily on impermeable pads with a secured cover to contain the material and prevent it from spreading off site.

6.3 CONTAINED NORM

Loose NORM, such as scale from tubing or sludge or from vessel cleaning, should be stored in sealed and marked containers on pallets or racks. No liquids should be stored for extended periods of time due to package degradation. Containers and equipment should be handled, moved, and stored in a way that prevents the escape of loose radioactive material into the environment. Containers and equipment should be inspected periodically and should be immediately repacked or resealed if found to be leaking.

6.4 SEALED OPENINGS

All openings on stored equipment or tubing containing NORM should be capped, plugged, or wrapped in plastic to prevent the spread of radioactive materials.

6.5 CLEANING EXTERIOR SURFACES

If the exterior surfaces of containers, tubing, and equipment must be cleaned to remove external NORM material, such cleaning should be done in accordance with the NORM removal guidelines in Section 5 of this document. All process water that contains NORM should be contained, recirculated, or filtered to remove material. The ultimate disposal of waste water should be by approved methods and in accordance with applicable permit requirements.

6.6 PREVENTING DISPERSAL OF NORM MATERIAL

To protect soil and surface water from dispersal in the NORM storage area, plastic ground covers should be utilized when handling unsealed containers or equipment. NORM waste that falls on the plastic cover should be recovered and stored in sealed containers. Water discarded must comply with applicable regulations. The operator should ensure that necessary discharge permits have been secured.

6.7 NOTIFYING EMPLOYEES AND CONTRACTORS

Employees or contractors who enter NORM storage areas should be informed of the presence of radioactive materials, the safety problems associated with exposure to radioactive materials, and the methods of minimizing exposure to radiation. If NORM storage areas qualify as radiation areas, employers should keep a copy of the OSHA regulations for protecting workers from ionizing radiation (29 CFR §1910.1096) and a copy of the employer's guidelines for working in NORM storage areas. In addition, it may also be necessary to maintain copies of applicable state regulations.

6.8 WORKER PROTECTION GUIDELINES

Employees and contractors working in NORM storage areas should adhere to the guidelines given in Section 4, "Worker Protection."

6.9 SIGNS OUTSIDE STORAGE AREA

Areas where NORM is stored should be identified with signs at all entrances, bearing the three-bladed radiation symbol (magenta blades on yellow background) and words like "Caution, Radioactive Material Storage Area." If whole-body radiation exposure at any point within the storage area exceeds 5 mrem (0.05 mSv) in 1 hour (29 CFR §1910.1096(d) (3)(ii)), the sign should contain the words "Radiation Area."

6.10 LABELS ON DRUMS AND EQUIPMENT

Containers, tubing, or equipment containing NORM should be tagged or labeled. The label should contain wording similar to the following:

WARNING: NATURALLY OCCURRING RADIOACTIVE MATERIAL AVOID BREATHING DUSTS

This label should include an identification code that corresponds to records of the material. Separate labels may not be needed for each joint of casing, tubing, or pipe if the joints are stored together.

6.11 RECORD KEEPING

Records should be maintained to document at least the following information:

a. An identification code
b. The storage location of the material
c. The type of radioactive material (scale, sludge, etc.)
d. The date the material or equipment entered storage
e. The original location of the material or equipment and the type of service
f. Measurement data that reflect the radioactivity of each container and piece of equipment
g. Results of radioactive surveys of the NORM storage area
h. Radiation exposure data for individuals required by OSHA regulations to wear personnel monitoring equipment
i. Training documentation

SECTION 7—TRANSPORTING NORM

The purpose of this section is to provide general information regarding the shipment of NORM-impacted materials. Recent revisions to the Department of Transportation (DOT) guidelines that became effective in 2004 have had a significant impact on the transportation of NORM-impacted material. The reader is advised to seek assistance from a waste management specialist to ship NORM-impacted materials that are classified as radioactive waste. Operators should consult applicable federal, state, and local regulations and waste management specialists to determine what specific regulations may apply and how they should be interpreted.

7.1 FEDERAL AND STATE REGULATION

DOT regulates the transportation of hazardous materials affecting interstate commerce through its regulations in 49 CFR Parts 171-180. Intrastate transportation of hazardous materials is regulated by state agencies, which have generally adopted the federal regulations. The state regulatory agency is usually the Department of Public Safety, the Department of Transportation, or the Department of Motor Vehicles.

7.2 DOT DEFINITIONS

DOT regulates the transportation of radioactive materials having a concentration greater than the following values:

Table 7.1—Exempt values for Ra-226 and Ra-228 as stated in 49 CFR §173.436

Isotope	Activity concentration for exempt material	Activity limit for exempt consignment
Ra-226[1]	2.7E-10 Ci/g (10 Bq/g)	2.7E-7 Ci (1E4 Bq)
Ra-228[2]	2.7E-10 Ci/g (10 Bq/g)	2.7E-6 Ci (1E5 Bq)
1. Ra-226 and progeny included in secular equilibrium: Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, and Po-210. 2. Ra-228 and progeny included in secular equilibrium: Ac-228		

In addition, 49 CFR 173.401(b) (4) allows a multiplier of 10 to be applied to the exemption values reproduced in Table 7.1. The multiplier is appropriate for material that meets the following condition: "Natural materials and ores containing naturally occurring radionuclides which are not intended to be processed for use of these radionuclides, provided the activity concentration of the material does not exceed 10 times the values specified in §173.436." Application of this factor yields the following values:

Table 7.2—Exempt values for Ra-226 and Ra-228 as stated in 49 CFR §173.436 and as modified based on §173.401

Isotope	10x activity concentration for exempt material	10x activity limit for exempt consignment
Ra-226[1]	2.7E-9 Ci/g (100 Bq/g)	2.7E-6 Ci (1E5 Bq)
Ra-228[2]	2.7E-9 Ci/g (100 Bq/g)	2.7E-5 Ci (1E6 Bq)
1. Ra-226 and progeny included in secular equilibrium: Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, and Po-210. 2. Ra-228 and progeny included in secular equilibrium: Ac-228		

NORM-impacted materials that do not exceed the values provided in Table 7.2 are not defined by DOT as radioactive and are exempted from the stated requirements for the shipment of radioactive materials. The vast majority of NORM-impacted materials are managed as non-radioactive shipments.

7.3 TRANSPORTATION GUIDELINES FOR NORM

7.3.1 Regulated NORM

If the operator determines that the NORM-impacted material is appropriately classified as radioactive, transportation guidance should be sought from a waste management organization. The responsibilities of the waste transportation contractor include:

- Packaging all NORM materials and soil in appropriate containers for shipment

- Surveying the packaged material using a gamma rate meter
- Collecting samples and analyzing to determine the correct manifest, shipping labels, and placards that are appropriate
- Identifying waste acceptance criteria for the waste disposal site selected
- Verifying that the waste meets the site waste acceptance criteria

SECTION 8—MANAGEMENT OF EQUIPMENT AND PROPERTY

The management of NORM-impacted property or equipment should comply with all applicable laws and regulations (Appendix D). It is imperative that decision makers clearly identify the objectives of the transfer of NORM-impacted property or equipment. This decision is complicated since there are currently no guidelines that apply to the transfer NORM impacted property or equipment to another user (for oil-field production activities) and for unrestricted release of NORM-impacted equipment or property.

The following sections will describe general approaches for the transfer of NORM-impacted property and equipment for continued use in production activities. Subsequent sections will discuss unrestricted release of property and equipment.

8.1 REGULATIONS—PROPERTY TRANSFER

As of the publication of this document, no state has regulations restricting (based on the radiological levels present) the transfer, of oil and gas properties and equipment containing NORM for continued operation. A review of representative state regulations indicates that copies of the results of the most recent radiation surveys must be transmitted to the new owner/producer prior to the property transfer, and the respective state should be notified of the transfer.

8.2 REVIEW/ASSESSMENT—PROPERTY TRANSFER

Prior to transfer of the property, potential environmental issues should be identified and clearly documented in the property transfer process. The identification of potential issues is usually accomplished by site reviews, audits, or assessments. This information should be used to evaluate and document the radiological levels associated with the equipment or property. While specific guidance is not provided, API suggests that sellers perform thorough surveys to characterize the radiological conditions of the property being transferred and prepare documentation that conveys this information to the buyer. The property review and assessment should provide a baseline of data concerning the character, volume, and location of NORM present on the date of transfer. Possible survey activities to be considered for inclusion are:

Gamma surface scans. The transfer survey should include gamma surface scans throughout the entire property and on structures and equipment. The areas to be surveyed can be gridded and surface scan results referenced to grid locations. Another alternative is a global positioning system (GPS) that integrates positioning information with instrument response. The final report, generated using this type of system, can include easily understood figures with the surface scan results superimposed on the property features.

Direct measurements for total and removable activity. Direct measurements for total and removable activity should be made at representative locations on equipment.

Exposure rate measurements. Exposure rate measurements at representative contact locations on equipment and at a height of 1 meter made at representative locations throughout the property should be made and included in the report. Direct measurement locations should be referenced on figures and the results included in the report.

Sampling and analysis for NORM. Samples of soil and scale should be collected and analyzed for NORM content. Samples should be sent to a radioanalytical laboratory for analysis. Results should be included in the report and sampling locations should be shown on figures.

Additional descriptive information that should be included in the report is a site history that includes a description of past and current operations, a site description including features and equipment, and any other pertinent information.

8.3 DISCLOSURE—PROPERTY TRANSFER

If environmental site reviews or assessments indicate the presence of NORM, disclosure of the results by the transferor, to the transferee, can be accomplished in many ways, including one or more of the following:

- Placing a general disclosure statement in the sales agreement or deed covering, among other items, NORM
- Transferring company files to the transferee
- Making specific reference to the presence of NORM in the sales agreement or deed
- Providing the transferee with copies of site review reports
- Providing access to the property and or equipment

8.4 REGULATIONS—PROPERTY RELEASE

Some states have considered potentially NORM-impacted property and equipment to fall under their general rules for radiation protection, while other states have issued specific regulations. Currently, approximately 13 states have regulations concerning the management of NORM-impacted property and equipment. There are differences among the states in the standards for unrestricted release of property and equipment. Examples of the types of criteria that are used are:

- Concentrations of NORM in surface and subsurface soil
- Exposure rates at 1 m from the surface
- Exposure rates at contact with the ground surface or equipment
- Exposure rates in boreholes
- Dose to individual using pathway analysis/dose assessment
- Total and removable surface activity levels

The situation is further complicated because the numerical values for the different types of criteria also vary. Due to the complexity of the current regulations (and difficulty in determining the appropriate criteria), the changing nature of the regulations, and the potential for future liability issues, API recommends that property owners contact a health physics professional for assistance in the survey and release of potentially NORM-impacted property or equipment.

Another factor pertinent to the release of equipment is the dichotomy that exists between some state regulations for unrestricted release of equipment and the acceptance values used by scrap metal facilities. The increased use of radiation monitors has resulted in the rejection of scrap metal that has been released under state guidelines. Consequently, some equipment that is not classified as NORM impacted by state rules will not be accepted by scrap dealers for recycling and may require cleaning prior to being accepted as scrap.

SECTION 9—NORM DISPOSAL

As of the publication of this bulletin, there are no federal and few state regulations directly applicable to disposal of oilfield NORM. Federal exemption transfers the regulatory burden for these wastes directly to the individual states in which the wastes are generated and/or managed. Currently, there is a range of state program levels in place. Some states are in the process of developing regulations for NORM disposal and some are prohibiting disposal until regulations are adopted. Texas and Louisiana have created regulatory programs to specifically address these types of wastes. In states that have NORM regulatory programs, there may be options for on-site disposal as well as commercial options. Waste disposal options and regulations are constantly changing and it is recommended that operators consult applicable state and local regulatory agencies, waste management specialists, and consider lease or landowner obligations before disposing of NORM-impacted material.

The disposal method(s) selected will depend on a number of factors and may include waste forms, waste characteristics, radiation levels or concentrations, waste volumes, cost, and land management issues. On-site disposal options typically include injection/encapsulation and surface or subsurface landspreading. Off-site disposal options include transfer to a NORM disposal facility, a commercial low-level radioactive waste facility, a commercial hazardous waste landfill, or in the case of equipment or tubulars containing NORM, a smelting facility. In some instances, waste is transported to a facility for treatment or processing prior to being sent to another facility for disposal. Waste disposal options at commercial facilities include treatment, injection, and burial.

Several organizations have prepared documents addressing issues associated with various disposal options for NORM-impacted material. The results of two general reports are summarized in Appendix E in Sections E.1 and E.2. Please note that this information has not been approved by state or federal agencies and should not be used as the basis for disposal decisions without obtaining appropriate agency approval.

9.1 NORM WASTE CATEGORIES

The two categories of NORM wastes, which must be disposed of, are diffuse NORM (scale, sludge and soil) and NORM-impacted tubulars and equipment such as separators, tanks, valves, etc. The type of waste to be disposed of may limit the options available.

9.2 INJECTION

Norm-impacted material can be disposed of by injection into a well that is scheduled to be plugged and abandoned, into a fractured formation, or a salt cavern. Injection provides greater environmental security than alternative surface pit or landfill disposal. Injection on site by the operator also provides disposal at a lower cost than off-site transport and disposal options. Use of a commercial facility, which performs the entire operation, may be a more attractive alternative to some operators. Operators should communicate closely with the commercial facility to ensure a clear understanding of the acceptance criteria and other conditions that may apply.

9.2.1 Plugged and abandoned wells

Well abandonment operations can be used as an opportunity to dispose of NORM when approved by appropriate regulatory agencies (Appendix E, Section E.3). Louisiana, Michigan, Mississippi, New Mexico, and Texas have regulations for the disposal of NORM-impacted material in plugged and abandoned wells. NORM impacted material may be encapsulated in steel tubulars that are placed into a well bore or mixed as a slurry and injected into the well. NORM obtained from cleaning tubulars and production equipment could be mixed with cement slurries if there are no hydrocarbons present. NORM should not be mixed with cement slurries used in isolating underground sources of drinking water (USDW), fresh water zones, or in the surface plug. This will ensure that groundwater contamination from NORM does not occur. NORM-impacted tubulars could be installed beneath or between all plugs in the wellbore or cemented in place within a full cement column. A plug should be set in the casing above the top joint of tubing. NORM-impacted tubulars should not be left in the wellbore at depths above the lowermost USDW to ensure that ground water contamination from NORM does not occur.

Reclamation of the well site includes sealing several feet of the well with grout or other suitable material. Materials disposed of in this manner remain nearly inaccessible from surface intrusion. However, inadvertent exposure must be minimized by institutional controls which may include: red-dyed cement in the surface plug, a radiation symbol notation welded to the top casing plate; a notation on the plugging record; and deed recording.

Currently there are no limitations to radionuclide concentrations or total activity of NORM-impacted material that may disposed of in this manner. Typically, well production casings are about 4 to 5 inches in diameter and therefore, can only accommodate a single string of tubing and a few hundred cubic feet of NORM-impacted solids. The limited volume available in each well bore and the multiple handing of material necessary with this approach make it a rather expensive waste management option. These factors have limited use to date. The use of deed restrictions may also limit use of this disposal method.

All plug and abandonment operations (with or without NORM disposal) are covered by detailed state regulatory guidance, and all states require reporting of NORM disposal operations. Operator and state abandonment records should provide details regarding the disposal of NORM in plugged and abandoned wells. Wells to be plugged and abandoned could also be used to inject NORM into the formation prior to permanent plugging as discussed below.

9.2.2 Hydraulic fracturing

Sludge and scale wastes containing NORM could be injected or fractured into formations that are isolated geologically and mechanically from USDW. This type of disposal may be used in association with the plugging and abandonment of any well including a Class II well with suitable geology permitted for this activity. Wells that inject material that is primarily liquid are operated at pressures below the fracture pressure of the formation and force liquids into the formation matrix (well injection). Formations selected for injection are limited to areas and horizons in which deeper formations have little or no economic value.

In order to dispose of material that contains solids, the solids must be crushed, ground, and processed, and then entrained with liquid wastes to form an injectable slurry. To inject wastes that contain relatively high concentrations of solids, injection pressures must be used that cause the formation to fracture (hydraulic fracturing). The fracture formed by this process is normally vertical, confined above and below by impermeable shale formation, and extends several hundred feet from the well. A well used for this purpose may be used multiple times.

Currently there are no limitations to radionuclide concentrations or total activity of NORM-impacted material that may be disposed of in this manner. The NORM wastes could be mixed using mud or cement mixing equipment. A clean fluid, such as water or mud, should follow the injection of the NORM waste slurry so that all NORM wastes are completely displaced into the formation. Operators should evaluate formation and injection fluid characteristics prior to injection of NORM wastes in order to ensure compatibility. Disposal by injection has the potential to dispose of more than 100,000 barrels of waste in a single well, depending on the geologic characteristics of the formation. During operation and at closure, the injection facility is monitored for leakage, and at closure, cement and clay are used to seal the top region of the well. When the well is closed, it is cut below the ground surface and capped to prevent intrusion.

Although disposal wells are numerous in oil and gas producing states, few states have allowed disposal by injection. Texas has permitted seven wells for the disposal of NORM-impacted material since 1995; Louisiana has permitted one, for noncommercial use only. Materials appropriate for this method of disposal include liquids and solids that can be sufficiently reduced in size to form a slurry.

9.2.3 Salt cavern

Salt caverns have been used for several decades for the storage/disposal of various hydrocarbon products (Appendix E, Section E.4). In recent years, their use for NORM-impacted materials has come under increased interest and review. The advantage of injection disposal in caverns is that caverns can be used for materials with a high percentage of solids. Wastes being considered for salt cavern are those that do not qualify for Class II injection well disposal because of the presence of solids. The wastes contain drilling fluids, drill cuttings, completion and stimulation waste, produced sand, tank bottoms, and soil containing NORM. Disposal treatment technologies include grinding the sediment and mixing with water to inject a slurry into the top of the salt cavern and allowing materials to precipitate. As the waste is injected, the cavern acts as a separator. The heavier materials settle to the bottom. Clean brine displaced by the slurry is removed from the cavern and either sold as product or disposed in an injection well. The cavern is plugged when it is filled. Currently, one commercial facility in Texas provides waste disposal by injection in a salt cavern. Louisiana and New Mexico have entered the permitting process but currently do not have an approved operating facility.

9.3 DISPOSAL AT COMMERCIAL LOW-LEVEL WASTE FACILITY

At this time, there is one commercial low-level waste facility operating in the United States. This Utah facility accepts NORM-impacted material and equipment, but is one of the more expensive alternatives. The operator must communicate closely with a representative to ensure that all acceptance criteria are clearly understood, documented, and met. Following is a brief overview of typical steps taken to ship waste to a commercial facility.

- Contact site representative
- Review waste acceptance criteria
- Document waste characteristics
- Submit waste characterization documentation to waste disposal organization for review
- Complete and submit a radioactive waste profile record or other applicable information
- Obtain a Generator Site Access Permit from the Utah Division of Radiation Control

The commercial facility will issue a "Notice to Transport" after the waste profile has been approved and a disposal agreement is in place. The waste will be transported, treated, and/or disposed. Upon final placement, a Certificate of Disposal will be issued.

9.4 DISPOSAL IN A SOLID WASTE LANDFILL

Michigan law permits disposal of NORM-impacted material up to a concentration of 50 pCi/g in landfills (Appendix E, Section E.5). A Michigan study found that landfill disposal of NORM wastes could be one of the most cost-effective disposal options for states to approve either by regulation or special permit.

9.5 EQUIPMENT RELEASE TO A SMELTER

When NORM-impacted equipment is smelted, residual NORM accumulates mainly in the slag, which allows the steel to be recycled. Several operating companies, who are members of the Petroleum Environmental Research Forum (PERF), are sponsoring an ongoing study that is investigating the viability of smelting NORM-impacted equipment. Recycling of metal by smelting has been of interest in Europe, China, and Australia. Smelting could be a viable option for NORM-impacted tubulars and other equipment if approved by appropriate regulatory agencies. In Australia, scrap steel from gas plants may be recycled if it has less than (500,000 Bq/kg). However, this process has come under close public scrutiny due to the discrepancy between the guidelines established for nuclear and non-nuclear materials. The guidelines for non-nuclear materials submitted for recycling tend to be higher. This is an option that is currently not available in the United States.

9.6 LANDSPREADING AND BURIAL

In some states loose NORM can potentially be disposed of by surface or subsurface landspreading or burial on the property at which the material was generated (Appendix E, Section E.6). Landspreading involves spreading the NORM-impacted materials over a tract of land using standard earth moving equipment. The soil may also be tilled to enhance mixing. Subsurface landspreading is essentially the same process performed at slightly greater depths and may include application of a cover layer of soil or other material. Some states allow NORM-impacted material to be buried on the site in which they were generated. Regulations governing landspreading vary from state-to-state with respect to permit requirements, application restrictions, siting restrictions, final treatment levels, and landowner notification.

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APPENDIX A—SOME PROPERTIES OF RADIOACTIVITY

A.1 Radioactivity

Radioactivity can be defined as that process by which an unstable atomic nucleus undergoes spontaneous disintegration with the emission of corpuscular (mass) or electromagnetic radiation. If an isotope of an element disintegrates and emits such radiation, it is said to be "radioactive" and is called a "radioisotope." With a few exceptions, nuclei relieve the stress of an imbalance in their proton to neutron ratio by the emission of an alpha particle or a beta particle.

Alpha (α) particles are charged nuclear fragments having a mass and charge the same as that of a helium-4 nucleus; two protons and two neutrons (He^{++}). Alpha particles are generally of high energy (3 to 8 MeV) but transfer that energy to the transport medium in a very short distance. Therefore alpha radioactivity is easily shielded by such things as a few inches of air, a piece of paper, or the outermost layers of skin. This property makes alpha radiation essentially non-hazardous as an external exposure source but potentially an internal source.

Beta (β) particles are charged fragments emitted from the nucleus. They have the mass and charge of an electron. Beta particles are generally emitted with somewhat less energy than that of the alpha particle, but are significantly more penetrating and hence can cause skin burns and pose a potential external exposure risk as well as an internal one.

Gamma rays are similar to x-rays. They are short wavelength (high energy) electromagnetic radiation (photons) of nuclear origin and range from a few KeV to several MeV. Gamma rays are the most penetrating of the three types of radioactivity and hence present the highest external and lowest internal radiation exposure risk. It is the gamma radiation one usually surveys for in the field to detect the presence of radioactive substances.

A.2 Naturally occurring radioactivity

Today, it is recognized that all elements found in nature with atomic number greater than 83 (bismuth) are radioactive. These isotopes belong to chains of successive decays, and all the members in one such chain constitute a radioactive family, or series. Three of these families include all the natural activities in this region of the periodic chart. One has uranium-238 (U-238) as the parent substance, and after 14 transformations (8 of them by α-particle emission and 6 by β-particle emission) reaches a stable end product, Pb-206. This is known as the uranium series and includes Ra-226 and its progeny. This is the series of most concern to the petroleum industry. Thorium-232 (Th-232) is the parent of the so-called thorium series, with Pb-208 as its stable end product. It includes Ra-228 and its progeny and is of lesser concern in oil and gas operations.

Those working in certain oil and gas operations need to keep in mind that the uranium series contains the isotope Ra-226. This is the radioactive contaminant that occurs in some scales (usually barite); its half-life is 1,620 years. Obviously, one cannot wait for it to decay perceptibly from the activity at which it is found. From its decay comes Rn-222. With its half-life of some 92 hours, it grows into secular equilibrium in 20 to 30 days. Radon is a noble gas at standard temperature and pressure, but its relatively short half-life prevents its complete escape from the crystal lattice in scales such as barite; hence, all the subsequent progeny are trapped in the scale as well, giving rise to the gamma radiation from Pb-214 and Bi-214, which account for nearly all the gamma emission from a Ra-226 scale. If Rn-222 has accumulated in a closed system for several days, there will be an equilibrium activity of Pb-214 and Bi-214, which must be allowed to decay away before exposure to the system. This is the reason the radon gas must be swept out of the container and the vessel allowed to "cool" for a period of about 4 hours before work is conducted on it (4 hours equals approximately 9 halflives of lead-214).

Another consideration unique to the uranium series is the production of the 22-year half-life of Pb-210 in a system where Rn-222 has been present for a period of years. This isotope and its progeny (Bi-210 and Po-210) will accumulate on the sides or inside coatings of the container and will obviously take many years to die away. One feature of these two radionuclides is that their decay is not accompanied by significant gamma radiation; hence they are very difficult to detect in the field. Accordingly, they can be in high concentration, yet be undetectable through steel walls.

The thorium series is somewhat different from the uranium series in its radiogenic characteristics, even though it contains the same elements. The main operationally important difference is that the radium isotopes have much shorter halflives than Ra-226 and for any of the progeny past radium to be present in any significant amount, one must wait for the grow-in of Th-228 with its half-life of 1.9 years. It is also important to note that the radon gas isotope (220) has a half-life of less than a minute, which severely restricts its occurrence unsupported by its parent in producing operations.

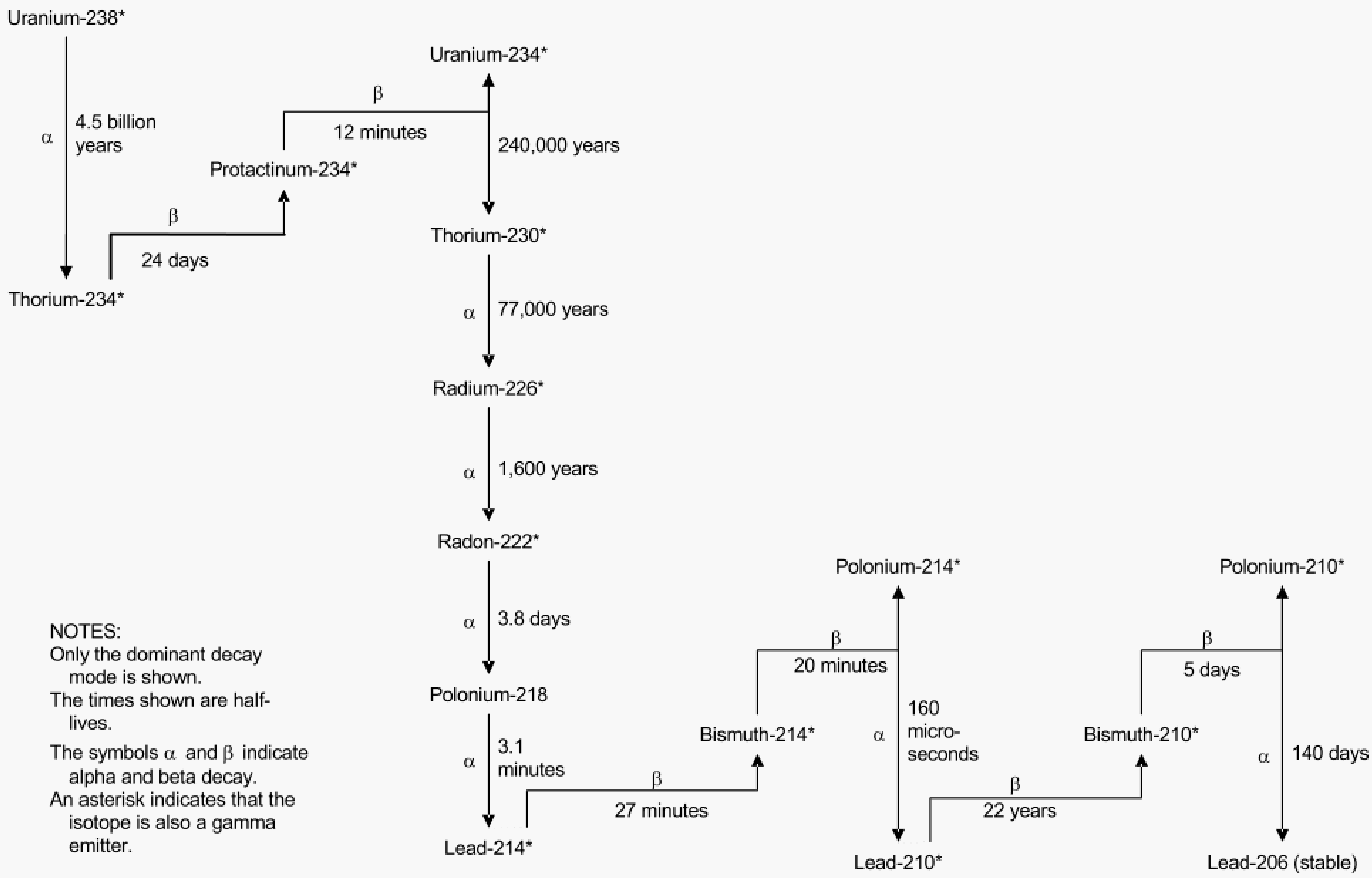

Figure A.1—U-238 Decay Series

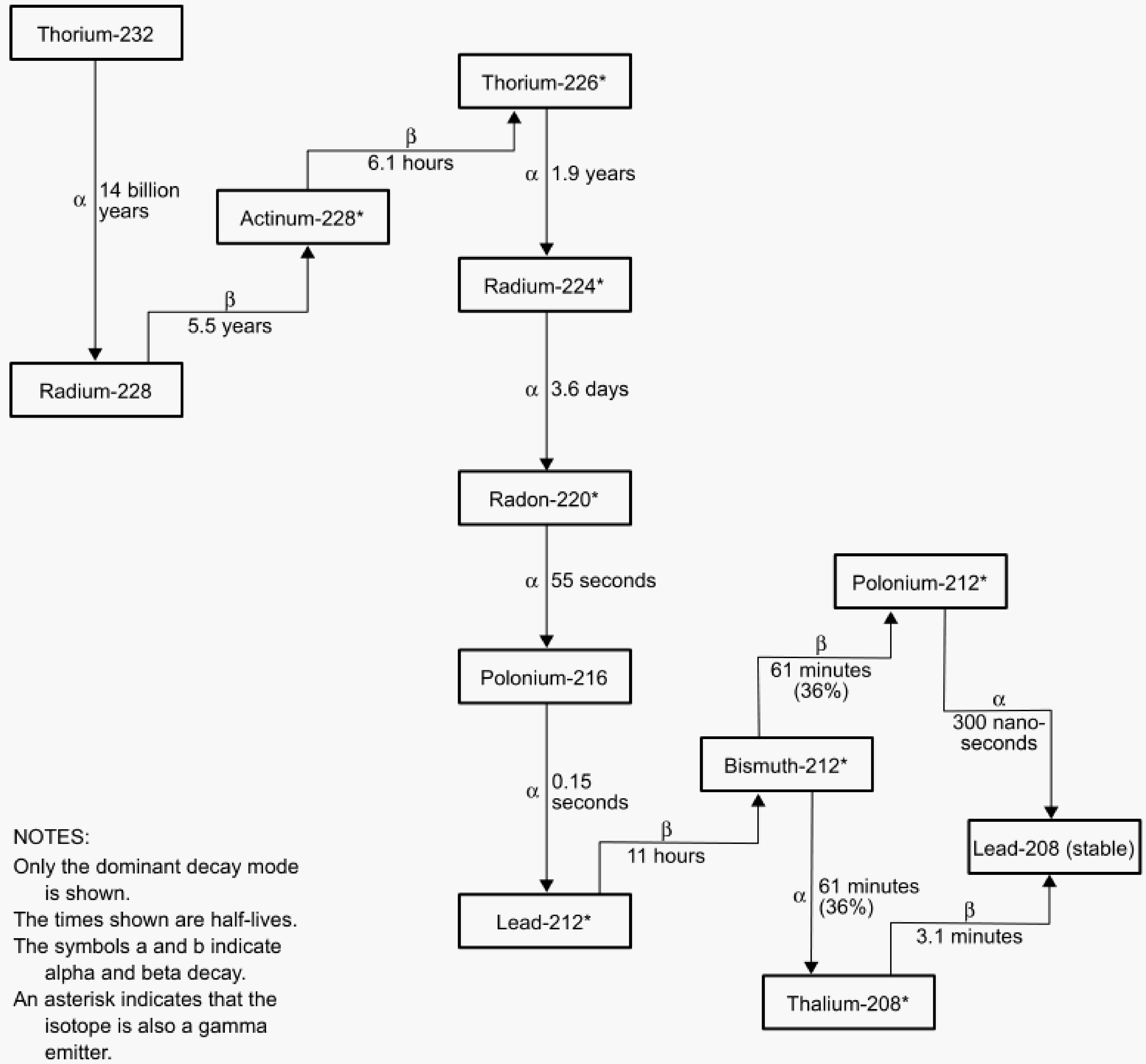

Figure A.2—Th-232 Decay Series

APPENDIX B—GLOSSARY OF RADIATION TERMINOLOGY

absorbed dose: The mean energy deposited by ionizing radiation per unit mass of the body or organ or tissue of the body; unit: gray (Gy), 1 Gy = 1 joule per kilogram.

activity (radioactivity): The number of nuclear transformations that occur in a quantity of material per unit of time. The international scientific (SI) unit is the Becquerel (Bq), 1 Bq = 1 disintegration per second (dps). Non-SI units used include the Curie (Ci), 1 Ci = 3.7 x 1010 Bq or fractions thereof, e.g., microcurie (μCi), picocurie (pCi) etc.

ALARA: A principle of risk management according to which exposures are kept "as low as reasonably achievable," economic and social factors being taken into consideration. ALARA is the guiding principle of radiation protection.

alpha radiation (alpha decay, α-particles): A high energy positively charged particle ejected from the nucleus of an unstable (radioactive) atom when it decays, consisting of two protons and two neutrons. An alpha particle is a helium nucleus.

annual limit on intake (ALI): The intake by inhalation, ingestion, or through the skin, of a given radionuclide in a year by reference man, which would result in a committed dose equal to the relevant dose limit. The ALI is expressed in units of activity.

background radiation: The amount of radiation to which an individual is exposed, which arises from natural radiation sources such as terrestrial radiation from radionuclides in the soil, cosmic radiation from space, and naturally occurring radionuclides deposited in the body from foods, etc.

Becquerel (Bq): An SI unit of radioactivity, equivalent to 1 nuclear transformation per second. Used as a measurement of the quantity of a radionuclide, since the number of radioactive transformations (disintegrations) is directly proportional to the number of atoms of the radionuclide present. The Bq replaces an earlier unit, the curie (Ci).

beta radiation (beta decay, β-particles): The ejection of a high energy negatively charged subatomic particle from the nucleus of an unstable atom. A beta particle is identical in mass and charge to an electron.

conditional release limit: The quantity or activity of NORM, which under certain approved conditions, can be released without restriction, into the public domain.

committed dose: The total dose received from a radioactive substance in the body during the remainder of a person's life (assumed as 50 years for adults, 70 years for children) following the intake of the radionuclide.

Curie (Ci): A unit of activity equivalent to 3.7 x 10^{10} disintegrations per second. The Ci has been replaced in international usage by the becquerel, Bq.

decay (radioactive decay): A process followed by an unstable nucleus to gain stability by the release of energy in the form of particles or electromagnetic radiation (or, more rarely, by the capture of an atomic electron or by the fission of the nucleus). Radionuclides in NORM materials decay with the release of alpha particles and beta particles, sometimes accompanied by the emission of energetic gamma rays.

decay series (radioactive decay series): A chain of radionuclides, each of which transforms by radioactive decay into the next member of the chain until a stable nuclide results. The first member is called the "parent," the intermediate members are called "progeny," and the final stable member is called the "end product." In the two important NORM decay series, U-238 and Th-232 are the parents; Pb-206 and Pb-208 are the end products.

derived working limit (DWL): A practical working limit derived from regulatory limits. Derived working limits can be compared to measured values at the work site to assess compliance with regulatory limits.

diffuse NORM: NORM material that is low in radioactive concentration, uniformly dispersed, and relatively large in volume.

discrete NORM: NORM material, which has much higher levels of radioactive concentration than the surrounding environment, and which can be non-uniformly distributed (for example, scrap pipe).

dose coefficient (DC): A factor that relates the amount of radiation dose (sievert) delivered to the body per unit of activity (becquerel) taken into the body; unit: (Sv/Bq).

electron volt [eV and multiples; therefore: kilovolt (keV0 and megavolt (MeV)]: The energy acquired by an electron in moving through a potential difference of 1 Volt. Units are used to designate the energy of individual rays. Alpha particles typically have energies of a few MeV; gamma-rays can have energies of several hundred keV.

effective dose: Radiation dose for primary radiation dose limits. Effective dose represents the sum of the equivalent doses received by different tissues of the human body, each multiplied by a "tissue weighting factor" (WT); unit: sievert (Sv).

equilibrium (radioactive): In a radioactive decay series, the state that prevails, when the activities of successive progenies tend to be a constant, equals the activity of the parent. This so-called "secular equilibrium" may only be attained if the precursor is very long-lived relative to any member of the decay chain. For simplicity, such equilibrium is usually assumed in the case of Ra-226 and its progeny. Care should be exercised in making such assumptions.

equivalent dose: The absorbed dose multiplied by a "radiation weighting factor" (WR), which accounts for the different potential for adverse effects of the different types of radiation. Unit: sievert (Sv).

excepted (exempt): The formal term used in transportation regulations indicating the shipment is exempt from regulations governing the transport of dangerous goods.

gamma radiation (γ-rays or gamma photons): Electromagnetic radiation (energy in the form of photons) emitted from an exited nucleus in the process of ridding itself of excess energy. At higher energies (above about 100keV), gamma rays are highly penetrating and are attenuated through the transfer of energy to target atoms.

Gray (Gy): The SI unit of absorbed radiation dose corresponding to the absorption of 1 joule of radiation energy per kilogram of material. For gamma and beta radiations, the gray is numerically equal to the sievert (Sv). See Absorbed Dose.

half-life, radioactive: The elapsed time required for a radioactive material to lose half of the activity it had at the start, through radioactive decay. Thus after two half-lives, the material would have one quarter of its original activity.

IAEA: International Atomic Energy Agency.

ICRP: International Commission on Radiological Protection.

incremental dose: Radiation dose found in excess of the local background radiation dose.

low specific activity scale (LSA scale): Scales that form in well tubulars and that contain a relatively low level of radioactivity per unit mass, which, however, is in excess of the background level. "LSA scale" is a term often used by European workers; elsewhere it may be referred to as "NORM scale."

monitor (instrument), radiation: Any instrument used to measure radiation exposure or exposure rate.

NORM (naturally occurring radioactive materials): Refers to radioactive materials and chemicals present in their natural form such as scale, deposits, solids, or solutions with radionuclide concentrations in excess of normal background.

NORM-impacted material: NORM material present in excess of natural background quantities in a place it is not wanted.

occupationally exposed workers (NORM workers): Employees who have the potential to receive exposure to sources of NORM radiation as a result of their regular duties. The annual occupational dose limit that applies to this category of workers in an occupational exposure environment is 5 rem (0.05 Sv).

pancake detector: A gas-filled detector, usually of the Geiger-Mueller type, having the form of a cylinder with a low ratio of height to radius. This facilitates the fitting of a larger entrance window, making the detector more sensitive for the detection of alpha and beta ray surface activity.

personal dosimetry threshold: The annual effective dose; above which radiation dosimetry of individual workers is required.

photons (x-ray or gamma rays): See gamma radiation.

rad: An historical radiation unit for measuring radiation energy absorption (dose); equivalent to 100 ergs per gram in any medium. Rad is a acronym of Radiation Absorbed Dose that has now been replaced in the SI system of units by the "gray" (Gy).

radiation weighting factor (w): A value recommended by the ICRP and usually adopted by national regulatory agencies used to convert absorbed dose from various types of ionizing radiation into its dose equivalent in terms of biological harm from alpha, beta, or gamma radiation. For gamma rays and beta particles, w = 1.0; for alpha particles and fast neutrons, w = 20.

radiochemical analysis: Analysis to identify the specific activities (if any) of specified radionuclides in a sample. Radiochemical analyses usually involve complex chemical isolations and determinations of activity using radiation detectors.

radionuclide or radioisotope: A particular form of an element, characterized by a specific atomic mass and atomic number, whose atomic nucleus is unstable and decays or disintegrates with a statistical probability characterized by its physical half-life. The distinction between "nuclide" and "isotope" is somewhat academic, but essentially "nuclide" emphasizes nuclear rather than the chemical behavior.

Radium-226 (Ra-226): A radioactive element with a half-life of 1600 years. It is a decay product of natural uranium, and is frequently the dominant NORM nuclide. It decays into the radioactive gas, Rn-222. Other radium isotopes include Ra-228, Ra-224, and Ra-223, all of which are sometimes present in oilfield NORM.

radon: The only radioactive gas in NORM, generated during the radioactive decay of radium nuclides. Nuclides of radon include Rn-222, from Ra-226, and Rn-220 (called thoron), from Ra-224.

radon progeny: The products of radon (Rn-222) or thoron (Rn-220) decay into progeny having short halflives. Radon decay products include Pb-214 and Bi-214, whereas thoron produces Pb-212. All of these products emit penetrating gamma rays.

rem: An historical unit of human dose equivalent. Rem is a acronym derived from of Roentgen Equivalent Man and was replaced in 1977 by the sievert in the international system of units.

Roentgen (R): The classical unit of radiation ionization in air. This unit is frequently misapplied as a unit of exposure in humans. The Roentgen has been replaced in international system of units by "coulomb per kg."

scintillator, scintillation detector or counter: A scintillator is a piece of transparent solid or liquid substance that emits flashes of light when ionization occurs within it. The scintillator is coupled optically to a sensitive detector of these flashes, such as a photomultiplier, to form a scintillation counter or detector. Such detectors give out electrical pulses. The frequency of these pulses and their amplitudes may be measured electronically to determine the nature of the radiation that caused the ionization in the scintillator. Special liquid scintillators are designed to be solvents for specific materials.

Sievert (Sv): a unit used to derive a quantity called dose equivalent. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Dose equivalent is often expressed as millionths of a sievert, or micro-sieverts (μSv). One sievert is equivalent to100 rem.

sodium iodide (NaI): In crystal form, and with the addition of minute quantities of thallium, this material provides a scintillator that is suitable for the detection of gamma radiation.

specific activity (radioactive concentration): The number of pCi (Bq) per unit of mass of solid material. Units: pCi/g (Bq/g). For liquids or gases pCi/l (Bq/l) or pCi/m^3 (Bq/m^3) are usually used

tissue weighting factor (WF): A weighting factor developed by the ICRP which assigns a relative share of total radiation dose detriment to specific organs and tissues. Localized radiation exposures to specific organs and tissues can be quantified.

unconditional release limits: The quantity of NORM below which, NORM can be released into the public domain without restrictions.

waste minimization: Waste minimization refers to the activities of reduction, recycling, reuse, or recovery of NORM products.

working level (WL): A unit for potential alpha energy concentration (PAEC) resulting from the presence of radon progeny equal to the emission of 1.3×10^5 MeV of alpha energy per liter of air. In SI units the WL corresponds to 2.1×10^{-5} J m^{-3}.

working level month (WLM): A measure of the cumulative exposure to radon progeny in air. One WLM is defined as the exposure received by an individual inhaling air containing a radon progeny concentration of 1 WL for a period of 170 hours, the assumed number of hours in a working month. One WLM is equivalent to 3.54 mJ h m^{-3}.

x-ray: Energetic electromagnetic radiation having energies somewhat less than gamma-rays (~40 keV).

APPENDIX C—LIMITS FOR RADIATION DOSE

Table C.1—Limits for radiation dose OSHA 1910.1096(b)(1) Table G-18

Organ	Limit-rem/quarter	Comments
Whole body	1.25 (0.0125 Sv)	OSHA 1910.1096(b)(2)(i) During any calendar quarter the dose to the whole body shall not exceed 3 rem (0.03 Sv). OSHA 1910.1096(b)(2)(ii) The dose to the whole body, when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N-18) rem, where "N" equals the individual's age in years at his last birthday.
Extremities	18.75 (0.1875 Sv)	
Skin	7.5 (0.075 Sv)	
Occupational exposure of a minor	10% of the limits above	OSHA 1910.1096(b)(3) No employer shall permit any employee who is under 18 years of age to receive in any period of one calendar quarter a dose in excess of 10% of the limits.

The guiding principle behind radiation protection is that radiation exposures should be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account. This means that radiation doses for both workers and the public are typically kept lower than their regulatory limits. Regulatory dose limits are set well below levels where measurable health effects have been observed. In accordance with current knowledge of radiation health risks, the Health Physics Society recommends against quantitative estimation of health risks below an individual dose of 5 rem (0.05 Sv) in 1 year or a lifetime dose of 10 rem (0.1 Sv) above that received from natural sources. Doses from natural background radiation in the United States average about 0.3 rem per year. A dose of 5 rem (0.05 Sv) will be accumulated in the first 17 years of life and about 25 rem (0.25 Sv) in a lifetime of 80 years. Estimation of health risk associated with radiation doses that are of similar magnitude as those received from natural sources should be strictly qualitative and encompass a range of hypothetical health outcomes, including the possibility of no adverse health effects at such low levels. There is substantial and convincing scientific evidence for health risks following high-dose exposures. However, below 5–10 rem (0.05-0.1Sv), which includes occupational and environmental exposures, risks of health effects are either too small to be observed or are nonexistent.

In 2005 the International Commission on Radiological Protection (ICRP) made recommendations on revisions to the limits for ionizing radiation exposure for workers and for the public. The following is a brief summary of these recommendations and is provided for information only.

Occupational exposure

1. A limit on effective dose of 2 rem (0.02 Sv) per year, averaged over 5 years (10 rem or 0.10 Sv in 5 years), with the further provision that the effective dose should not exceed 5 rem (0.05 Sv) in any single year.
2. An equivalent dose to the lens of the eye of 15 rem (0.15 Sv) in a year.
3. An equivalent dose to the extremities (hands and feet) or the skin of 50 rem (0.5 Sv) in a year.

Public exposure

1. The limit should be expressed as an effective dose of 0.1 rem (1 mSv) in a year. However, in special circumstances a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 0.1 rem (1 mSv) per year.
2. An equivalent dose to the lens of the eye of 1.5 rem (15 mSv) in a year.
3. An equivalent dose to the skin of 5 rem (50 mSv) in a year.

APPENDIX D—STATUTES AND REGULATIONS PERTAINING TO NORM

There are currently no federal statutes or regulations that specifically cover generation, storage, transport, or disposal of oilfield NORM other than the regulations that apply generally to other radioactive materials.

A useful summary of the existing NORM guidelines for the states that have established guidelines is provided in Table D.1. Web site addresses are also included where available. Please note that, for unrestricted release of property, some states include a pathway analysis with comparison to an annual dose equivalent value that the state has specified, e.g. 100 mrem/yr (1 mSv/y), which is in addition to the concentrations of NORM in soil. As mentioned previously, operators should work closely with state regulators in the determination of guidelines appropriate for the management of NORM-impacted material.

Table D.1—Summary Of Existing Oil And Gas Producing States' NORM Regulations And Guidelines

State	Exemption levels/release criteria
Arkansas	***Equipment/property:*** ≤50 µR/h including background at any accessible point; and surface contamination below the following limits (dpm/100 cm^2): • For U-nat., U-235, U-238, and associated products (including Po-210) except Ra-226, Th-230, Ac-277, and Pa-231: average of 5,000; maximum of 15,000; removable of 1,000. • For Ra-226, Ra-228, Th-230, Th-228, Pa-231, and Ac-227: average of 100; maximum of 300; removable of 20. • For beta-gamma emitters: average of 5,000; maximum of 15,000; removable of 1,000. ***Soil/material:*** <5 pCi/g Ra-226 and/or Ra-228, and <150 pCi/g of any other NORM radionuclide. ***Unrestricted transfer of land:*** <5 pCi/g Ra-226 or Ra-228 above background averaged over the first 15 cm of soil below surface, averaged over 100 m^2; and ≤15 pCi/g averaged over subsequent 15 cm soil intervals.
Louisiana	***Equipment/property:*** ≤50 mR/h at any accessible point. ***Soil/material:*** ≤5 pCi/g Ra-226 or Ra-228 above background, and ≤150 pCi/g of any other NORM radionuclide. ***Unrestricted transfer of land:*** ≤5 pCi/g Ra-226 or Ra-228 above background averaged over the first 15 cm of soil below surface, averaged over 100 m^2, and <15 pCi/g averaged over subsequent 15 cm soil intervals; or ≤30 pCi/g of Ra-226 or Ra-228 averaged over 15 cm depth increments, provided the total effective dose to individual members of the public does not exceed 100 mrem/yr. http://www.deq.state.la.us/planning/regs/title33/33V15.pdf
Michigan (Guidelines)	***Equipment/property:*** ≤10 mR/h above background; and surface contamination below the following limits (dpm/100 cm^2): • for alpha radiation: average of 100; maximum of 300; removable of 20. • for beta-gamma radiation: average of 5,000; maximum of 15,000; removable of 1,000. ***Soil/material:*** ≤5 pCi/g Ra-226 above background. ***Unrestricted transfer of land:*** ≤5 pCi/g Ra-226 above background averaged over the top 15 cm soil layer, averaged over 100 m^2, and ≤15 pCi/g averaged over succeeding 15 cm thick soil layers.

Mississippi (Guidelines)	***Equipment/property:*** ≤25 mR/h above background at any accessible point; and ≤2000 dpm/100cm^2 from accessible internal and external surfaces. ***Soil/material:*** ≤50 microR/hr above background. ***Unrestricted transfer of land:*** ≤50 microR/hr above background at any discrete point; and ≤200 microR/hr including background at every 0.15 meter interval in five boreholes per acre or at least 3 boreholes per site location, 1 meter deep. ***State of Mississippi*** http://www.msdh.state.ms.us/msdhsite/index.cfm/30,279,102,pdf radN92%2EPDF ***Mississippi Oil and Gas Board*** http://www.ogb.state.ms.us/rulebook.htm
New Mexico	***Equipment/property:*** ≤50 mR/h including background; and removable surface contamination must be ?1,000 dpm/100 cm^2. ***Soil/material:*** ≤30 pCi/g Ra-226 above background, and ≤150 pCi/g of any other NORM radionuclide above background. ***Unrestricted transfer of land:*** ≤30 pCi/g Ra-226 above background in soil in 15 cm layers, averaged over 100 m^2. http://www.nmcpr.state.nm.us/nmac/cgi-bin/hse/homepagesearchengine.exe?url= http://www.nmcpr.state.nm.us/nmac/parts/title20/20.003.0014.htm;geturl;terms= NORM
Texas	***Equipment/property:*** ≤50 mR/h including background at any accessible point; and surface contamination below the following limits (dpm/100 cm^2): average of 5,000, maximum of 15,000, and removable of 1,000. ***Soil/material:*** ≤30 pCi/g Ra-226 or Ra-228, and ≤150 pCi/g of any other NORM radionuclide. ***Unrestricted transfer of land:*** ≤30 pCi/g Ra-226 or Ra-228 averaged over the first 15 cm of soil, averaged over 100 m^2. http://www.tdh.state.tx.us/radiation/uranium.htm#NORM

The following table provides the conversion of values used in NORM regulations into SI units.

Table D.2—Conversion of NORM Regulations and Guidelines to SI Units

Measurement Type	Value in Traditional Units	Value in SI Units
Exposure Rate	10 μR/h 25 μR/h 50 μR/h 200 μR/h	0.1 μSv/h[1] 0.25 μSv/h 0.5 μSv/h 2 μSv/h
Surface Activity	20 dpm/100 cm^2 100 dpm/100 cm^2 300 dpm/100 cm^2 1000 dpm/100 cm^2 3000 dpm/100 cm^2 5000 dpm/100 cm^2 15000 dpm/100 cm^2	<1 Bq/100 cm^2 2 Bq/100 cm^2 5 Bq/100 cm^2 17 Bq/100 cm^2 50 Bq/100 cm^2 83 Bq/100 cm^2 250 Bq/100 cm^2
Concentration in Media	5 pCi/g 15 pCi/g 30 pCi/g 150 pCi/g	0.2 Bq/g 0.5 Bq/g 1.1 Bq/g 5.5 Bq/g

1. For the purpose of the photons of interest in oilfield NORM, the conversion of μR/h to μSv/h is appropriate but approximate.

References

Conference of Radiation Control Program Directors, *Suggested State Regulations for Control of Radiation, Part N*, dynamic document at http://www.crcpd.org/SSRCRs/TOC_4-2004-on-line.pdf.

APPENDIX E—DISCUSSION OF REPORTS ON MANAGEMENT AND DISPOSAL ALTERNATIVES FOR NORM-IMPACTED MATERIALS

Numerous reports have been published that evaluate the disposal alternatives for NORM-impacted materials. Below is a summary that includes abstracts and key tables relevant to radiological dose assessments associated with the major disposal options that are either available or under review. Section E.1 and E.2 describe a number of disposal options and associated radiological dose assessments. Section E.3 contains a discussion of subsurface disposal of petroleum industry wastes containing NORM via injection into Class II wells and provides estimates of potential radiological doses to individuals consuming water from a shallow aquifer. Section E.4 discusses a report that evaluated the feasibility, legality, economics, and human health risk of disposing of NORM-impacted oilfield wastes in salt caverns. The report in Section E.5 evaluated the feasibility, legality, economics, and human health risk of disposing of NORM-impacted oilfield wastes in landfills permitted to accept only nonhazardous wastes. In Section E.6, the disposal of NORM wastes by landspreading was modeled to evaluate potential radiological doses and resultant health risks to workers and the general public. Please note that this information has not been approved by state or federal agencies and should not be used as the basis for disposal decisions without obtaining appropriate agency approval.

E.1 Management and disposal alternatives for NORM wastes

Rogers and Associates performed a study for the American Petroleum Institute and prepared a May 1990 report titled "Management and Disposal Alternatives for NORM Wastes in Oil Production and Gas Plant Equipment." This study considered all of the pathways by which people could be exposed to NORM radiation and calculated the maximum radionuclide concentration that could be disposed by various options (Table E.1) without exceeding established radiation exposure limits (Table E.2). The exposure limits used in the report have not been approved by state or federal agencies and should not be used as a basis for disposal decisions without obtaining appropriate agency approval. The various options considered provide different levels of isolation for NORM. The maximum concentration levels (Table E.3) referred to are hypothetical only, and merely demonstrate the maximum mathematical values that would be permissible under the various disposal options.

A summary of the disposal alternatives, type of wastes, and radium concentration limits from the Rogers and Associates report follows:

Table E.1—Description of Disposal Methods

Disposal method	Description
Landspreading	Landspreading involves disposal by spreading sludge and scale on the surface of open lands in an area where NORM was not originally present above background levels.
Landspreading with dilution (landfarming)	Landspreading with dilution involves mixing of the applied NORM thoroughly within the top 8-inch (20.3 cm) layer of soil using agricultural equipment in an area where NORM was not originally present above background levels.
Non-retrieved line (surface) pipe	Buried line pipe used at a facility could be abandoned in place after being flushed to remove any oil or gas present.
Burial with unrestricted site use	Burial with unrestricted site use involves burial of NORM with at least 15 feet (4.6 m) of cover that is level with the surrounding terrain, minimizing erosion potential.
Commercial oil industry waste facility	Disposal in a commercial oil industry waste facility assumes burial with other oilfield wastes where NORM waste represents less than 7% of the total waste volume.
Commercial NORM waste facility	A NORM waste disposal site is designed to contain NORM for long periods and is deeded to the state for permanent monitoring and restricted future use after closure.
Commercial low level radioactive waste facility	A low-level radioactive waste disposal site is defined and licensed under Nuclear Regulatory Commission regulations with numerous protective features and restrictions.
Plugged and abandoned well	Well abandonment operations provide an opportunity to dispose of NORM
Well injection and hydraulic fracturing	Sludge and scale wastes could be injected or fractured into formations that are isolated geologically and mechanically from USDW.
Equipment release to a smelter	Smelting may be a viable option for NORM-impacted tubulars and other equipment

Table E.2—Radiation Concentration and Exposure Limits

Exposure Pathway	Reference Value
Indoor Radon Inhalation	2 pCi/l
Radon Flux Into a Building	2 pCi/m2/s
Groundwater Ingestion (ra-226 + Ra-228)	5 pCi/l
General Public-All Other Pathways	25 mrem/y
Intruder-All Other Pathways	100 mrem/y

Table E.3—Radium Source Concentration Limits for Disposal (picocuries/gram)

Disposal alternative	Sludge	Scale	Equipment and scale
Landspreading[1]	120	120	NA[2]
Landspreading with dilution[1,3]	260	260	NA
Non-retrieved surface pipe	2,700	6,700	NA
Burial with unrestricted site use[4]	29	130	440
Commercial oil industry waste facility[4]	410	1,800	6,200
NORM disposal facility	1,000	4,500	68,000
Commercial LLW disposal facility[5]	50,000	50,000	100,000
Plugged and abandoned well[5]	100,000	100,000	100,000
Well injection[5]	100,000	100,000	NA
Hydraulic fracturing[5]	100,000	100,000	NA
Smelting	NA	NA	40,000

1. Four barrels per 100 square meters giving a 0.63 cm average layer thickness.
2. NA - Not applicable.
3. Diluted by mixing in the top 20 cm soil layer.
4. For 4.6 m of depth.
5. If the limit is greater than 100,000 picocuries/gram, it is reported as 100,000 picocuries/gram.

E.2 Management of NORM generated by the petroleum industry

Argonne National Laboratory performed a study for the U.S. Department of Energy Office of Fossil Energy National Petroleum Technology Office dated September 1996 titled "Radiological Dose Assessment Related to Management of Naturally Occurring Radioactive Materials Generated By The Petroleum Industry." This report evaluated radiological doses from equipment cleaning, subsurface disposal, landspreading, equipment smelting, and equipment burial associated with NORM waste streams.

Summary

A preliminary radiological dose assessment of equipment cleaning, subsurface disposal, landspreading, equipment smelting, and equipment burial was conducted to address concerns regarding the presence of NORM in production waste streams. The assessment estimated maximum individual dose equivalents for workers and the general public. Sensitivity analyses of certain input parameters also were conducted. On the basis of this assessment, it is concluded that (1) regulations requiring workers to wear respiratory protection during equipment cleaning operations are likely to result in lower worker doses, (2) underground injection and downhole encapsulation of NORM wastes present a negligible risk to the general public, and (3) potential doses to workers and the general public related to smelting NORM-impacted equipment can be controlled by limiting the contamination level of the initial feed. It is recommended that (1) NORM wastes be further characterized to improve studies of potential radiological doses; (2) states be encouraged to permit subsurface disposal of NORM more readily, provided further assessments support this study's results; (3) further assessment of landspreading NORM wastes be conducted; and (4) the political, economic, sociological, and nonradiological issues related to smelting NORM-impacted equipment be studied to fully examine the feasibility of this disposal option.

Conclusions

Better characterization of the source term is needed to adequately assess the radiological impacts associated with various NORM management and disposal alternatives. The results from this assessment must be regarded as preliminary. Absolute health risks cannot be determined from these preliminary estimates because of the uncertainty related to the source term concentrations and because of the conservative nature of many of the input assumptions. For the same reasons, conclusions about risk to human health should not be drawn by comparing the estimated doses with existing or proposed regulatory standards. Given these limitations, it is still possible to draw some general conclusions regarding the selected NORM management and disposal methods and to compare the estimated doses as a preliminary indication of the relative risks associated with each method. The existing regulated standards can be used to provide a benchmark value that adds perspective to the results. The following conclusions can be drawn on the basis of the results of this assessment:

- External exposures are roughly equivalent for workers at licensed and at unregulated equipment cleaning facilities. However, the potential doses to workers from inhalation or ingestion of NORM particulates may be greater for workers at unregulated facilities if respirators and protective clothing are not used during dry pipe-cleaning operations. Additional information about the dry pipe-cleaning processes (e.g., dust loading factors, worker practices) and the source term are needed to fully quantify the potential doses related to the inhalation and ingestion pathways.
- The estimated doses to the general public associated with casing failures during underground injection of NORM wastes are higher than those associated with casing failures during downhole encapsulation. However, the estimated doses associated with either subsurface disposal method appear to be so low that risk to the general public from either method is negligible.
- Assuming conservative residential land use (i.e., individuals living and growing their own food on-site), landspreading with dilution presents the highest potential dose to the general public of all of the methods assessed in this study.
- Estimated doses to the general public from both smelter stack emissions and use of products made from recycled steel and slag are lower by at least two orders of magnitude than estimated doses related to unrestricted shallow burial of the same quantity of NORM-impacted equipment. Furthermore, limiting the levels of radioactrivity of the initial feed can control doses resulting from smelting equipment that contains NORM.

Recommendations

On the basis of these conclusions, the following studies and potential policy actions are recommended:

- NORM wastes generated by the petroleum industry should be characterized further to improve efforts to assess potential doses to workers and the general public. Further characterization of the source term concentration is particularly important. Existing data collected at the state and company levels should be aggregated to improve efforts to calculate statistically representative source term concentrations.
- Provided further assessment supports the results of this study, indicating that subsurface disposal methods constitute realistically safe methods for disposing of NORM wastes, state regulatory agencies should be encouraged to permit subsurface disposal projects more readily. Underground injection projects should not be considered to pose a significantly greater risk to the general public than downhole encapsulation projects. Regulators should strive to educate the public about the realistic risks related to subsurface disposal so that unfounded fears do not complicate the permitting process.
- Further assessment of the potential radiological doses to the general public resulting from landspreading with dilution is needed to fully evaluate this disposal alternative.
- Because this study did not consider the political, economic, sociological, and nonradiological issues related to smelting NORM-impacted equipment generated by the petroleum industry, further study is needed to fully examine the feasibility of this disposal option.

E.3 NORM disposal in Class II injection wells

Argonne National Laboratory made a presentation (meeting not specified) for the U.S. Department of Energy U.S. Department of Energy, Office of Fossil Energy Office of Fossil Energy National Petroleum Technology Office in 1997 "Radiological Dose Assessment of NORM Disposal in Class II Injection Wells." In this study, subsurface disposal of petroleum industry wastes containing NORM via injection into Class II wells was modeled to estimate potential radiological doses to individuals consuming water from a shallow aquifer.

Summary

Subsurface disposal of petroleum industry wastes containing NORM via injection into Class II wells was modeled to estimate potential radiological doses to individuals consuming water from a shallow aquifer. A generic model was developed for the injection of 100,000 barrels of NORM waste containing 2,000 picocuries per liter of radium into a layered geologic system. In separate modeling runs, it was assumed that a casing failure released the entire volume of NORM into each successive geologic layer, including the shallow aquifer. Radionuclide concentrations and related potential doses were calculated for receptors located in the shallow aquifer from 0 to 20 miles downgradient of the injection well. The results, summarized in Tables E.4 and E.5, indicated that even under conservative assumptions, calculated radionuclide concentrations and potential doses associated with subsurface disposal of NORM in Class II wells were below levels of regulatory concern. The preliminary results from a dose assessment of a specific project entailing injection of NORM into Class II wells support the conclusions of the generic study.

Table E.4—Estimated Activities and Potential Doses Associated with Subsurface of 4.2 Million Gallons (100,000 Barrels) of NORM in a Generic Setting

Top aquifer failure depth (feet)	Receptor location downgradient from injection well (miles)					
	0.0		0.2		0.5	
	Activity level (pCi/L)	Annual dose (mrem)	Activity level (pCi/L)	Annual dose (mrem)	Activity level (pCi/L)	Annual dose (mrem)
300	*	*	1.317	1.00	0.211	0.20
900	0.250	0.20	0.155	0.10	0.053	0.04
1,500	0.015	0.01	0.017	0.01	0.010	0.08
* No value calculated because receptor location is coincident with failure location.						

Table E.5—Estimated Activities and Potential Doses Associated with Subsurface Injection of 2,100 Gallons (50 Barrells) of Radioactive Effluent during the NORM Demonstration Project

Receptor location downgradient from injection well (feet)	Effluent radioactivity level (pCi/L)			
	40,000		80,000	
	Activity level (pCi/L)	Annual dose (mrem)	Activity level (pCi/L)	Annual dose (mrem)
100	1.940	1.500	3.870	3.000
500	0.173	0.100	0.346	0.300
1,000	0.061	0.050	0.122	0.090
5,000	0.005	0.004	0.011	0.008

E.4 Disposal of NORM-impacted oilfield wastes in salt caverns

Argonne National Laboratory performed a study for the U.S. Department of Energy Office of Fossil Energy National Petroleum Technology Office, dated August 1998, titled "Disposal of NORM-Contaminated Oil Field Wastes in Salt Caverns." This report evaluated the feasibility, legality, economics, and human health risk of disposing of NORM-impacted oilfield wastes in salt caverns.

Scope

Salt caverns have been used for several decades to store various hydrocarbon products. In the past few years, four facilities in the United States have been permitted to dispose of nonhazardous oilfield wastes (NOW) in salt caverns. Several other disposal caverns have been permitted in Canada and Europe for similar wastes. To date, caverns have not been used to dispose of oilfield wastes that have been contain naturally occurring radioactive materials (NORM). There are only a few approved methods for disposing of NORM wastes and only a handful of commercial disposal facilities that are licensed to accept NORM waste. This report evaluated the feasibility, legality, economics, and human health risk of disposing of NORM-impacted oilfield wastes in salt caverns.

Technical feasibility

NORM waste is physically and chemically similar to nonhazardous oilfield waste (NOW). Its primary difference from NOW is the presence of radionuclides in NORM waste. The presence of radionuclides may require additional safety precautions when handling the NORM waste, but the actual disposal process would be no different from that for NOW. NOW waste is currently being disposed of without difficulties in four U.S. salt caverns and in several Canadian caverns. There is no technical reason why these caverns or other future disposal caverns could not equally well accept NORM waste other than produced water, which is disposed of primarily by injection.

Legality

No existing federal regulations specifically address handling and disposal of NORM wastes. In the absence of federal regulations, individual states have taken responsibility for developing their own regulatory programs. These programs have been evolving rapidly over the last few years. Salt caverns used for disposal of oilfield wastes are considered to be Class II injection wells under most state regulations. A review of federal underground injection control (UIC) regulations and NORM and UIC regulations from the five states that have expressed some interest in cavern disposal indicated that there are no outright prohibitions against NORM disposal in salt caverns, except for Louisiana, which prohibits disposal of radioactive wastes or other radioactive materials in salt domes. Presently, however, only Texas and New Mexico are working on disposal cavern regulations, and no states have issued permits to allow cavern disposal of NORM waste.

Economics

Current NORM waste disposal costs range from \$15/bbl to \$420/bbl. These costs reflect the information provided by disposal companies to the authors in early 1998 and may not reflect actual total disposal costs. It is also difficult to compare cost figures from one disposal company to another because the companies do not always include the same types of services in their quoted prices.

None of the existing Texas NOW disposal cavern operators have made even preliminary estimates of what they would charge to dispose of NORM waste if the regulatory agency gave them approval to do so. NOW disposal caverns have proven cost competitive with other NOW disposal facilities in the same geographic area. This study does not constitute a formal market analysis, and the costs to upgrade a cavern disposal operation for NOW to one that disposes of NORM waste have not been quantified. Nevertheless, there is a reasonable chance that NORM waste disposal cavern companies would be able to install the additional waste handling equipment and implement expanded monitoring and worker safety procedures and still compete economically with existing off-site commercial NORM disposal facilities once regulatory agencies allow the practice to occur.

Human Health Risk

Caverns are located deep below the earth's surface. The process of filling caverns with waste is performed at low pressure and should not cause cavern failure. Following cavern plugging and closure, internal cavern pressure could increase from salt creep and geothermal heating to a point at which leaks or releases might occur. Even if such releases did occur, the likelihood that contaminants would migrate off-site to a potential human health receptor site (a drinking water well) is small. On the basis of assumptions that were developed for a generic cavern and generic NORM wastes, the estimated worst-case human health risks from the chemical contaminants of NORM waste are very low (excess cancer risks of between 1×10^{-8} and 2×10^{-17}), and the hazard quotients (referring to noncancer health effects) for NOW are between 6×10^{-5} and 1×10^{-7}. Normally, risk managers consider risks of less than 1×10^{-6} and hazard quotients of less than 1.0 to be acceptable. The excess cancer risks estimated for the radiological contaminants are orders of magnitude lower; even for the 100% Probability of Release Case, risks are estimated at 1×10^{-13} to $3\ 10^{-22}$ and, consequently, are dwarfed by the risks from the chemical contaminants. No noncancer health risks were estimated for radionuclides.

Conclusions

This report provides evidence that cavern disposal of NORM waste poses a very low human health risk and is most likely technically feasible. From a legal perspective, there are no fatal flaws that would prevent a state regulatory agency from approving cavern disposal of NORM. Cavern operators would probably charge more for NORM waste disposal than the \$1.95/bbl to \$6/bbl that they currently charge for NOW disposal. Given that those companies handling most of the NORM waste are currently charging \$100/bbl or more for NORM waste disposal, there is probably plenty of leeway to make facility upgrades and still produce a profit. The ability for a NORM waste disposal cavern to be cost competitive looks promising, assuming regulatory agencies approve the practice.

E.5 Disposal of petroleum industry NORM in nonhazardous landfills

Argonne National Laboratory performed a study for the U.S. Department of Energy Office of Fossil Energy National Petroleum Technology Office and the American Petroleum Institute dated September 1999 titled "An Assessment of the Disposal of Petroleum Industry Norm in Nonhazardous Landfills." This report evaluated the feasibility, legality, economics, and human health risk of disposing of NORM-impacted oilfield wastes in landfills permitted to accept only nonhazardous wastes.

In the past few years, many states have established specific regulations for the management of petroleum industry wastes containing NORM above specified thresholds. These regulations have limited the number of available disposal options for NORM-containing wastes, thereby increasing the related waste management costs. In view of the increasing economic burden associated with NORM, the industry and its regulators are interested in identifying cost-effective disposal alternatives that still provide adequate protection of human health and the environment. One such alternative being considered is the disposal of NORM-containing wastes in landfills permitted to accept only nonhazardous wastes. The Michigan Department of Environmental Quality (MDEQ) has issued guidelines allowing the disposal of materials containing Ra-226 in landfills that are designed and permitted to receive nonhazardous municipal wastes. These guidelines are applicable to radium-bearing NORM wastes generated by the petroleum industry. Other states that have developed NORM regulations or guidelines, however, do not allow this type of disposal.

In this study, the disposal of radium-bearing NORM wastes in nonhazardous landfills in accordance with the MDEQ guidelines was modeled to evaluate potential radiological doses and resultant health risks to workers and the general public. In addition, the study included an evaluation of the potential doses and health risks associated with disposing of a separate NORM waste stream generated by the petroleum industry wastes containing Pb-210 and its progeny. For both types of NORM wastes, a variety of scenarios were considered to evaluate the potential effects associated with the operational phase (i.e., during landfill operations) and future land use. Doses were calculated for the maximally exposed receptor for each scenario. For the radium-bearing wastes, the base-case analyses assumed that the disposal action involved 2,000 $m^3$of waste containing an average Ra-226 concentration of 50 picocuries per gram (pCi/g). For the lead-bearing wastes, it was assumed that the disposal action involved 20 m^3 of wastes containing an average Pb-210 concentration of 260 pCi/g.

For the operational phase worker, the primary exposure pathway evaluated in this study was external irradiation. A second pathway, inhalation of radioactive particulates, also was considered for the worker involved in placing the wastes in the landfill when the wastes were not containerized. For the general public living next to or in the vicinity of the landfill (i.e., within a 50-mile radius) during the disposal action, the primary exposure pathway was determined to be inhalation of radioactive particulates. For completeness, the external irradiation, ingestion of radioactive particulates, and ingestion of NORM-impacted foodstuff were also evaluated. A variety of future land use scenarios, including on-site residential, industrial, and recreational and off-site residential scenarios, were considered. For all of the on-site scenarios, the primary exposure pathways were assumed to be external irradiation and inhalation of indoor and outdoor Rn-222. Depending on the scenario, other less likely pathways (e.g., inhalation of radioactive particulates, inadvertent ingestion of NORM-impacted soil, and ingestion of foodstuffs grown on the property) also were considered. For the off-site residential scenario, the only exposure pathways evaluated were ingestion of NORM-impacted groundwater and inhalation of radon. The study also included reviews of (1) the regulatory constraints applicable to the disposal of NORM in nonhazardous landfills in several major oil and gas producing states, and (2) the typical costs associated with disposing of NORM, covering disposal options currently permitted by most state regulations as well as the nonhazardous landfill option.

Conclusions

Regulatory constraints were reviewed in this report. It was found that the disposal of NORM-impacted wastes in nonhazardous municipal landfills is not explicitly allowed in any state except Michigan. In a few of the states reviewed in this study, NORM wastes may be allowed in other types of nonhazardous landfills, or in municipal landfills by special approval only. In other states, there seems to be less latitude both in the state regulations and on the part of individual regulators.

NORM disposal costs were included in this report. This study concluded that the disposal of regulated NORM wastes in nonhazardous landfills could be one of the most cost-effective disposal options available to the petroleum industry if approved on a widespread basis. However, because disposal costs depend on a number of factors such as volume, radium content, requirements for waste analyses, competition for market share, they are quite variable. As a result, it is difficult to single out the least expensive disposal option for the petroleum industry. This determination must be made on a case-by-case basis. Nevertheless, one could conclude that an increase in the number of available disposal options would most likely reduce NORM disposal costs for the industry.

The following conclusions can be drawn based on the results of the radiological dose and risk assessments presented in this report regarding the disposal of 2,000 m^3 of radium-bearing NORM containing an average Ra-226 concentration of 50 pCi/g:

- Potential radiological doses and resultant health risks for workers actively involved in landfill operations would be negligible.
- Potential doses to an individual living adjacent to the landfill during the NORM disposal action and to the general population living within a 50-mile radius would be negligible.

- Potential doses to future industrial and recreational users of the landfill property would be negligible.
- Potential doses to hypothetical future residential users of the landfill property are most sensitive to depth of the NORM waste layer and integrity of the landfill cap. These doses would be negligible on the basis of the assumptions that (1) the NORM wastes would be placed at a depth greater than approximately 10 feet below the cap and (2) the landfill cap would not be breached during construction of the home.
- Provided the NORM wastes are placed deeper than approximately 10 feet below the landfill cap, the Michigan policy allowing wastes containing up to 50 pCi/g to be disposed of in Type II landfills is protective of human health.
- Increasing the total volume would increase the worker doses linearly and could increase the potential doses to the off-site resident via the groundwater pathway. However, it is estimated that doses for these receptors would be negligible, and increasing the volume probably would not change this overall conclusion. Radiological doses to the future-use receptors would not be affected by increasing the total volume. Doses to these receptors are primarily affected by changes in the location of the NORM waste within the landfill.

Regarding the disposal of lead-bearing NORM wastes, the results of this assessment indicate that the risk to workers or to the general public associated with the disposal of 20 m^3 of wastes containing an average Pb-210 concentration of 260 pCi/g would be negligible. Increasing the disposal volume would not significantly change this overall conclusion. Worker doses would increase linearly with volume, but doses to future users of the property would still be zero because once the waste is buried, a complete exposure pathway to a future receptor does not exist.

Recommendations

On the basis of the conclusions presented above, the following recommendations are suggested:

It may be feasible for other states besides Michigan to consider issuing regulations allowing the disposal of NORM wastes containing up to 50 pCi/g of Ra-226 in municipal, nonhazardous landfills. In approving of this type of disposal, regulators should consider the total volume of radium-bearing wastes that are disposed of in a single landfill and cell, as well as the depth of the NORM waste layer within the landfill. Property records denoting that a landfill was in operation at that location should also note that radium-bearing wastes were disposed of therein.

- Regulators should consider allowing the disposal of NORM wastes containing radium in concentrations greater than 50 pCi/g on a case-by-case basis.
- States should also consider regulations governing the disposal of wastes containing Pb-210 in municipal, nonhazardous landfills. As they should for radium-bearing wastes, the regulations should consider the allowable concentrations of Pb-210 and the total volume that can be disposed of in a single landfill.
- States may want to consider allowing NORM wastes to be disposed of in other categories of nonhazardous landfills, provided the requirements for deed restrictions and protection of the landfill cap are equivalent to those for municipal landfills.

E.6 Disposal of petroleum industry NORM via landspreading

Argonne National Laboratory performed a study for the U.S. Department of Energy Office of Fossil Energy National Petroleum Technology Office and the American Petroleum Institute dated December 1998 titled “Potential Radiological Doses Associated with the Disposal of Petroleum Industry NORM via Landspreading.” In this study, the disposal of NORM wastes by landspreading was modeled to evaluate potential radiological doses and resultant health risks to workers and the general public.

Background

As a result of oil and gas production and processing operations, NORM sometimes accumulates at elevated concentrations in by-product waste streams. The primary radionuclides of concern in NORM wastes are Ra-226 of the U-238 decay series, and Ra-228 of the Th-232 decay series. The production waste streams most likely to contain elevated radium concentrations include produced water, scale, and sludge. Scales and sludges removed from production equipment often are disposed of by landspreading, a method in which wastes are spread over the soil surface to allow the hydrocarbon component of the wastes to degrade.

In this study, the disposal of NORM wastes by landspreading was modeled to evaluate potential radiological doses and resultant health risks to workers and the general public. A variety of future land use scenarios including residential, industrial, recreational, and agricultural scenarios were considered. The waste streams considered included scales and sludges containing NORM above background levels. The objectives of this study were (1) to estimate potential radiological doses to workers and the general public resulting from the disposal of NORM wastes by noncommercial landspreading activities, and (2) analyze the effect of different land use scenarios on potential doses. Doses were calculated for the maximally exposed receptor for each scenario. Potential exposure pathways evaluated for the worker included external radiation, incidental ingestion of NORM-impacted soil, inhalation of suspended NORM particulates, and inhalation of outdoor Rn-222. Depending on the land use scenario, potential exposure pathways evaluated for the general public included external radiation; inhalation of radioactive particulates; inhalation of indoor and outdoor Rn-222; and inadvertent ingestion of soil containing NORM; and ingestion of crops, milk, and meat grown on the property. Potential doses were modeled for a unit concentration of 1 pCi/g of Ra-226 in soil; other radionuclides of concern were modeled although their contributions to total dose were minimal. Because dose increases linearly with radium concentration, doses and health risks were extrapolated for a range of radium concentrations.

Conclusions

The results of this assessment provide estimates of annual doses and resultant health risks to workers and the general public for a variety of potential land use scenarios. On the basis of these results, the following conclusions can be drawn:

- Potential radiological doses and resultant health risks to workers actively involved in landspreading NORM wastes are below accepted public dose limits when Ra-226 concentrations in soil after landspreading are below 1,000 pCi/g, because landspreading does not require excessive handling of the waste and typical exposure times are limited.
- Potential radiological doses to the general public for all land use scenarios evaluated are reasonably low (i.e., below 60 mrem/yr considering all pathways) when the concentration of Ra226 in soil after landspreading is 5 pCi/g or less above the background level.
- Potential doses to residents and industrial workers can vary greatly depending on a variety of factors such as type of building construction (e.g., crawl space, basement, slab), construction practices employed (e.g., the degree of excavation and/or regrading, use of clean cover material), and natural processes such as the erosion rate.
- Concentrations of Ra-226 in soil after landspreading that are above approximately 10-16 pCi/g for the residential receptor (depending on construction type) and 35 pCi/g for the industrial receptor result in potential radiological doses exceeding 100 mrem/yr, assuming the layer of clean cover material has been allowed to erode away.
- For the residential receptor living in a home with a crawl space, when the cover layer is maintained at a thickness of 0.5 feet, a Ra-226 concentration in soil after landspreading greater than 12 pCi/g may result in doses exceeding 100 mrem/yr, of which 80% is attributed to inhalation of radon. Doubling the cover layer thickness does not appreciably affect the upper limit on Ra-226 concentration.
- For the resident of a home with a basement, when the cover layer is maintained at a thickness of 0.5 feet, doses would not exceed 100 mrem/yr until the Ra-226 concentration in soil exceeded approximately 65 pCi/g. If the cover layer thickness is doubled, this dose limit would not be exceeded until the Ra-226 concentration exceeded several hundred pCi/g. This conclusion would apply to any case in which the NORM waste has been totally excavated from within the footprint of the building.
- Potential radiological doses to the general public associated with a future agricultural land use scenario are negligible except when concentrations of Ra-226 in soil after landspreading exceed several hundred pCi/g (e.g., 200 pCi/g corresponds to 10 mrem/yr.)

Recommendations

On the basis of the above conclusions, the following recommendations are suggested:

- Landspreading activities that result in Ra-226 concentrations of 10 pCi/g in soil should be evaluated on a case-by-case basis to estimate potential future risk to the general public. Future land use scenarios in which individuals are exposed over long periods to a soil Ra-226 concentration level of 10 pCi/g or more (e.g., the residential scenario), may result in unacceptably high doses depending on a variety of factors. These factors include the type of building construction (e.g., crawl space, basement, slab), construction practices employed (e.g., the degree of excavation and/or regrading, use of clean cover material), and natural processes (e.g., erosion rate).
- States that decide to allow landspreading of NORM that result in Ra-226 concentrations greater than 5 pCi/g above background should consider establishing policies that will restrict future land use or, at a minimum, ensure that future land owners are advised of the landspreading activities and the potential associated health risks. Such a policy is especially important because Ra-226 has such a long half-life.

SENES Consultants Limited performed a study for the American Petroleum Institute dated November 1997 titled "Probabilistic Estimates of Dose and Indoor Radon Concentrations Attributable to Remediated Oilfield Naturally Occurring Radioactive Material (NORM)." The objective of this work was to evaluate the concentration limit of 30 pCi/g Ra-226 in pipe scale and sludge left near the surface of remediated oilfield sites and returned to unrestricted public access.

Background

The scope of the work included an assessment of potential doses from radioactivity in pipe scale and sludge to users of remediated pits, tank battery sites, and land farms. In this assessment, an estimated distribution of radium concentration in NORM material ranging from natural background levels to 30 pCi/g was evaluated. The probabilistic method used for calculating potential doses and indoor radon concentrations was consistent with EPA's Science Policy Council guidance issued in February 1997. The assessment focused on external gamma doses and indoor radon concentrations to which occupants of housing developments located on remediated oilfield sits would be potentially exposed. An empirical model, using the large database of measured radon concentrations, was developed to estimate the annual average radon concentration in homes built on remediated sites. The external gamma radiation model was based on dose calculations and factors reported in NCRP #94 (1987). Both models were assessed using probabilistic methods so that the predicted distribution of doses incorporated the uncertainty and variability of input parameters.

Conclusions

In the first case, the distribution of Ra-226 concentrations in NORM was based on the predictions of Rogers and Associates in the 1989 paper titled "Methods for measuring NORM in Petroleum Production Equipment, 1989." The incremental gamma radiation doses to residents of homes built on remediated sites (no cover over the NORM) and total indoor radon concentrations were calculated to be:

	Incremental External Gamma Dose, mrem/y from Ra-226 only		Indoor Radon Concentration (total), pCi/l	
Remediated Site	Mean	95th Percentile	Mean	95th Percentile
Pit and Tank Battery	17	70	1.4	4.6
Landfarm	6.9	35	1.4	4.0
Natural Background[1]	4.2	5.9	1.3	3.9
1. Gamma dose for total Ra-226 in natural background.				

The distributions of predicted indoor radon levels from the distribution of Ra-226 concentrations in remediated pits and land farms applications were almost indistinguishable from the measured distribution of indoor radon levels from natural background Ra-226 in soil. This is largely a result of the low radon emanation fraction for oilfield NORM.

The annual external gamma dose rate from Ra-226 in NORM is higher than the corresponding dose rate attributable to Ra-226 in background. However, the extreme (95th percentile) dose is substantially less than the 100 mrem/y limit set by the Nuclear Regulatory Commission on licensed facilities.

For comparison, distributions of dose and indoor radon concentrations were calculated for the scenario in which all soil at the remediated site contained 30 pCi/g of Ra-226. The results were:

	Incremental External Gamma Dose, mrem/y from Ra-226 only		Indoor Radon Concentration (total), pCi/l	
Remediated Site	Mean	95th Percentile	Mean	95th Percentile
Pit and Tank Battery	110	160	6.1	21
Landfarm	48	100	2.5	8.4

A second approach to estimating doses and indoor radon concentrations to which residents on remediated oilfield sites may be exposed was based on external gamma and soil survey methodologies used by oil companies during remediation of sites before release for unrestricted public access. The major advantage of this approach was that there was no dependence on measured or assumed radium concentration distributions in NORM. In this approach, an area of elevated radium concentration remaining on a remediated site was characterized based on the survey criteria. Using output from MicroShield, it was demonstrated that gamma and soil surveys using a twice background criterion would ensure that an area 9 square meters was the largest area containing Ra-226 at a concentration of 30 pCi/g that would be left on a remediated site. Using probabilistic methods and the indoor radon method described in the report, it was determined that such an area would result in a doubling (from 5% to 10%) in the expected fraction of homes that would have indoor radon concentrations in excess of 4 pCi/l compared to average background conditions.

Recommendations

Where management practices ensure that Ra-226 concentrations in soil at remediated sites do not exceed 30 pCi/g, it was shown that the reasonable maximum external gamma doses and indoor radon concentrations were in compliance with regulatory limits and guidelines. It was also shown that external gamma and soil survey methodologies used by oil companies during remediation of sites before release to unrestricted public access facilitates compliance with the standards.

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